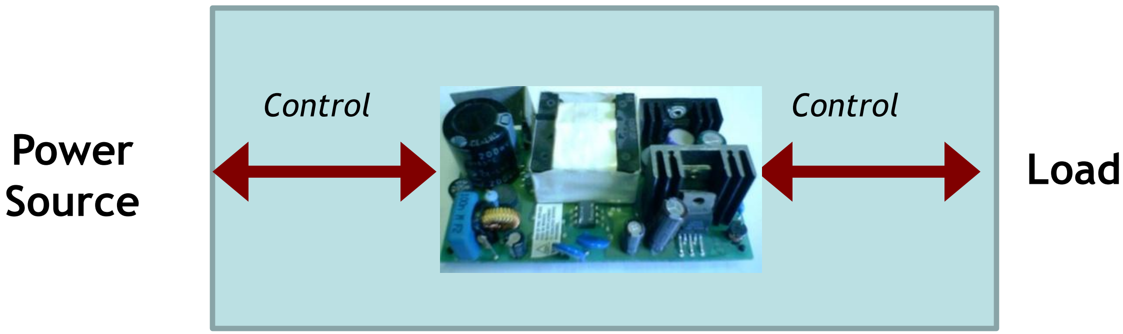
Intelligent Electricity

Rajeev Ram, Program Director, ARPA-E

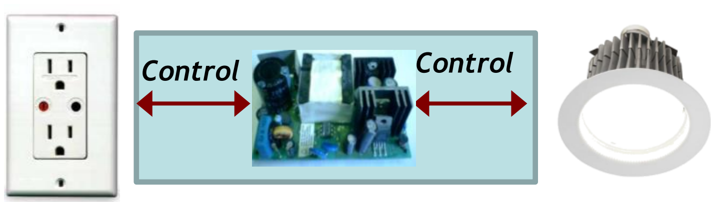
2010: 30% of all electric power flows through power electronics
2030: 80% of all electric power will flow through power electronics

ROLE OF POWER ELECTRONICS

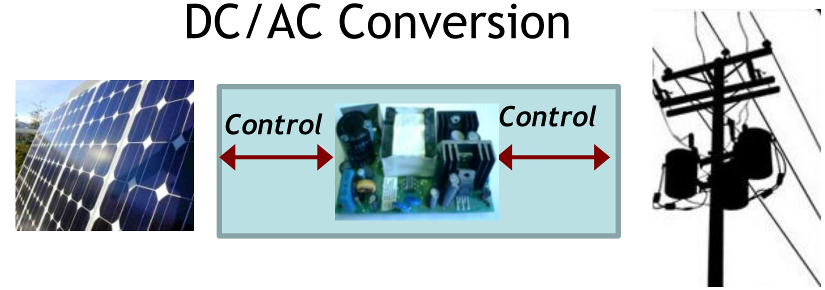
2010: 30% of all electric power flows through power electronics
2030: 80% of all electric power will flow through power electronics



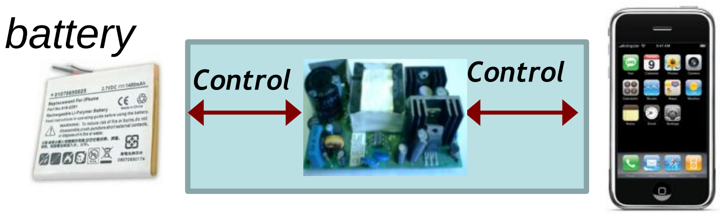
AC/DC Conversion



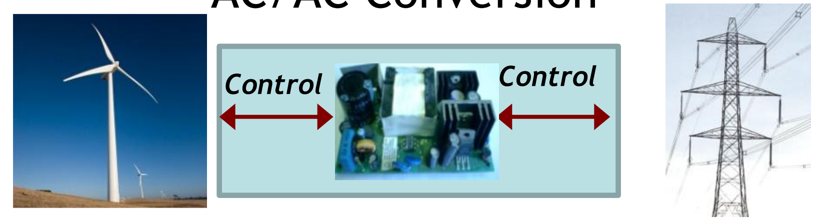
DC/AC Conversion



DC/DC Conversion

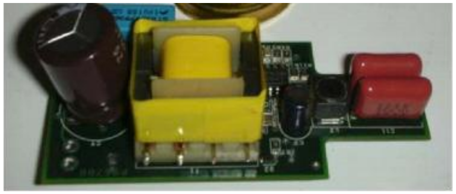


AC/AC Conversion



POWER MAGNETICS WHITE SPACE

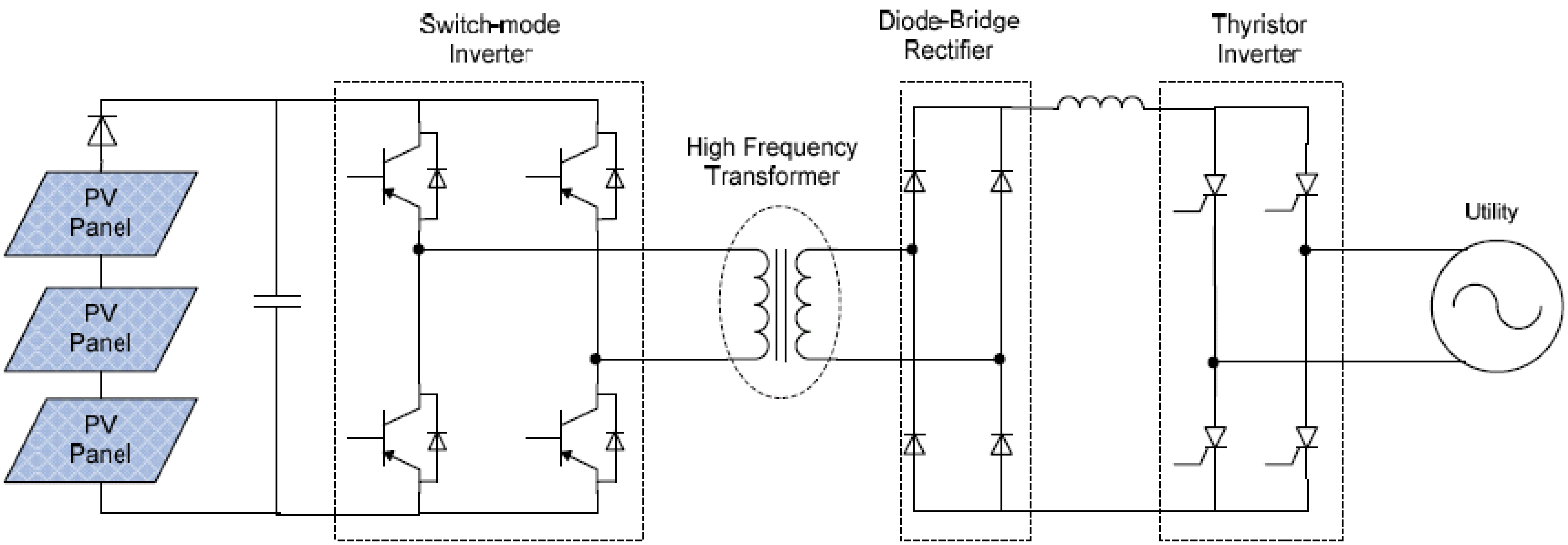
>92% Dimmable LED Driver

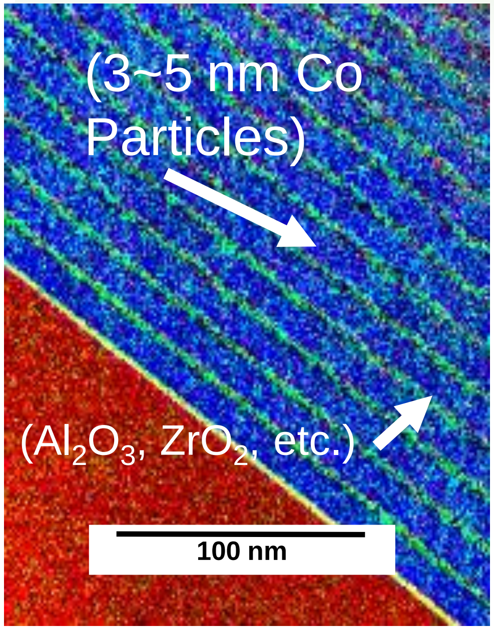


1MW PVInverter

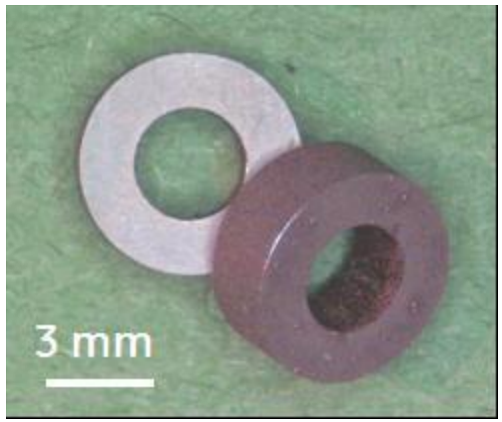
	10 W	1000 W	100 kW	10 MW
50 kHz	N/A	Now: ferrite, amorphous	Now amorphous, ferrite, nanocrystalline	Future: exisitng and new materials
500 kHz	Now: ferrite	Now: ferrite Future: new materials	Future: new materials	
5 MHz	Now: thin-film	Future: new materials		
50 MHz	Future: thin-film and air core			

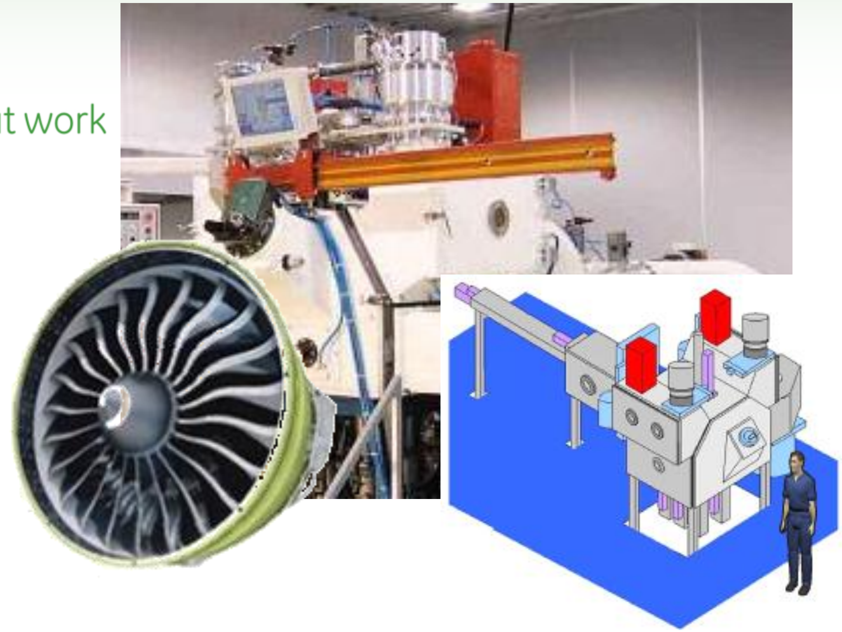
HV SWITCHES AND HI-FREQUENCY TRANSFORMERS





GE imagination at work





MINIATURE (FAST) MAGNETICS NEEDS FAST SWITCHES

Bandgap (energy to 'free electron') increases

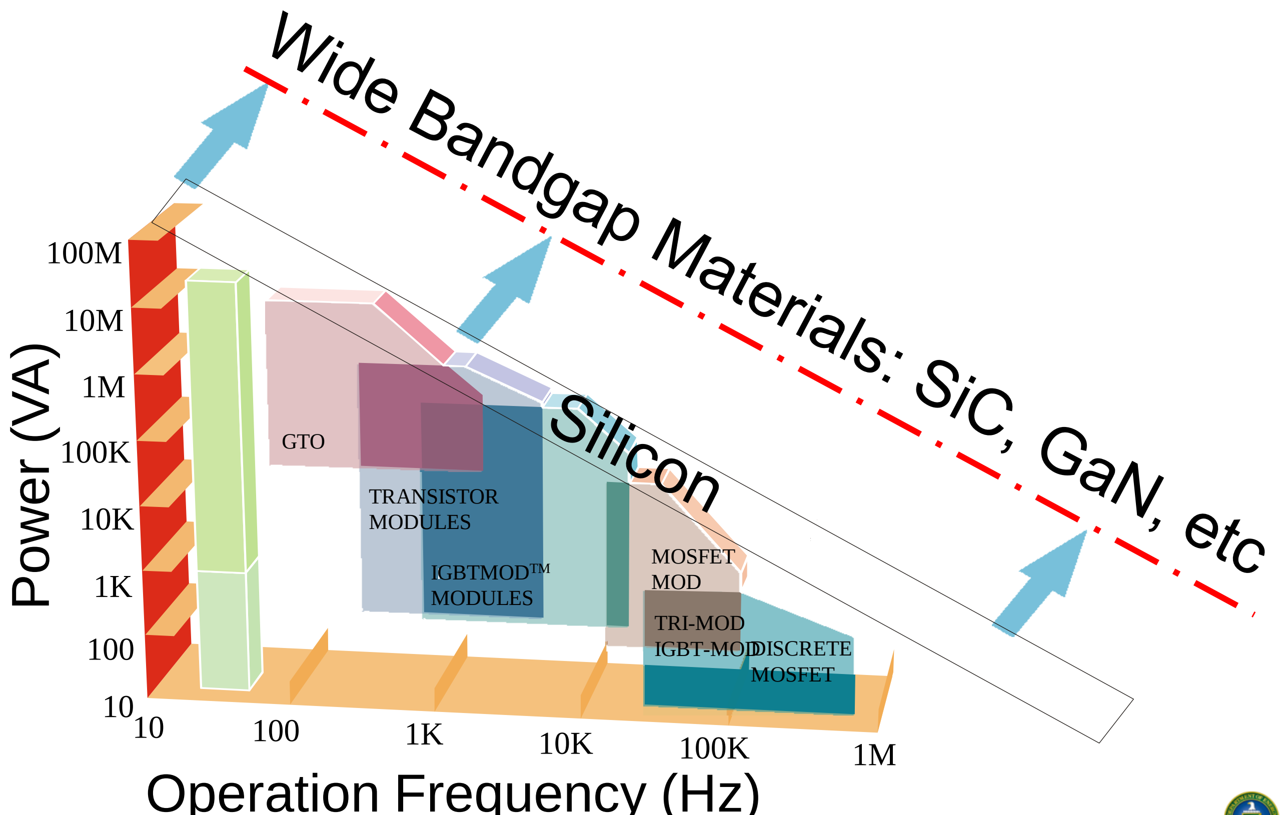
Breakdown voltage increases

Drift region can be decreased

Reduces transit time

Increases frequency

Reduces on-resistance

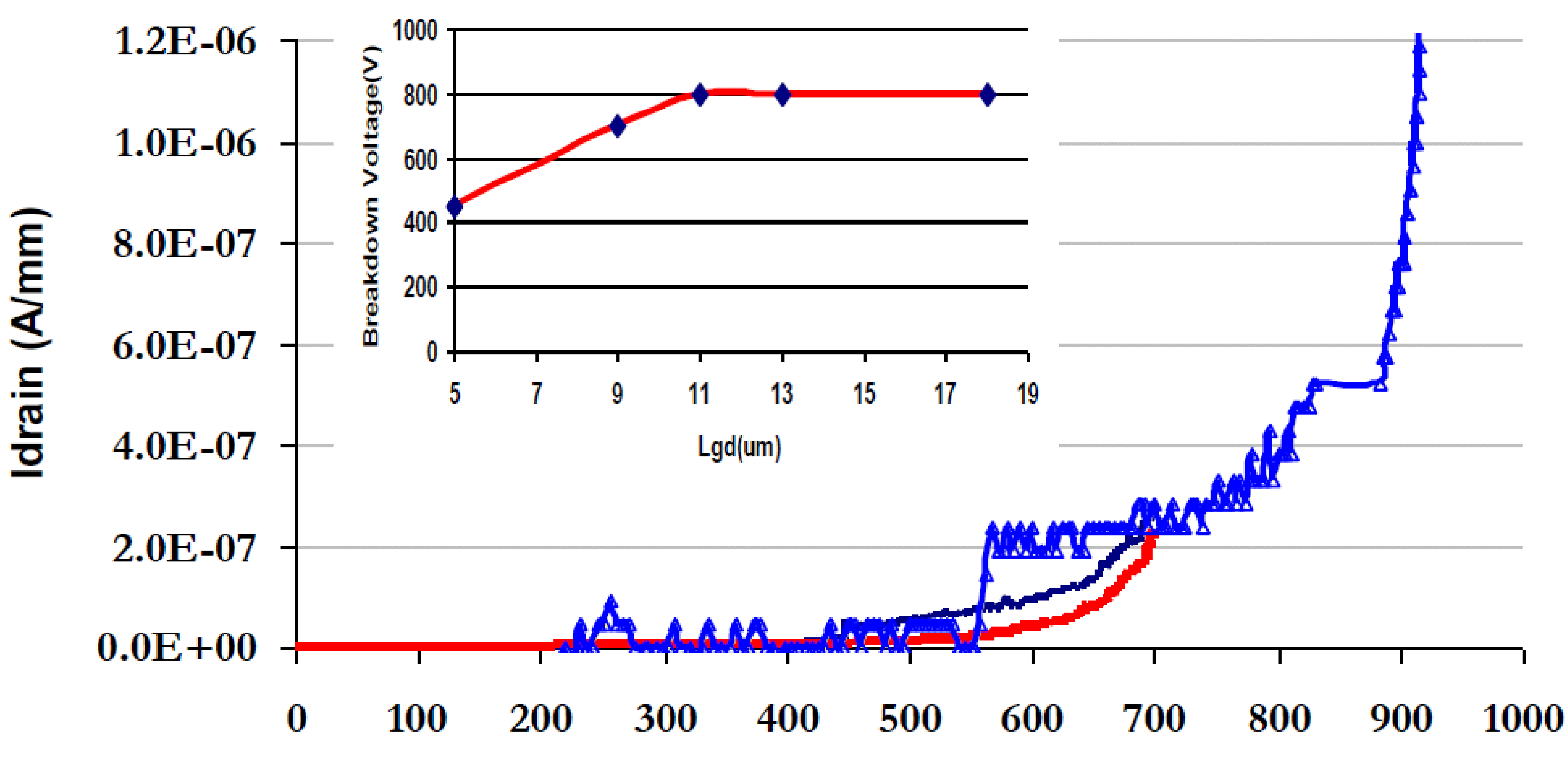


AUTOMOTIVE ELECTRONICS

- 600V GaN-on-Si with sintered interconnects & double-side cooling.
- Reduce energy losses and cost by at least 50% relative to Si IGBT

(Wg=100 mm, Lg=2um)

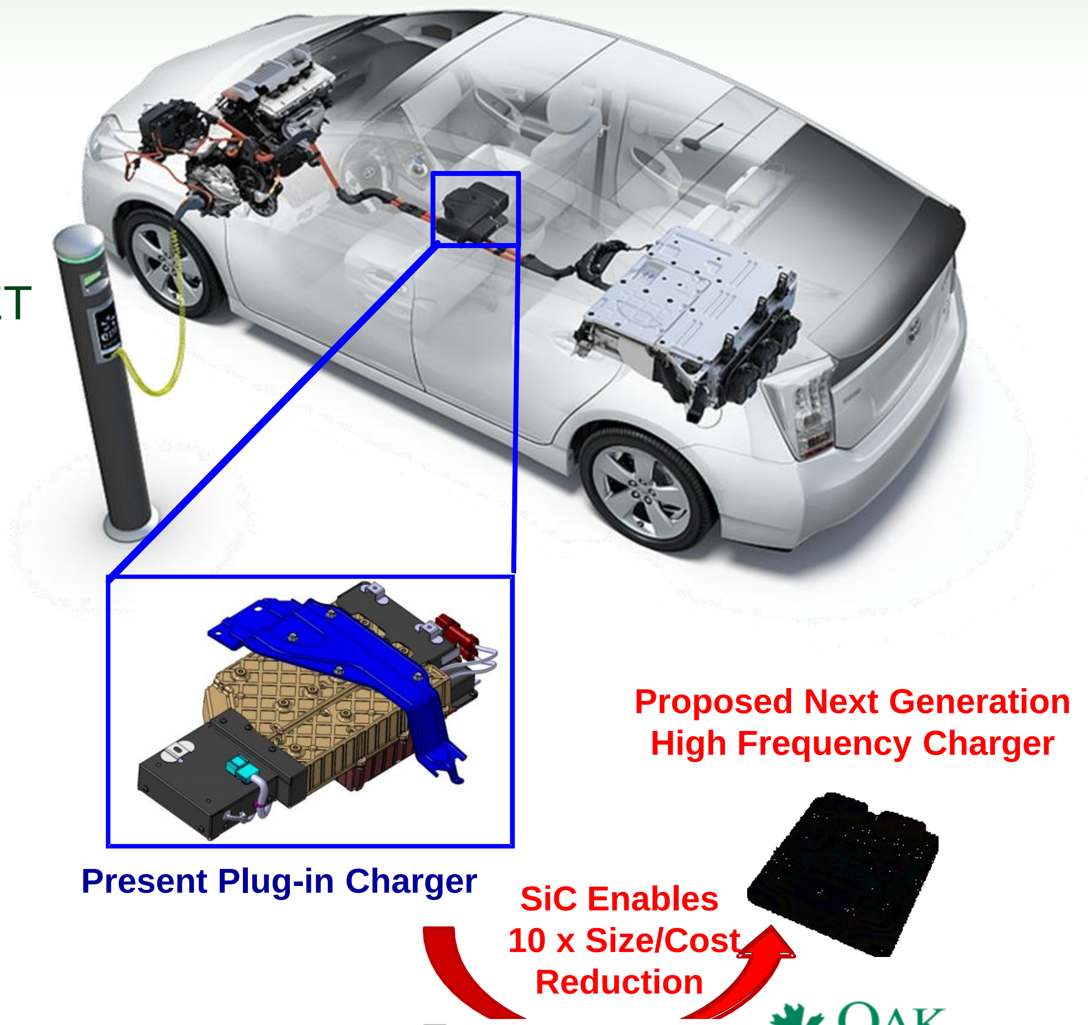
Ion/Ioff(600 V) > 10^6



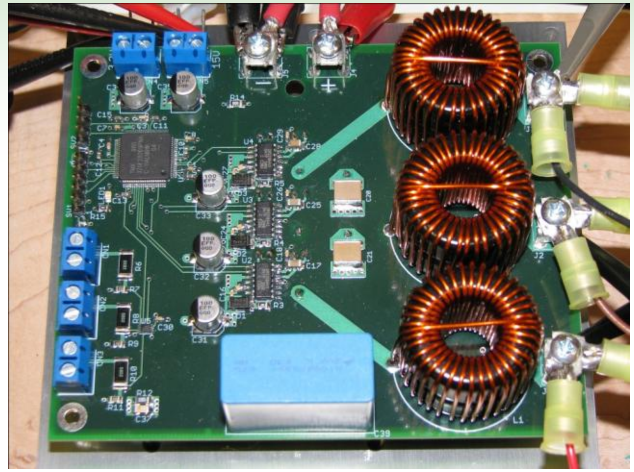
Vg=-10V , I BV = 0.1 uA / mm

AUTOMOTIVE ELECTRONICS

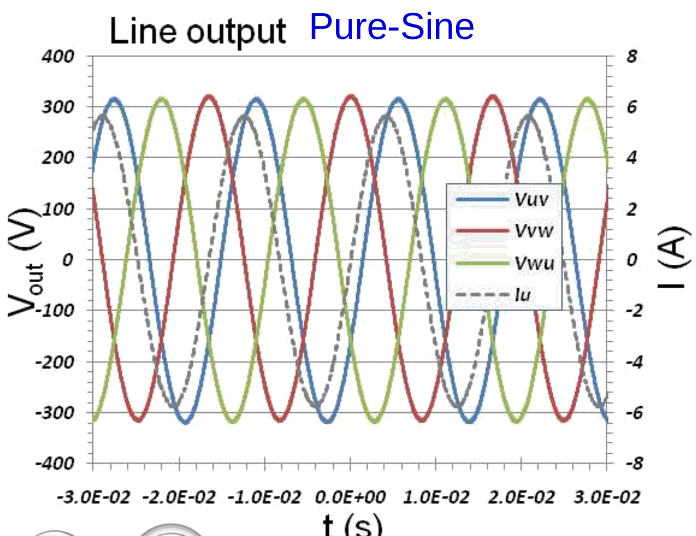
- Develop a Mult-Chip Power Module for >500 kHz
- Develop 1200V, 20A SiC MOSFET with isolated, integrated SiC gate drive
- Small, lightweight, few materials, low cost
- >94% efficiency, > 5kW/kg, > 100W/in3
- Integrate into Prius vehicle and demonstrate operation

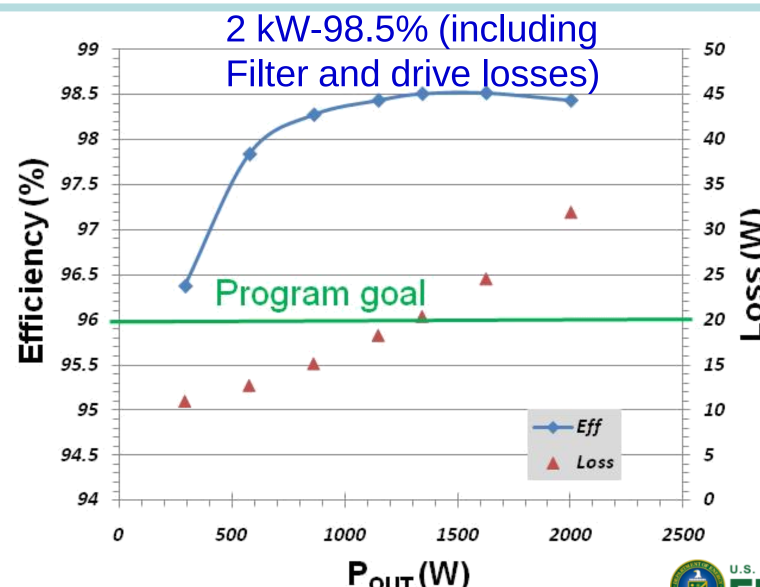


HIGH EFFICIENCY MOTOR DRIVE GAN-SIC

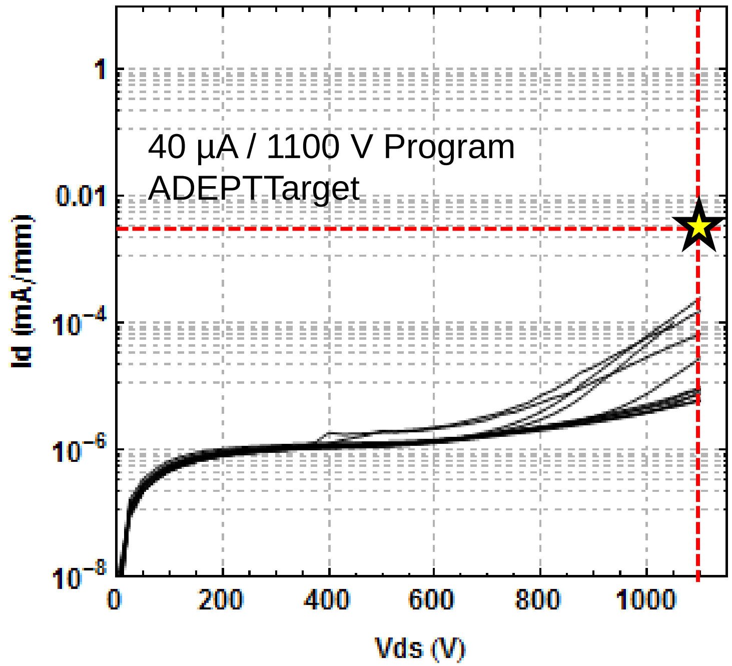


GaN/SiC 3-ph inverter with Integrated Filter, 100 KHz

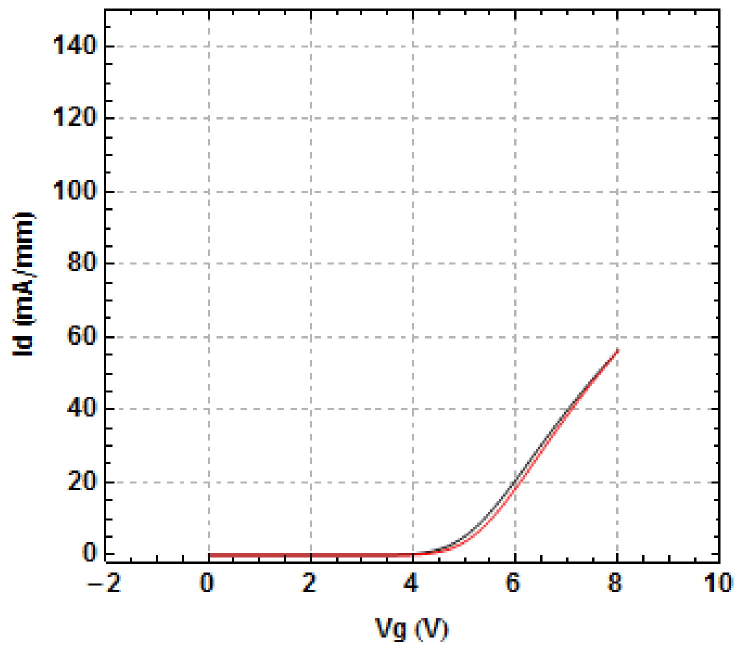




ENHANCEMENT-MODE GaN-Si

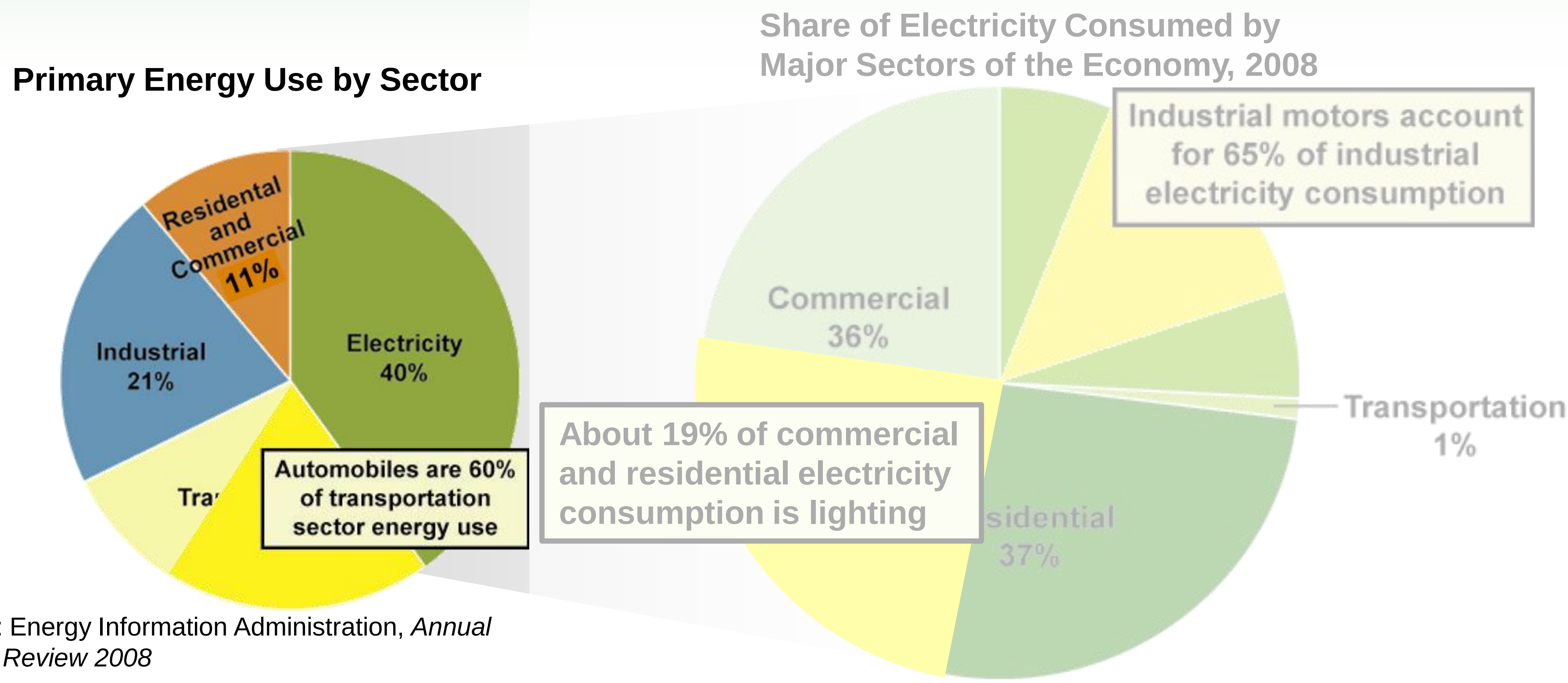


>1000V GaN on Si Material
(Buffer structure)



Transfer characteristic of GaN on Silicon E-mode HEMT, Vt>4V

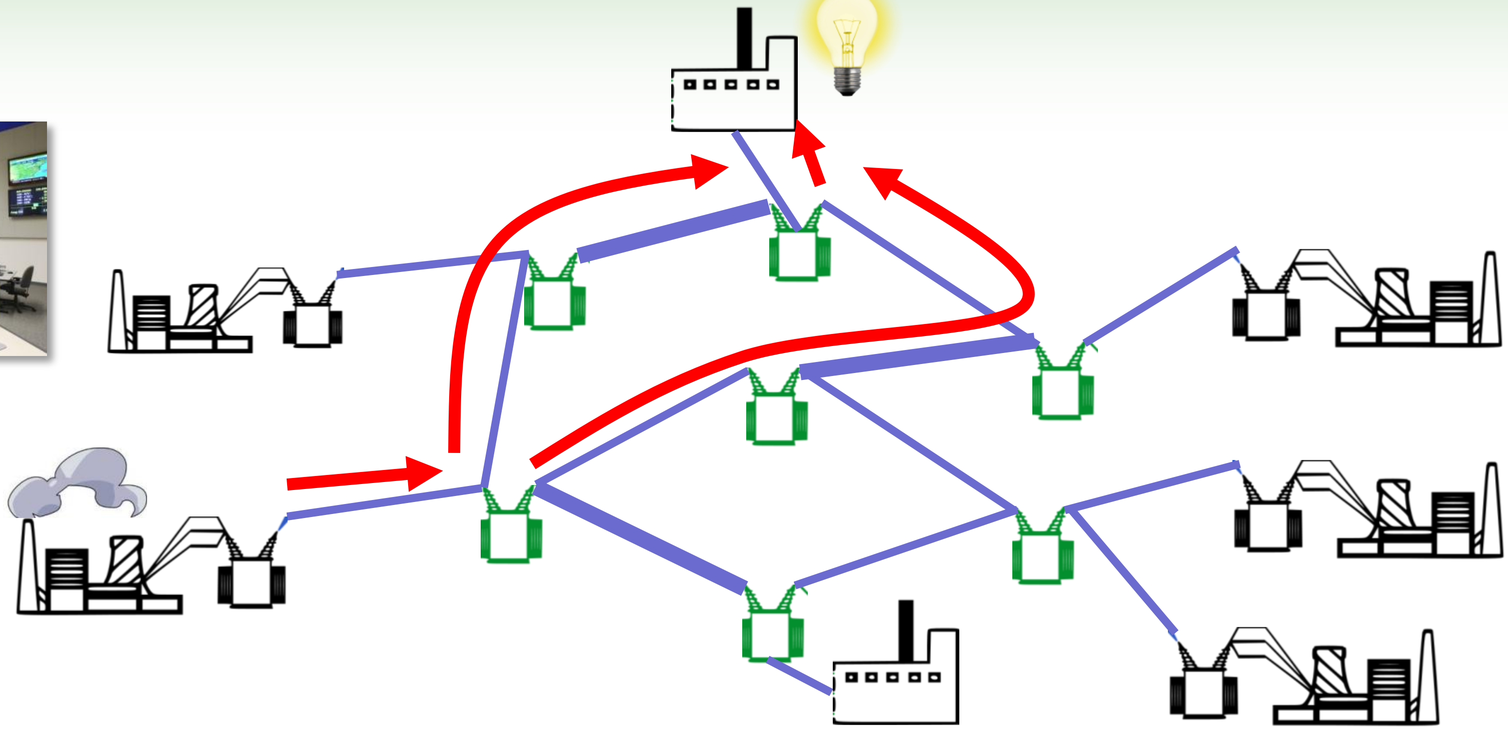
ROLE OF POWER ELECTRONICS



Source: Energy Information Administration, *Annual Energy Review 2008*

- **30-50% of cost for dimmable LED luminaire (ADEPT: MIT, Teledyne, CUNY)**
- **20% energy loss in industrial motors due to mechanical throttling (ADEPT: Transphorm)**
- **20% of material cost for HEV is power electronics (ADEPT: Delphi/IR, HRL/GM, APEI/Cree, CWRU)**

DELIVERING ELECTRICITY

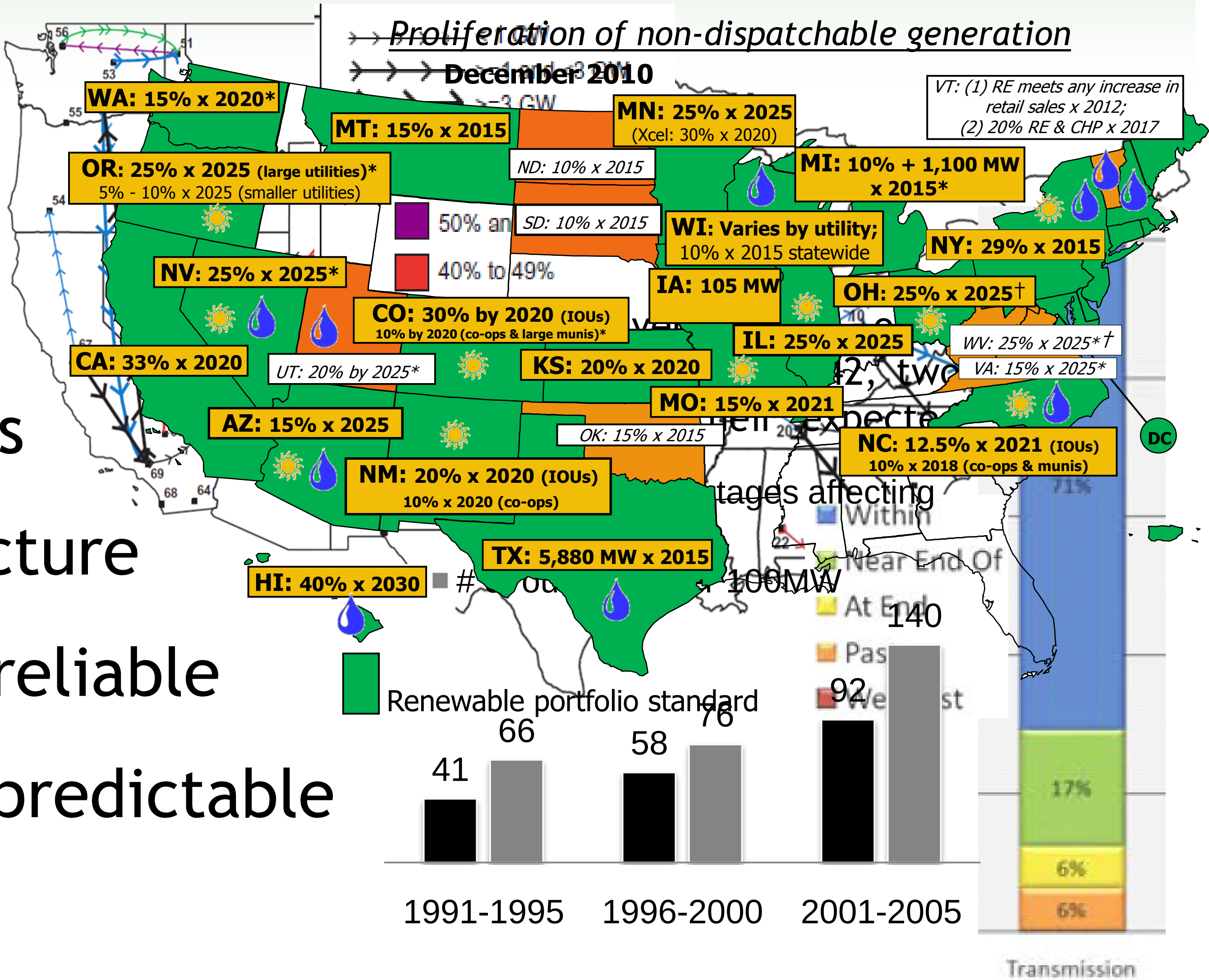


- Negligible storage – just in time delivery of power
- Centrally controlled
- Negligible control of path – Joules are indistinguishable

Not the internet

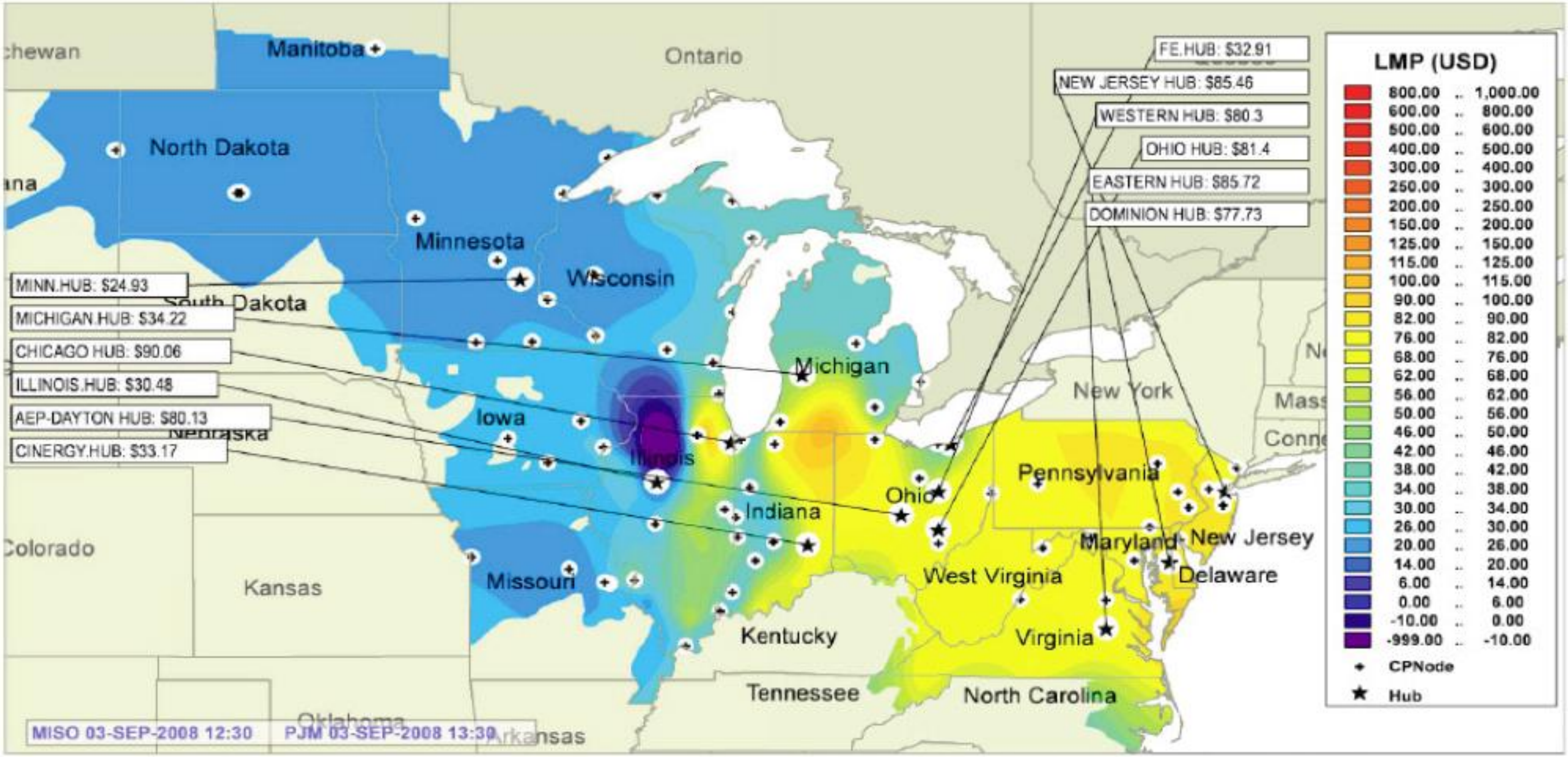
STATE OF THE GRID

- Congested Lines
- Aging Infrastructure
- Increasingly unreliable
- Increasingly unpredictable



INEFFICIENT MARKETS

Location marginal pricing



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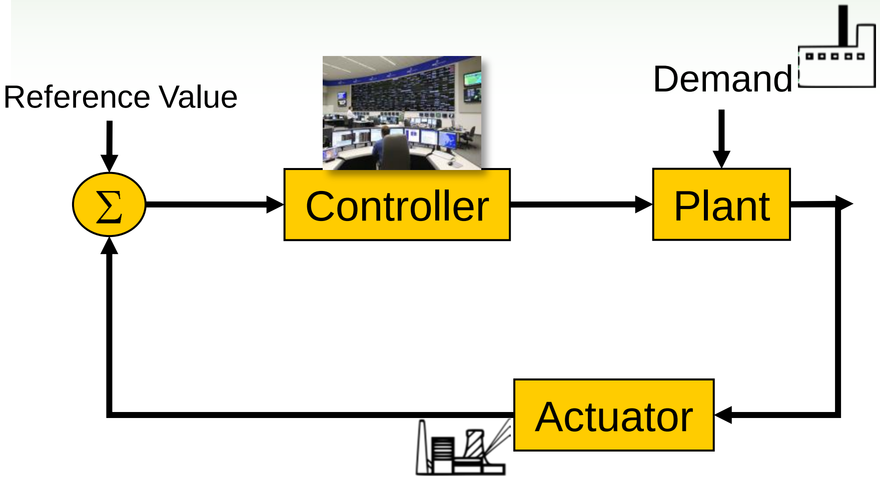
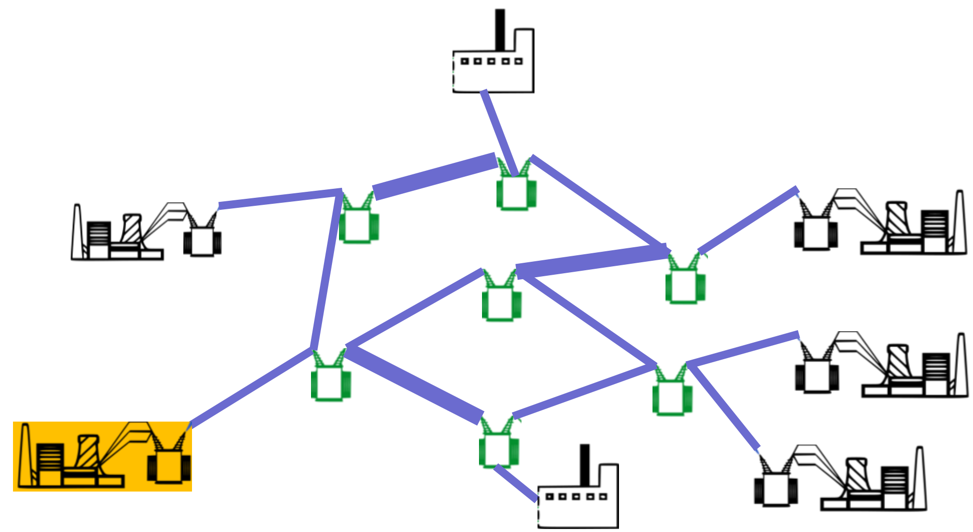
CONTROL AND ACTUATION OF THE GRID



__Demand Response__

Schedule demand

(eg. large industrial loads)



__Control in the Grid__

Flexible AC Transmission System:

•Static VAR

•STATCOM

•UPFC

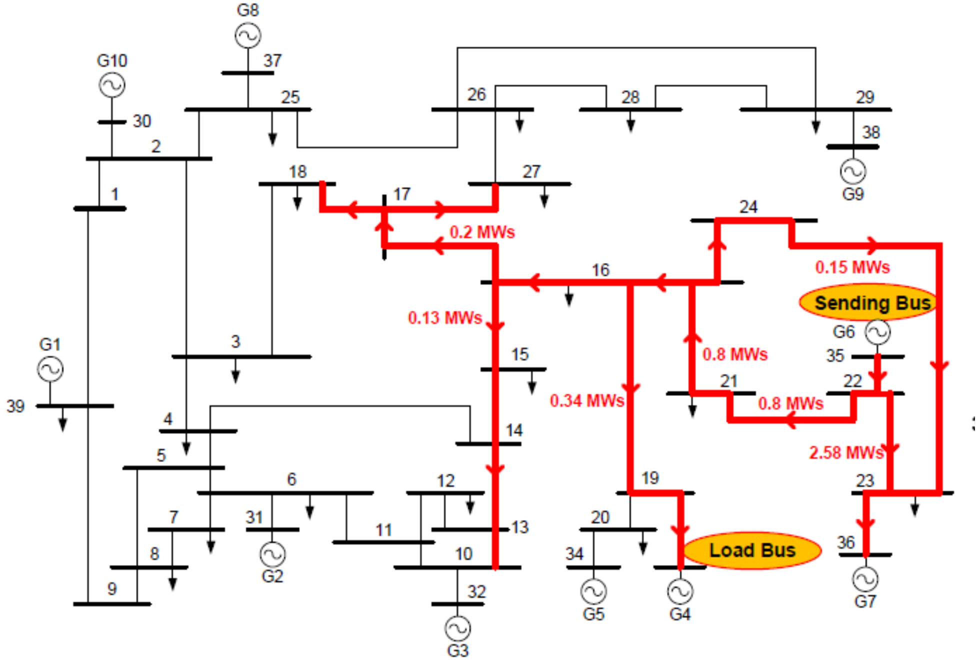
__Grid Storage__

Dispatch of intermittent generation

ROUTING ELECTRICAL POWER

GA Tech study of simplified IEEE 39 Bus system with 4 control areas, operation simulated for 20 years, 20% RPS phased in over 20 years, sufficient transmission capacity added each year to eliminate curtailment of renewable generation

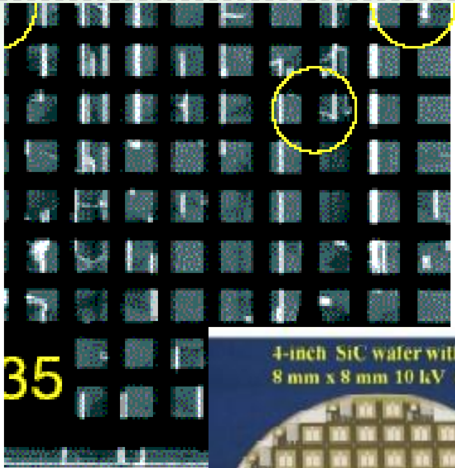
Today: Uncontrolled Flows | *Power Routing*



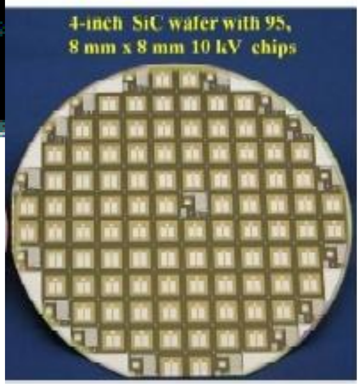
Base Case: 3.4 MW sent; 0.34 MW recd

- BAU case requires upgrade of 3 inter-regional paths, for a total of 186,000 MW-MILES
- Power flow control to route power along underutilized paths, 36,000 MW-miles of new lines needed, only 20% of BAU

SOLID-STATE TRANSFORMERS



NRL



- **Significantly improved SiC IGBTs**
  - **High voltage (20kV)**
  - **Extremely efficient (>98%)**
  - **Fast switching (50kHz)**

Cree

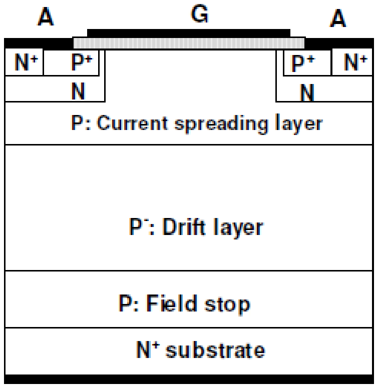
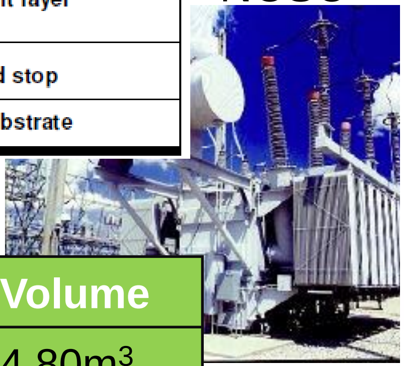
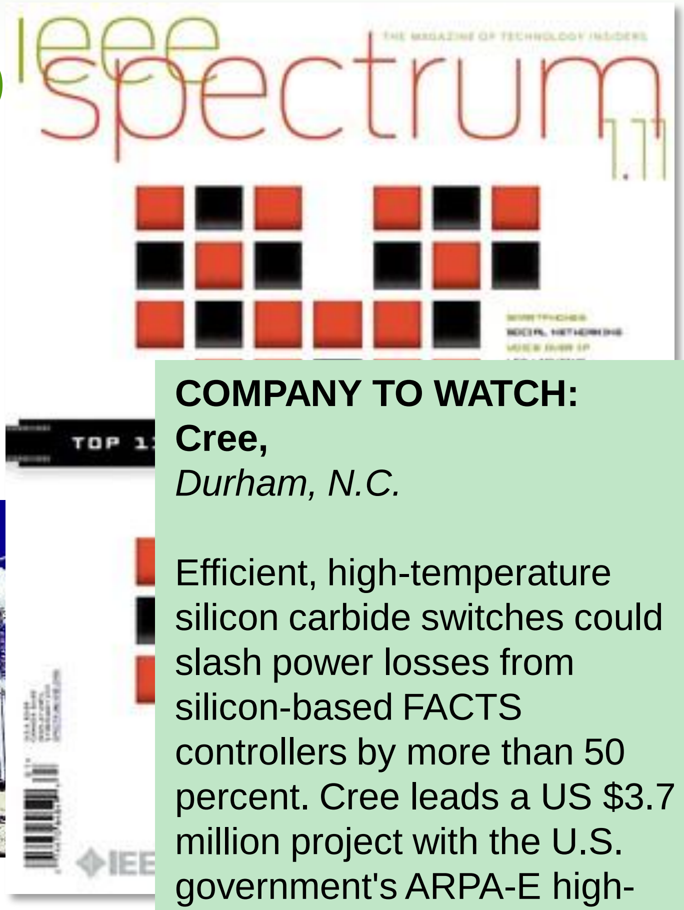


ABB
NCSU



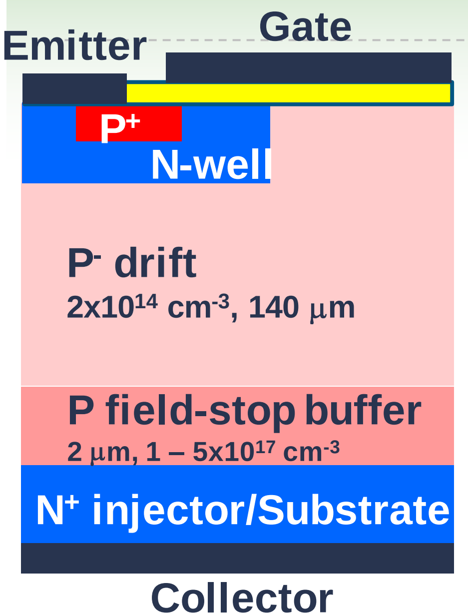


	Frequency	Mass	Volume
Today	60 Hz	8,160 lb	4.80m³
Tomorrow	50 kHz	100 lb	0.14m³

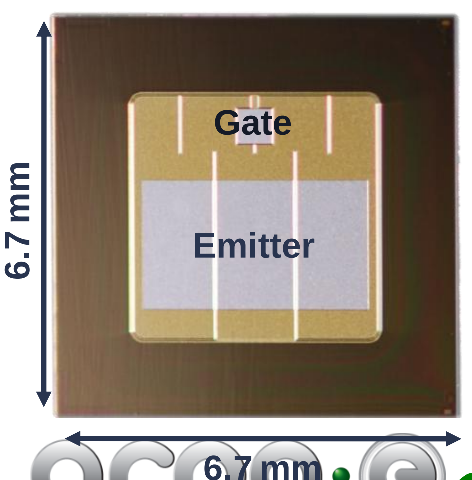
COMPANY TO WATCH:
Cree,
Durham, N.C.

Efficient, high-temperature silicon carbide switches could slash power losses from silicon-based FACTS controllers by more than 50 percent. Cree leads a US $3.7 million project with the U.S. government's ARPA-E high-risk energy R&D fund to engineer 15- to 20-kilovolt silicon carbide power modules ready for grid-scale power flows.

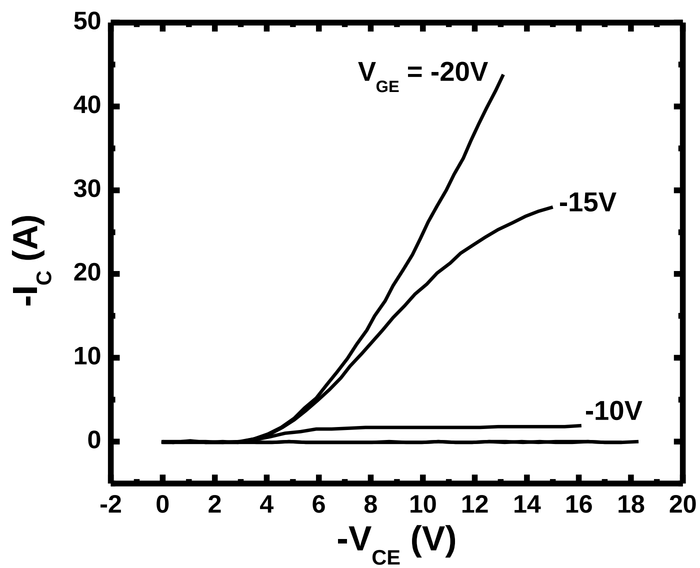
15 kV SiC P-IGBT

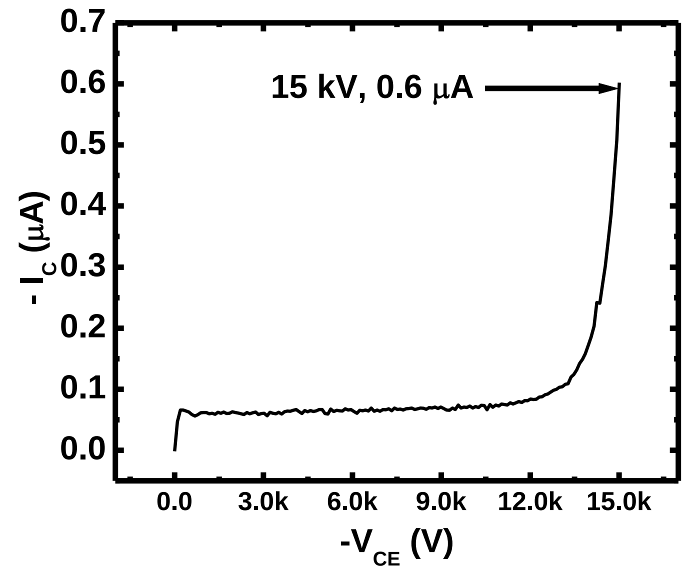


SiC P-IGBT Structure



Highest Breakdown Voltage Ever Reported for a Semiconductor Switch





V_F = 5.8V @ 5 A, V_{GE} = -20V
= 11.2 V @ 32 A (200 A/cm²)

15 kV Blocking
(V_{GE}=0V)

$R_{on,sp}$ = 24 mΩ-cm²
(V_{GE}=-20V, V_{CE}=-11.2V)

Room Temperature Device Characteristics

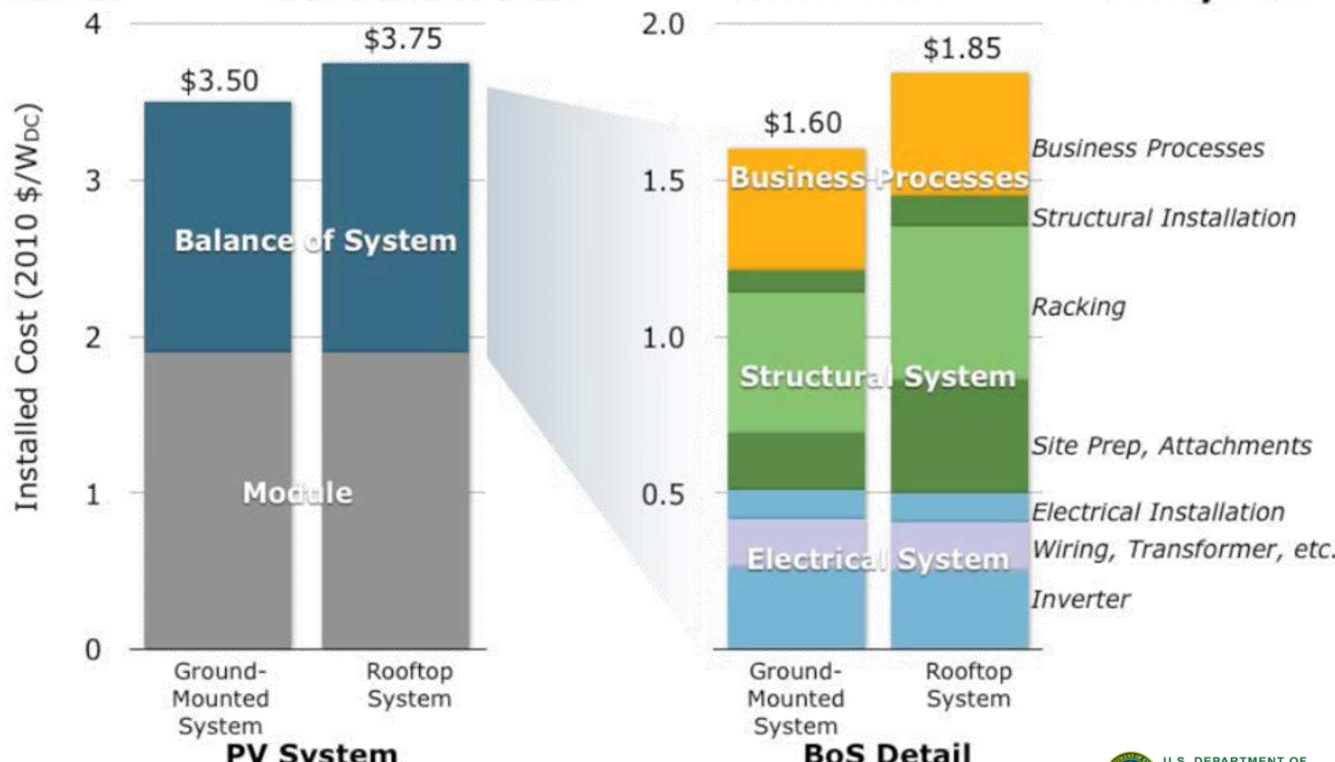
In today's integrated and digitized global market, where knowledge and innovation tools are so widely distributed. . . . :whatever can be done, will be done. The only question is will it be done by you or to you.

Thomas L. Friedman, Author, "The World Is Flat"

"Here, you see, it takes all the running you can do to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that."

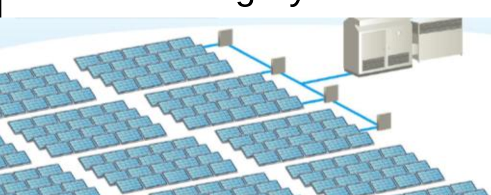
The Red Queen, *Through the Looking Glass*

PV POWER ELECTRONICS

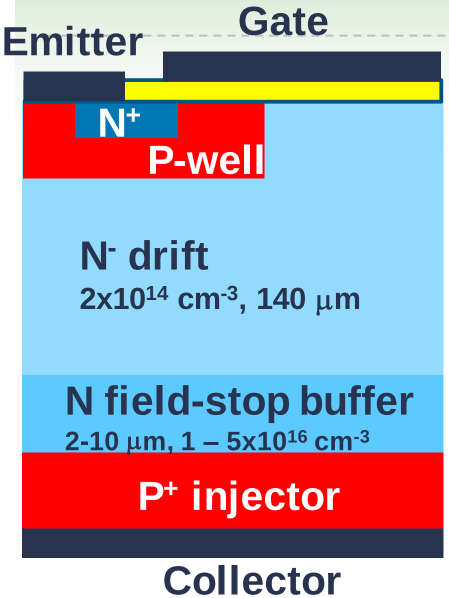


Source: Rocky Mountain Institute

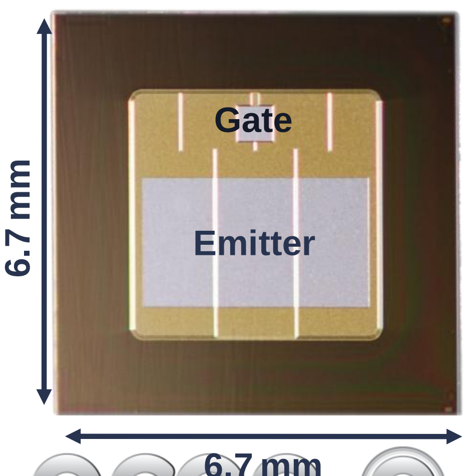
SOLAR ADEPT TARGETS

System Categories	Cost	Voltage & Power	CEC Efficiency	Size
Category 1 	$0.05/W	>3 converters/ module	>98% cell-to-AC MPPT	Single-chip DC/DC Inside Module Frame
Category 2 	$0.20/W	>600 V >250 W	>98% cell-to-AC	< 2 lbs Integrated: < 10 parts
Category 3 	<$0.10/W	100kW	>98% cell-to-AC MPPT	< 50 lbs
Category 4 	$0.10/W	> 2 MW scalable	>98% module-to-grid	< 1000 lbs

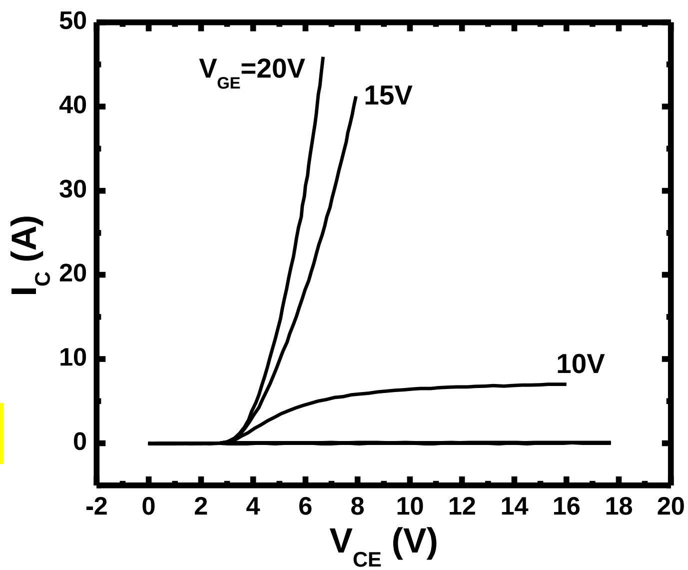
12.5 kV SiC N-IGBT

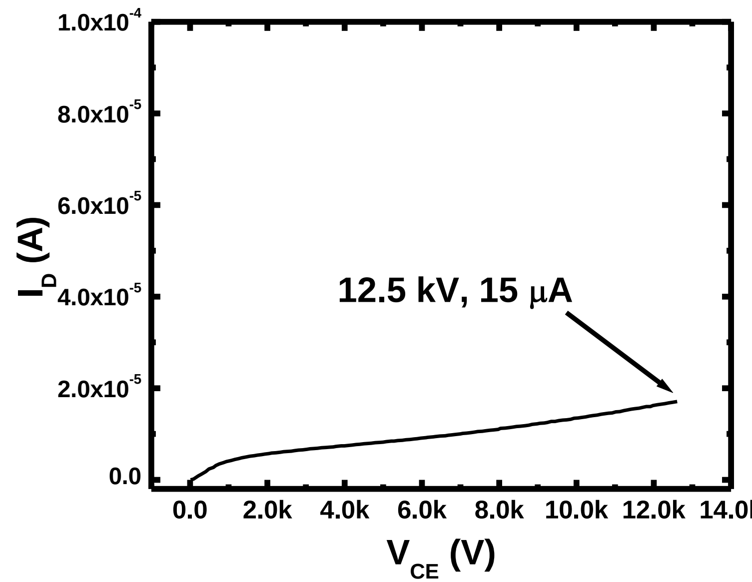


SiC N-IGBT Structure



12.5 kV SiC N-IGBT With Specific On Resistance ($R_{on,sp}$) of Only 5.3 mΩ-cm² !





V_F = 4.1V @ 5 A, V_{GE} = 20V
= 6.1 V @ 32 A (200 A/cm²)

$R_{on,sp}$ = 5.3 mΩ-cm²
(V_{GE}= 20V, V_{CE}= 6.1V)

12.5 kV blocking
(V_{GE}=0V)

Room Temperature Device Characteristics