Contract #: DE-SC0013819 Program Manager: Dr. Imre Gyuk Technical Point of Contact: Dr. Stan Atcitty

High Power Density GaN-Based Inverters for Grid-Tied Energy Storage

Department of Energy Phase I SBIR

APEI

Daniel Martin, PhD

Senior Staff Engineer, Switched-Mode Power Supplies

September 2015

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.
SAND No. 2015-7686 C

Wolfspeed™

APEI is now Wolfspeed

A CREE COMPANY

ACKNOWLEDGMENTS

I would like to thank **Dr. Imre Gyuk** of the DOE Energy Storage Program for funding this work and **Dr. Stan Atcitty** for his technical contributions.

Program Target Applications

Design and develop a high efficiency (>98%) power dense (>10 kw/L) bidirectional GaN based AC-DC converter for 480 Vac energy storage applications

Phase I | Phase II | Phase III

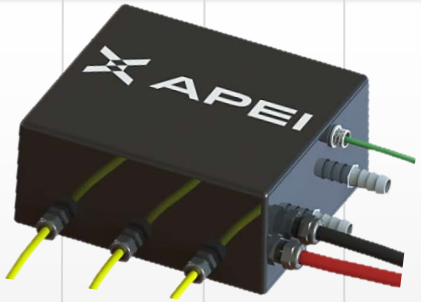
2015 | 2016 | 2017 | 2018 | 2019 | 2020

Develop a general hardware platform capable of using GaN and SI

Evaluate the benefits of GaN and begin Ph. II design

Start Program

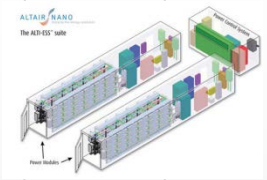
Key Deliverables: GaN AC-DC converter demonstrator and design



Design, build and test a >75 kW AC-DC for use in ESS

Interface converter between battery storage and Grid-tie

Key Deliverables: >75 kW AC-DC Converter



Fully qualify AC-DC converter for use in commercial applications

Wolfspeed will work with its partners to transition this AC-DC converter technology to a commercial product

PROGRAM TARGET APPLICATIONS

- Residential and light commercial (<10 kw)
  - Renewable energy storage and interface converter
  - Hybrid Electric/Electric vehicle
- Industrial (10 kW to MW scale)
  - Renewable energy storage and interface converter
  - Uninterruptible power supplies
  - Hybrid Electric/Electric heavy vehicle (locomotives, heavy machinery)

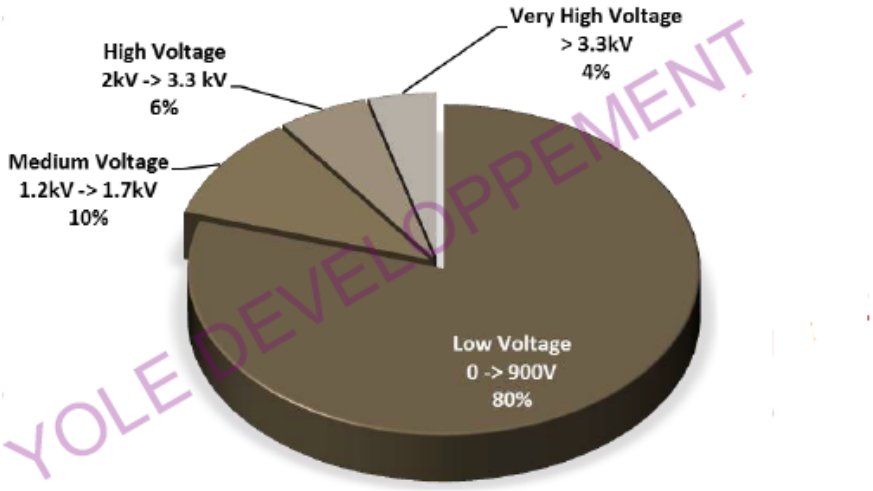
Source: Element

Source: Wind Farm in the Philippines

POWER ELECTRONICS AND ENERGY STORAGE MARKETS

Power Electronics Market

- **< 900 V** – GaN set to grow greatly in this area. GaN has the potential to offer higher performance and lower cost.
- **> 1.2 kV** – Currently, ideal Area for SiC; GaN research being done to penetrate this market



Power electronics market split by voltage range

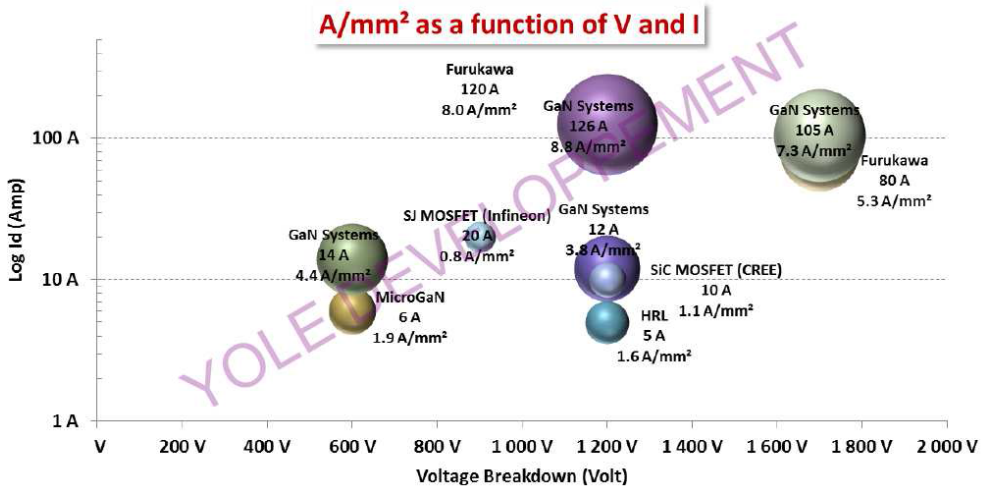
Source: Yole Développement

Energy Storage Market

- The global energy storage market is expected to grow to $400 B by 2020[1]

[1]. http://climatecrocks.com/2013/07/20/more-on-energy-storage-breakthrough-batteries/

ADVANTAGES OF GAN



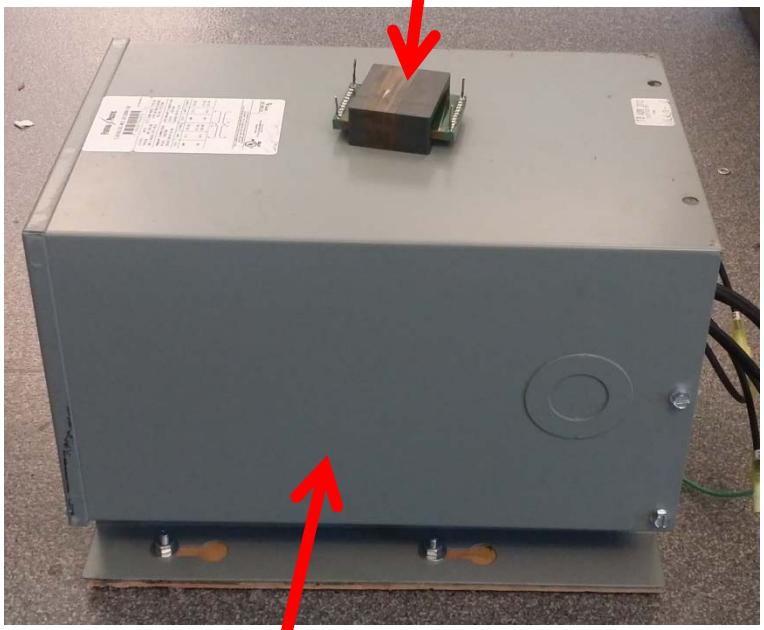
- Extremely fast switching which enables:
  - Smaller/less expensive filtering elements
  - Lower switching loss increases efficiency and reduces cooling requirements
- Cascode arrangement enables:
  - Simple drive requirements (Si MOSFET front end)
  - Usable anti-parallel diode

"Power GaN: Market & Technology Analysis," Yole Developpment.

NEED FOR HIGH EFFICIENCY TRANSFORMERLESS AC-DC CONVERTERS IN ENERGY STORAGE SYSTEMS

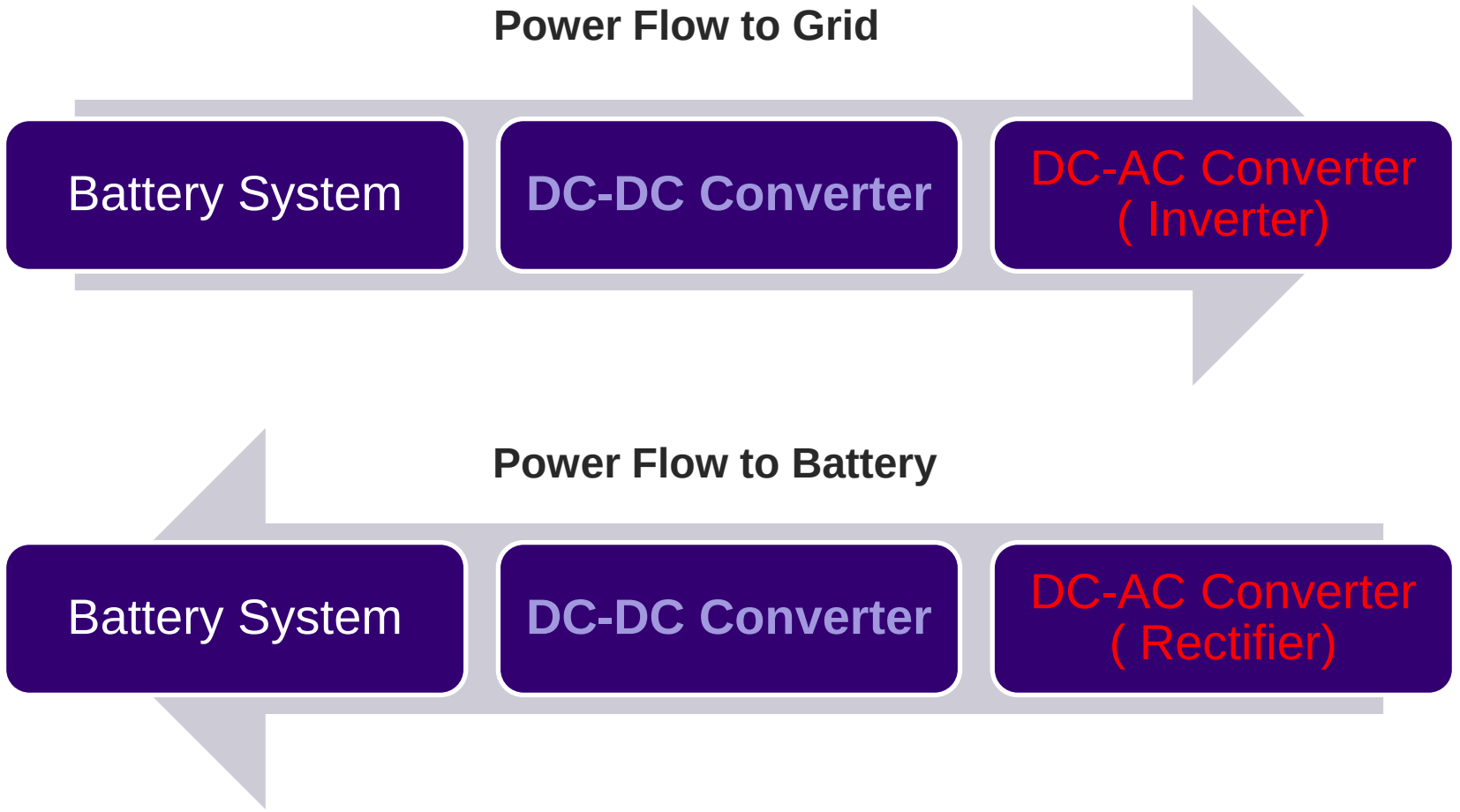
- By utilizing isolated high efficiency, high frequency isolated DC-DC converters, we can utilize a transformerless topology and therefore:
  - Dramatically reduce size/weight/cost of passive components
  - Reduce EMI/EMC
- **High efficiency is critical and can significantly decrease wasted energy, operational cost, and payback period**

100 kHz Ferrite Transformer
8 kW – 328 grams



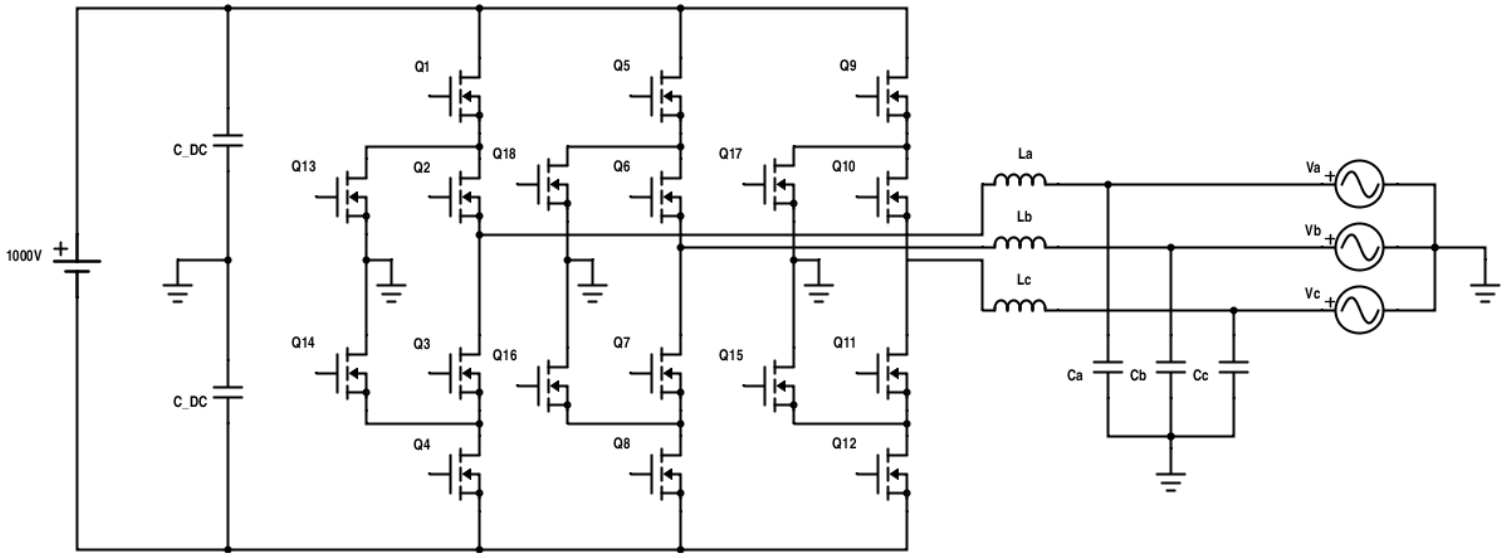
60 Hz Si-Steel Transformer
7.5 kVA – 150 lbs

NEED FOR BIDIRECTIONAL POWER FLOW



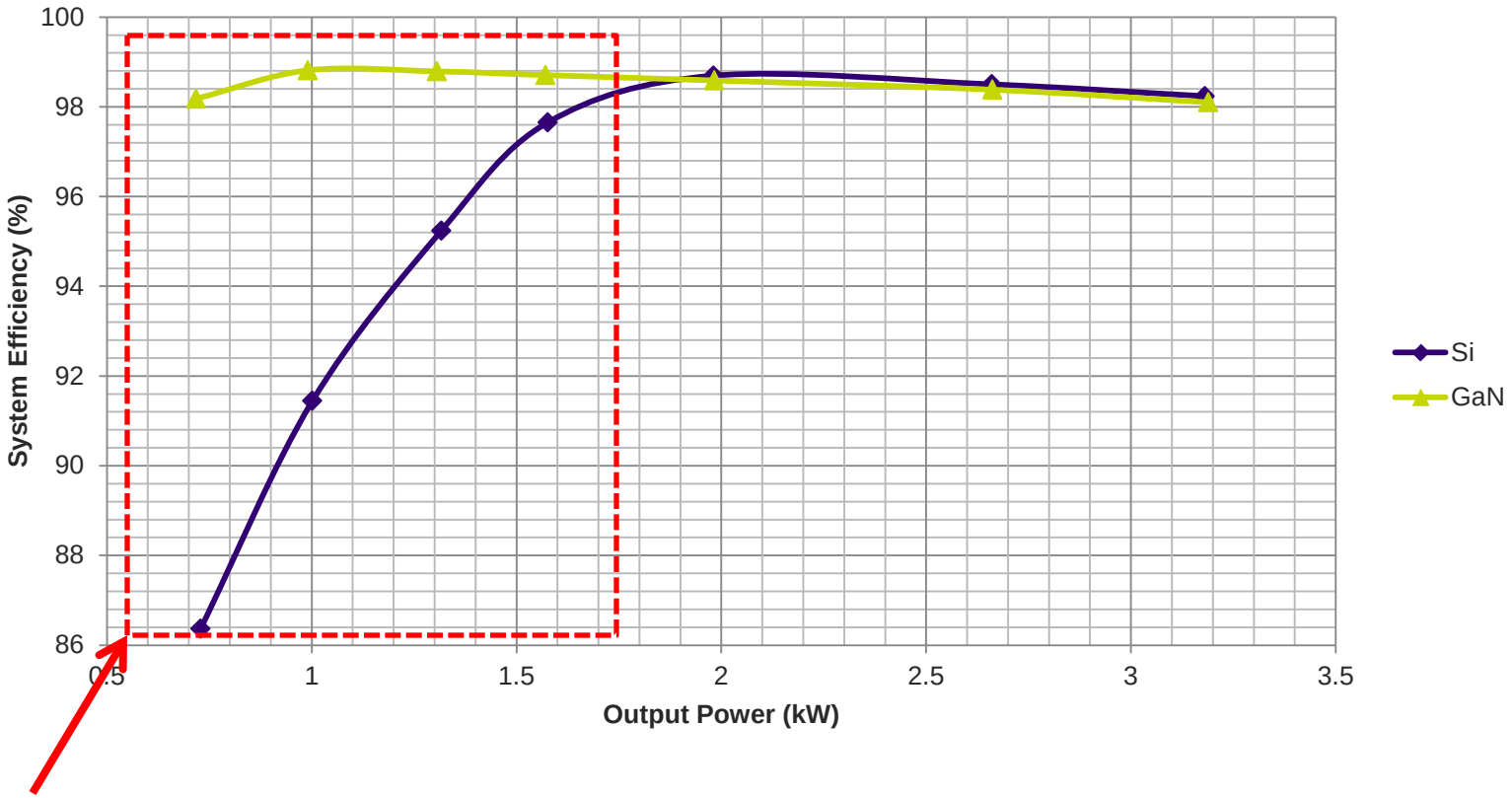
DC-DC converter currently being developed in Contract #: DE-SC0011963

TECHNICAL APPROACH



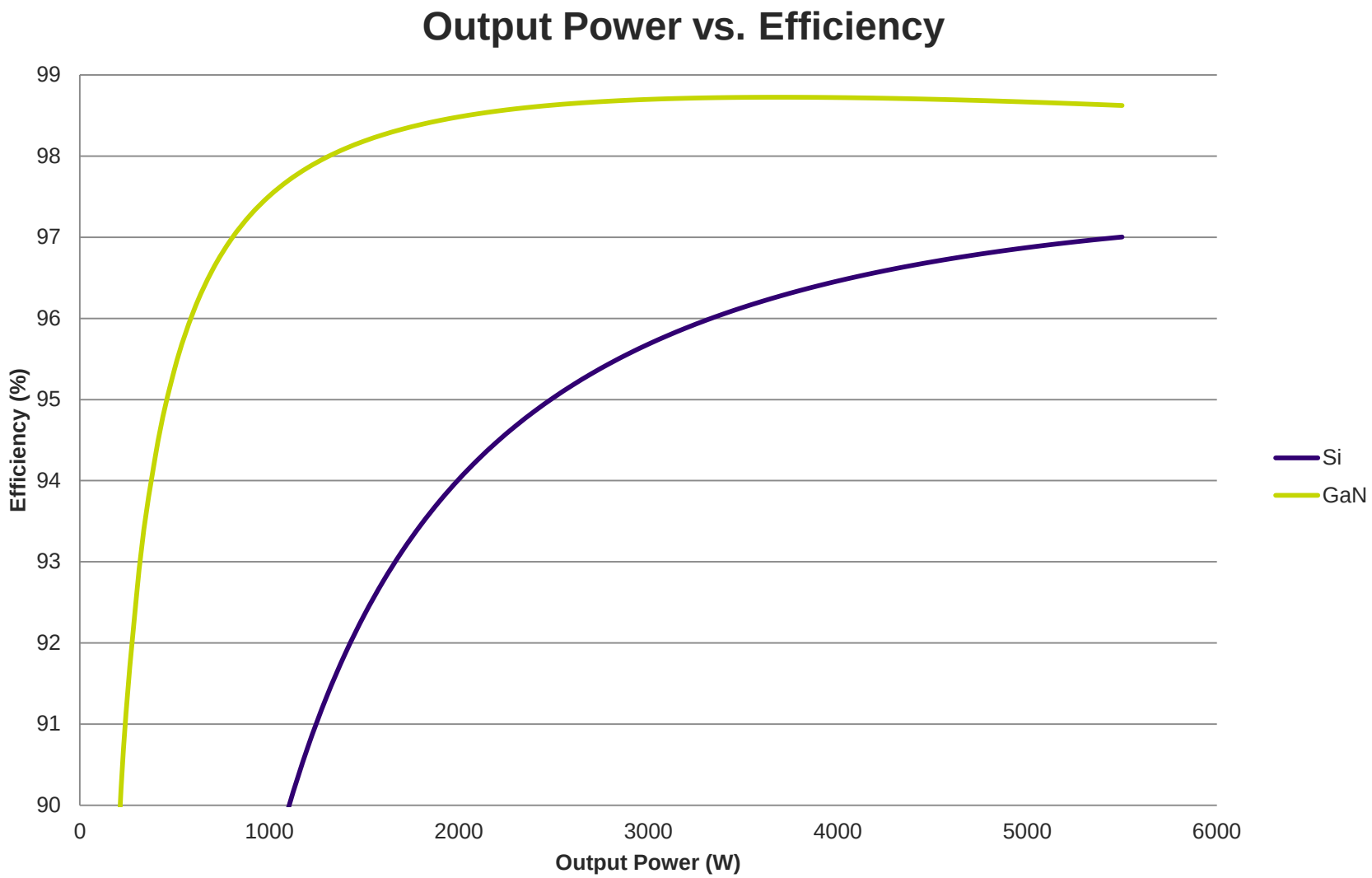
- Synchronous 3-Phase Neutral Point Clamped (SNPC) topology
  - Take advantage of device's channel in the reverse direction to reduce conduction loss vs. typical diode clamped topology
  - SNPC utilizes multilevel techniques to reduce switch voltage stress to half the DC link voltage (good for lower voltage GaN)
  - Synchronous operation opens possibilities for advanced modulation techniques aimed at reducing switching loss (will be explored in Phase II)
- Phase I will demonstrate a single phase leg at reduced power (>3kW)

GAN RESULTS FROM A 400 V ISOLATED DC-DC CONVERTER



Hard switching region (the proposed AC-DC converter will be hard switched) where GaN shows dominance over Si CoolMOS

INITIAL SIMULATION RESULTS



PHASE I TASKS

- Converter Design
  - Finalize specifications (complete)
  - Parts selection (complete)
  - Design and build (in progress)
  - Testing and optimization
- GaN Power Module Design
  - Device and material selection
  - Layout design
  - Thermal/Mechanical/Electrical simulation

PHASE II PLANS

- GaN Power Module Build
  - Use the design effort from Phase I to bring the first high power GaN NPC module to market
  - Utilize the power module in the AC-DC converter
- Converter Design/Build/Test
  - Scale the design demonstrated in Phase I to >75kW
    - Major thermal/mechanical design
    - Major magnetics design (high power/high frequency/high efficiency designs are challenging)
  - Investigate advanced soft switching techniques enabled by synchronous topology
  - Integrate the AC-DC converter with the DC-DC converter developed by APEI to bring a full grid to battery solution to market

SUMMARY

- High efficiency bidirectional AC-DC converters are critical for current and future energy storage systems
- GaN transistor technology can greatly improve efficiency compared to Si technology
- A custom GaN based power module is necessary to take full advantage of GaN and to deliver higher power levels
- The Phase I demonstrator and power module concept will cement the advantages of GaN and will help springboard a higher power (>75 kw) design for Phase II

Leading the Pack™

A CREE COMPANY