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Moving from Silicon to SiC: Learning to Think Differently!

Strategies for Commercialization and Market Insertion

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Outline

- Big Picture – the news is good!
- Barriers to Commercialization
- Economics and strategies for market penetration: What are the "low-hanging fruits”?
- Near, Mid-term and Long-term Opportunities
- Transformation of the Grid
- Summary

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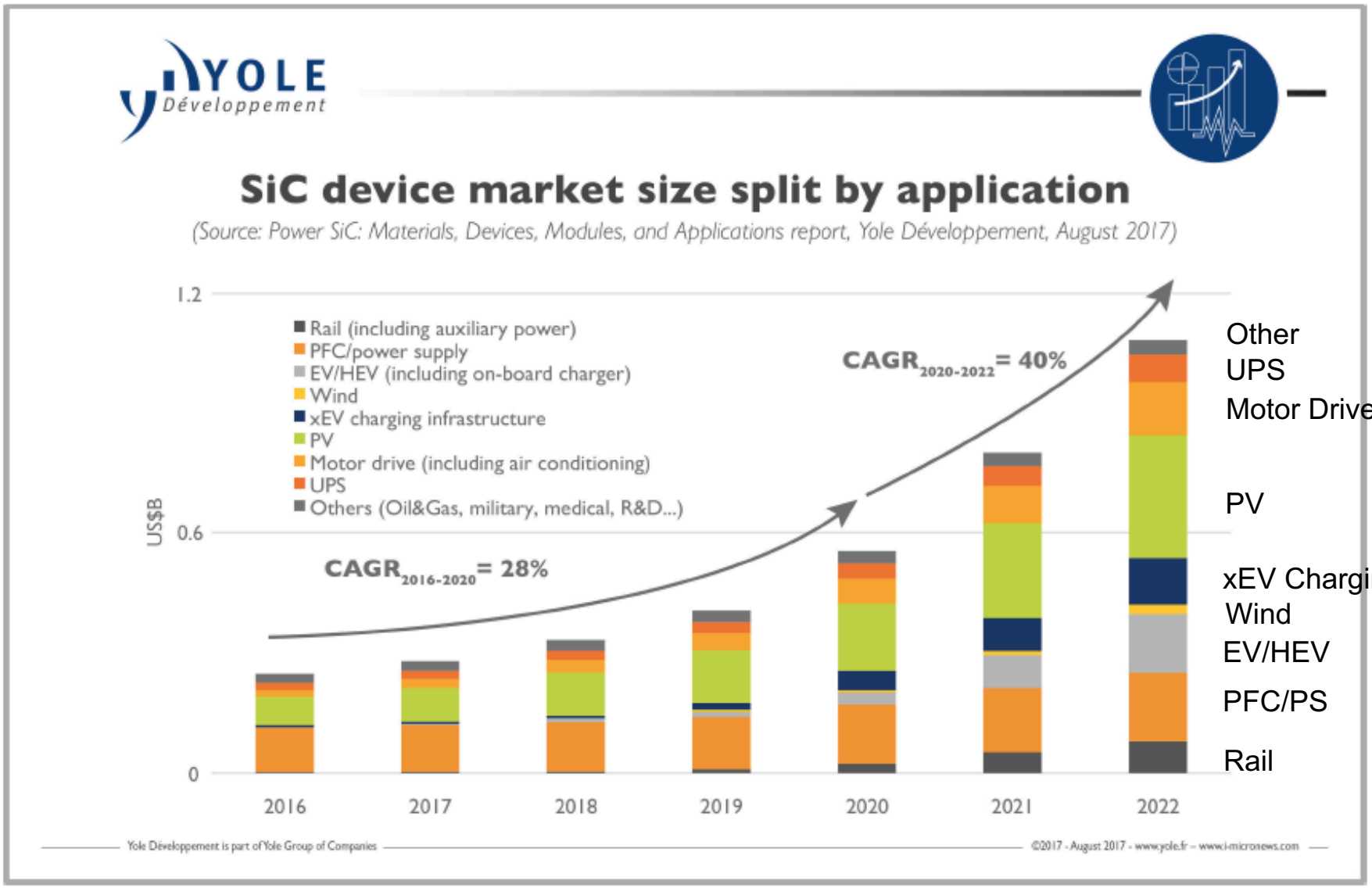
$1B/Yr SiC Device Revenue by 2022

~0.5 M/Yr, 150 mm Processed Wafers => 8 cents/Amp



China just built a 250-acre solar farm shaped like a giant panda

The Panda Power Plant in Datong, China.

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Interesting Statistics

- Si IGBT market projected to be $11B by 2022.
- Overall Power Electronics market projected to be $40B by 2022.
- Worldwide Electricity generation is expected to be 26 trillion kWh in 2020. At 5 cents/kWh, that is $1.3 trillion per year.
- Global sales of passenger cars are forecast to hit 78 million vehicles in 2017. At $20,000 per vehicle, that is $1.56 trillion per year.

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Barriers to Commercialization

- Performance, Reliability, Cost

  (GaN/Si put cost before reliability and lost 5 years)

- Lack of wide-spread knowledge of how to use SiC devices in a circuit (need text books)
- Lack of trained manpower with experience in SiC based power electronics – Power America and Traineeship programs

Comparison Si versus WBG for 400 V DC-link Hybrid Electric Vehicle (HEV) Inverter

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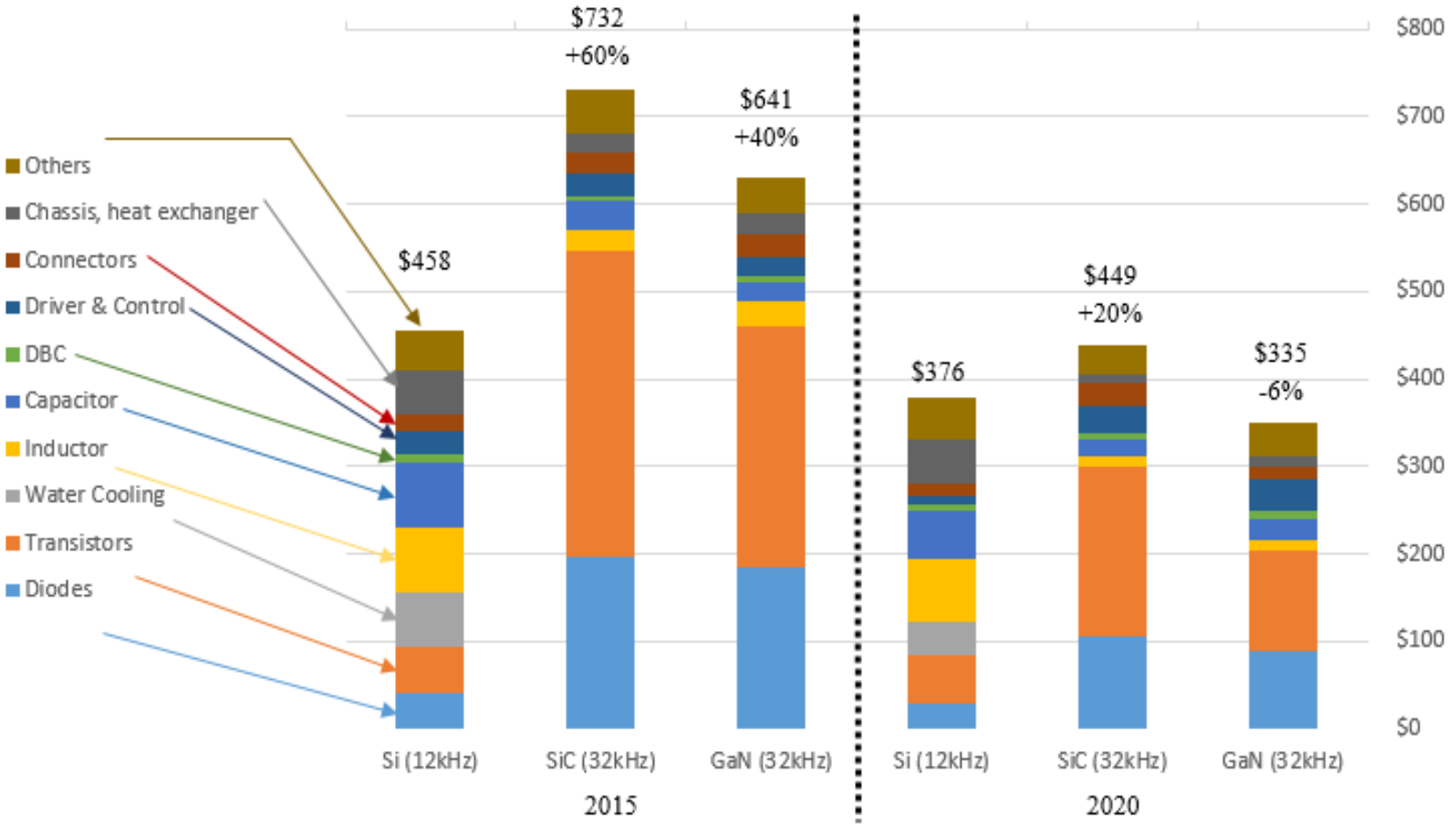
Comparison Si vs GaN vs SiC for 400 V DC-link HEV 60 kW inverter cost breakdown



P. Gueguen, "EV-HEV market and technology trends," presented at the Applied Power Electronics Conference and Exposition, Charlotte, North Carolina, 2015.

CURENT

THE UNIVERSITY OF TENNESSEE KNOXVILLE

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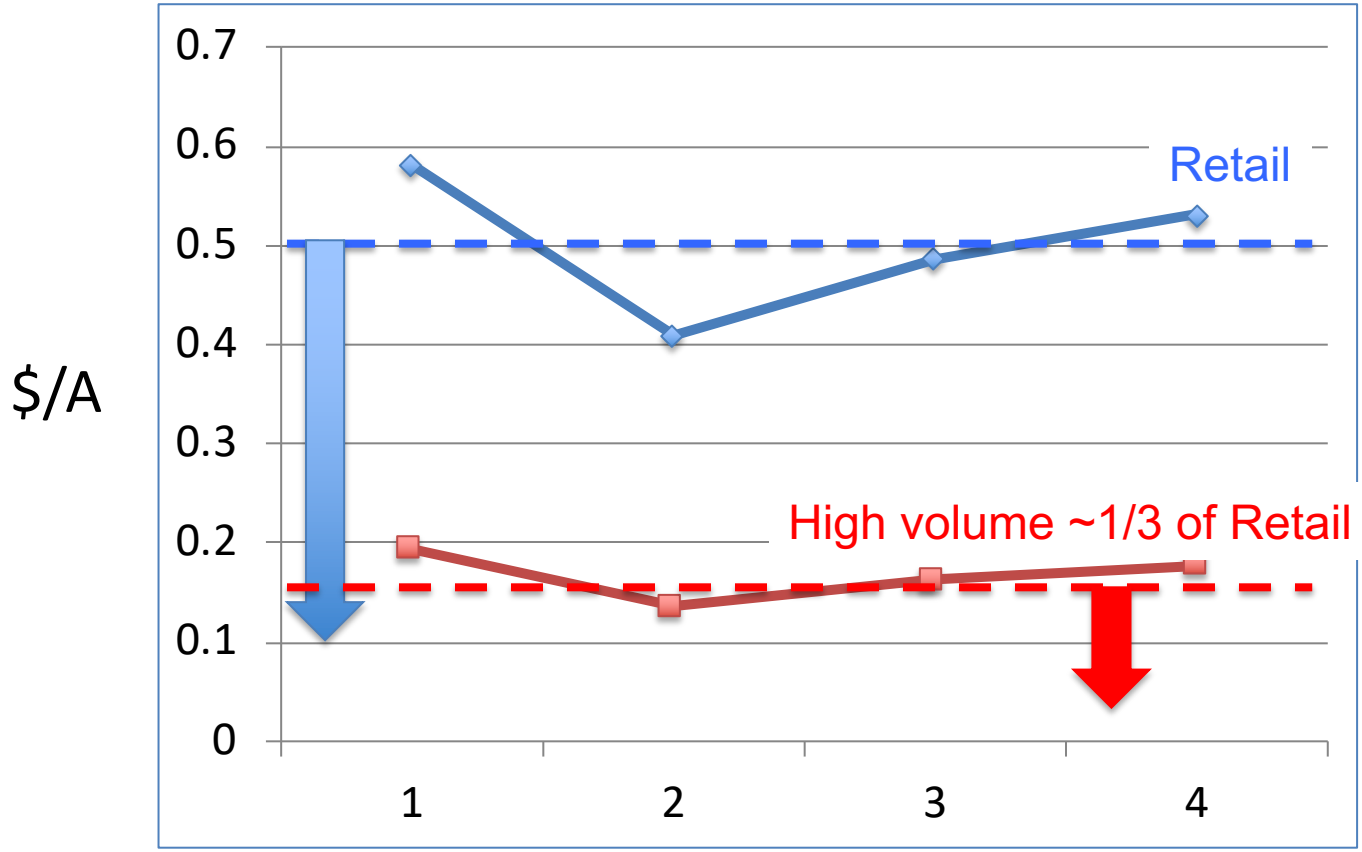
Retail Prices

Digi-Key Prices on Sept. 09, 2017

SiC MOSFETs,1200 V, 36-41 A (Tc), TO 247-3



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Commercial Foundry Models in USA

- **Captive Foundry – Vertically Integrated, one user (Cree/Wolfspeed)**

  Advantage: Do not have stacked margins => lower prices

  Disadvantage: Needs to be fully loaded at early stage, Capital intensive

- **Si+SiC Commercial Foundry – User defined process flow, many users (X-FAB)**

  Advantage: Fully loaded at early stage with Si => lower prices, Low capital

  Disadvantage: Complex coordination of many process flows (max: ~ 10 users)

- **Dedicated SiC Foundry – One process, many users (PEMC, NY)**

  Advantage: Many users can use the same process, simple coordination (can be 100 users or more)

  Disadvantage: Needs to be fully loaded at early stage, Capital intensive

Desirable:

- Si+SiC Commercial Foundry – One process, many users, design innovation
- Advantage:
  - Fully loaded at early stage with Si => lower prices, Low capital,
  - Simple coordination, >100 customers possible

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Lack of wide-spread knowledge of how to use SiC devices in a circuit

- Limited short-circuit capability requires fast response Desaturation protection for SiC devices.
- Desat circuits require re-design as output conductance of SiC MOSFETs is high – there is not a clear saturation.
- Dead-time setting for SiC devices is more critical compared to Si counterparts. Dead-time compensation is needed.
- New Gate Drivers are needed.
  - Sufficient gate driving capability for fast switching, including adequate gate voltage and sink/source gate current
  - Cross talk suppression
  - High dv/dt immunity capability

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What is Needed?

- Application notes, Text Books and Reference Designs are needed to explain successful designs in detail.
- Intelligent Gate Drivers are needed. UT Knoxville and The Ohio State University have done considerable work on gate drivers.

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Lack of trained workforce with experience in SiC based PE

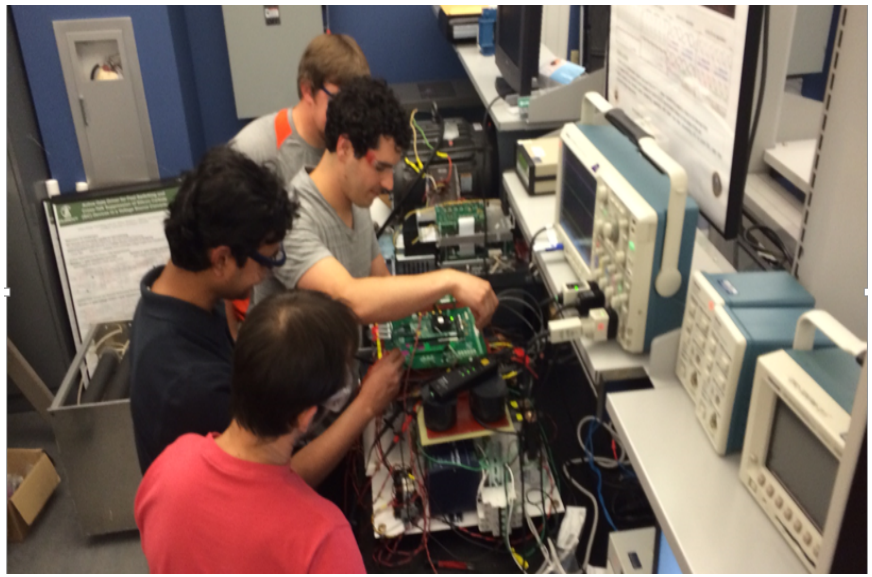
A large number (>100) of Graduate students are being trained to use SiC and GaN devices in Power Electronics.

Projects funded by:

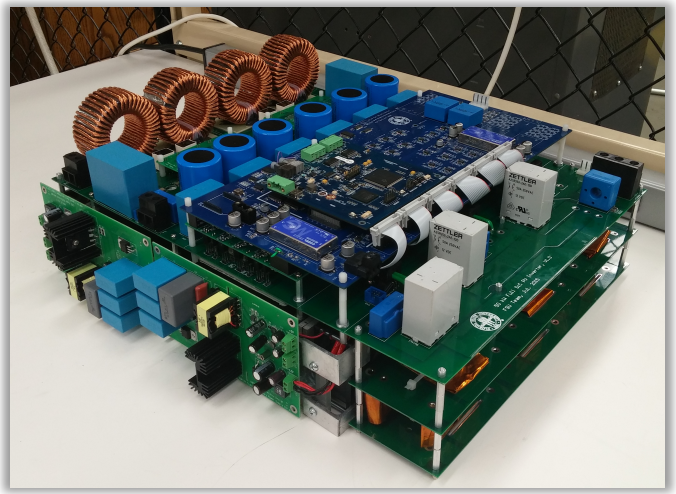
1. Power America (Department of Energy)
2. Traineeships at Virginia Tech and UT Knoxville (Department of Energy)
3. 1 MW Motor Drive (Department of Energy)
4. CIRCUITs (ARPA-e, Department of Energy)
5. Misc. Projects (Department of Defense)

WBG Power Electronics Traineeship at University of Tennessee

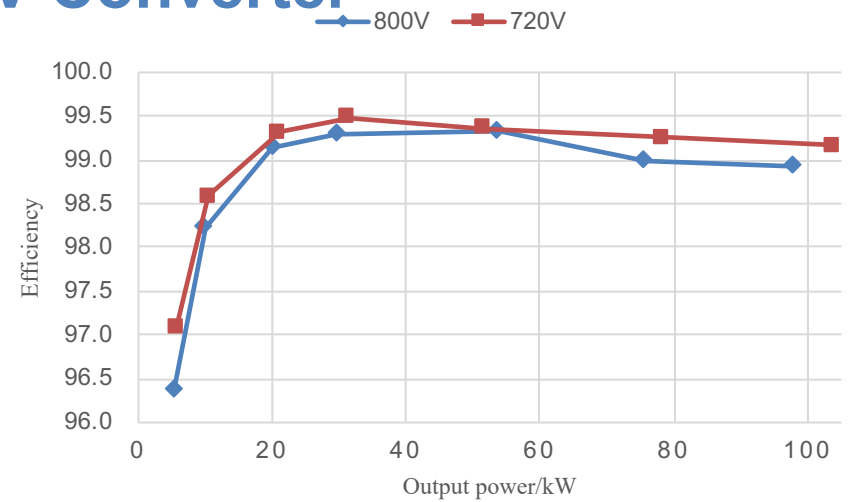
- Provide design-oriented education and hands-on training with WBG power electronics
- In 5-year period, recruit 30 M.S. or Ph.D. U.S. citizens for traineeship.
- Students will also have opportunities for research experiences and internships at nearby Oak Ridge National Laboratory and/or partner U.S. companies.



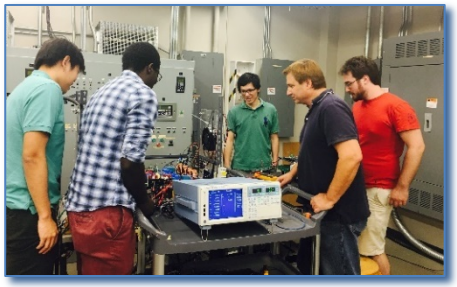
100kW SiC Filter-less PV Converter



45.4 W/in^3, 5kW/kg



CEC Efficiency@720V:99.2%



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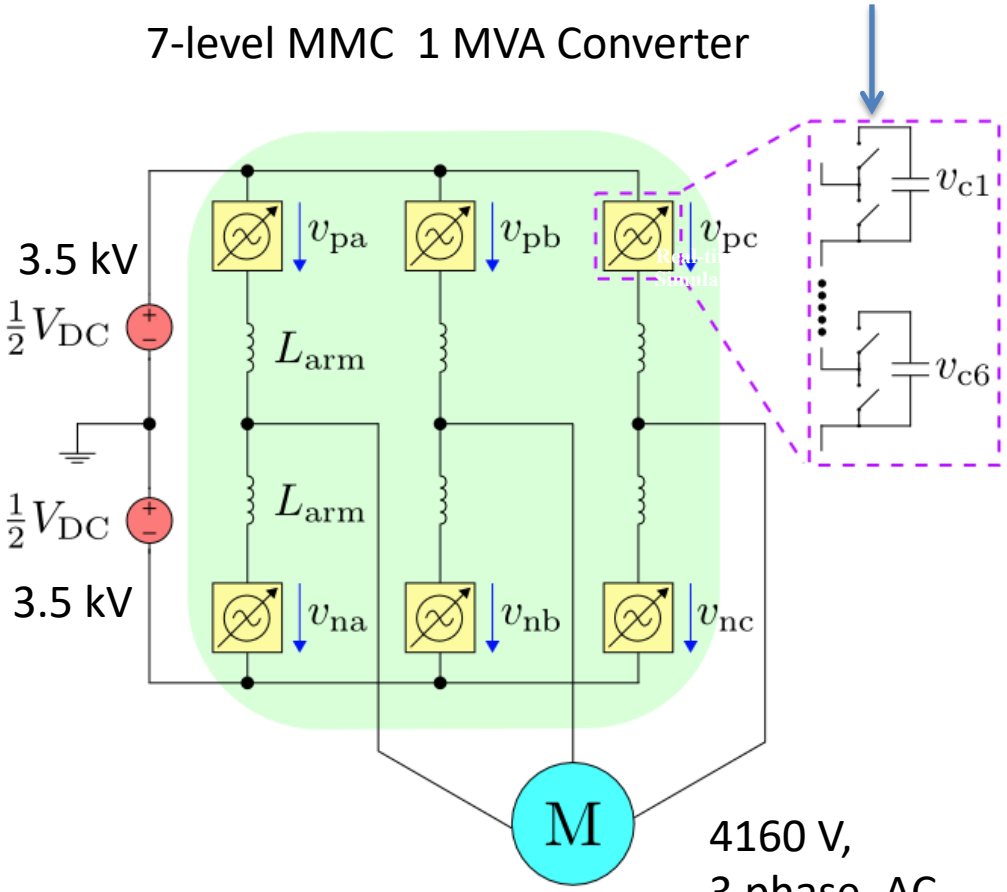
Development of a 1 MVA SiC-based Medium Voltage Variable Speed Drive

1-phase operational with full bus voltage of 7000 V

6, 1700 V modules
In Series

7-level MMC 1 MVA Converter



4160 V,
3 phase, AC
0-1000 Hz

* At this time, one third of the tower is populated for single phase based validations.

Tower Dimensions: 0.95 m * 0.7 m * 1.8 m = 1.2 m^3
Expected power density: 0.83 MW/m^3

Contact: Longya Xu, Jin Wang (OSU CHPPE)

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Strategies for market penetration: What are the "low-hanging fruits"?

- Stay on the SiC device price reduction path.
- SiC specific gate drivers are commercially needed.
- Train at least 100 Graduate students in SiC based power electronics by 2020.
- Detailed application notes, courses, videos and text books on SiC specific power electronics design strategies.
- Every university that has power electronics concentration should introduce WBG based courses.

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Near, Mid-term and Long-term Opportunities

Near Term (Next 5 years):

- PFC/Power Supply already happening
- String converters for PV 5-50 kW already happening
- Automotive drive train by 2020 and beyond. On-board chargers and Electric Vehicle Charging Stations.

Mid Term (5-10 years): 3.3 kV

- >100 kW grid-tied PV Converters
- 100 – 1000 hp medium voltage Variable Speed Drives, Locomotives
- >0.5 MW UPS

Long-Term (10-15 years): 6.5 – 12 kV

- 20-75% Renewables on the Microgrids, > 2 MW Wind Converters

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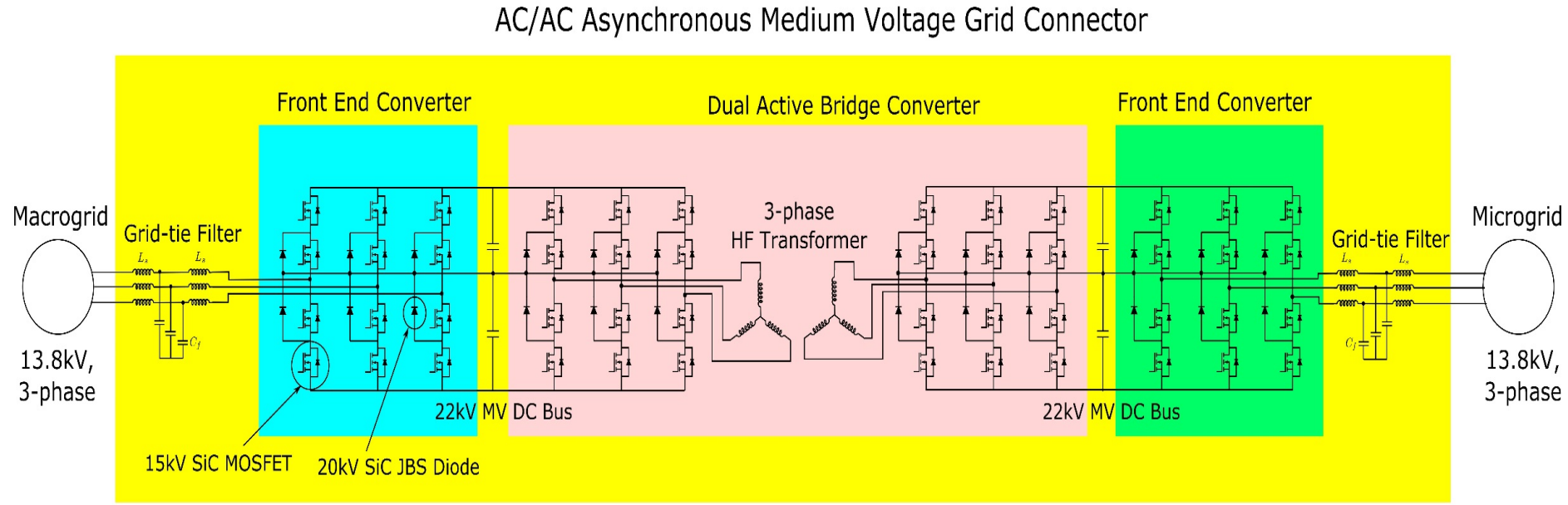
Transformation of the Grid

Asynchronous microgrids at 13.8 kV for >20% Renewables on the feeder



HV-HF 15 kV SiC Modules enable:

- Much Smaller Size and Weight (10x)
- Lower Cost Potential
- Better Performance
  - Lower impedance
  - Higher bandwidth

Courtesy: Prof. Subhashish Bhattacharya
NC State University

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Summary

- SiC has made it after 30 years. $ 1B revenue by 2022.
- Performance and Reliability of SiC devices are unmatched.
- Cost is headed down to within 1.5x of Silicon by 2020.
- SiC will replace silicon in most power electronics within the next decade.
- All Power Electronics curricula should include SiC device technology and power electronics.
- >20% renewables on the grid will need HV SiC based converters between microgrids and macrogrid.
- **One major gap: Process technology is not being taught in Graduate schools. This should be addressed as soon as possible.**