Sustainable Energy & Power Electronics

Jan 24, 2020

by

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University Distinguish Professor and Director Emeritus

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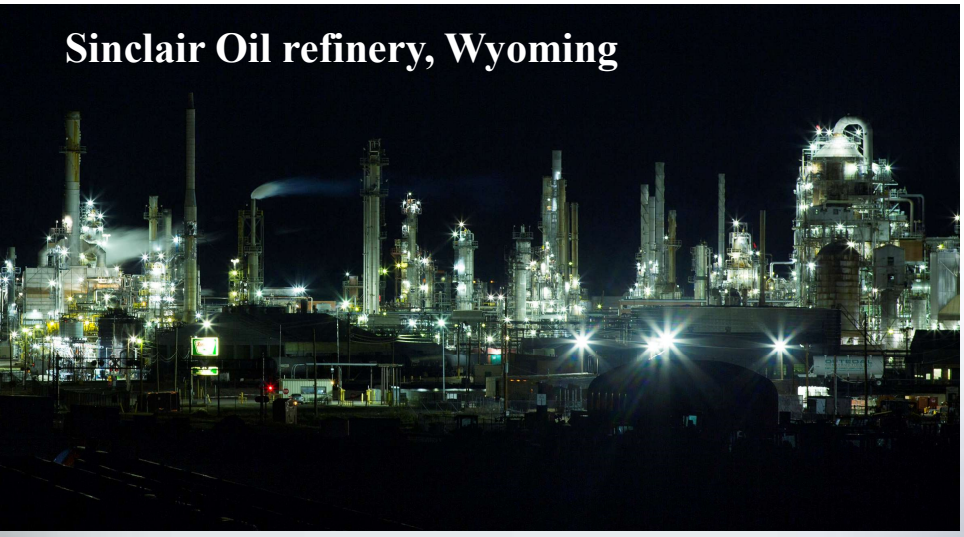
Virginia Tech,

Energy and Environment

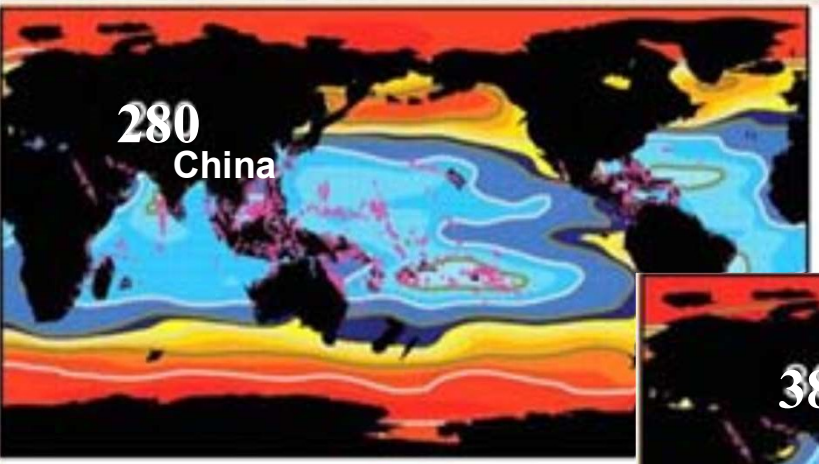

Sinclair Oil refinery, Wyoming

A Few Facts

- Population growth to 9 billion by 2050
- Energy consumption will double by 2050
- 65% global warming coming from energy generation and use

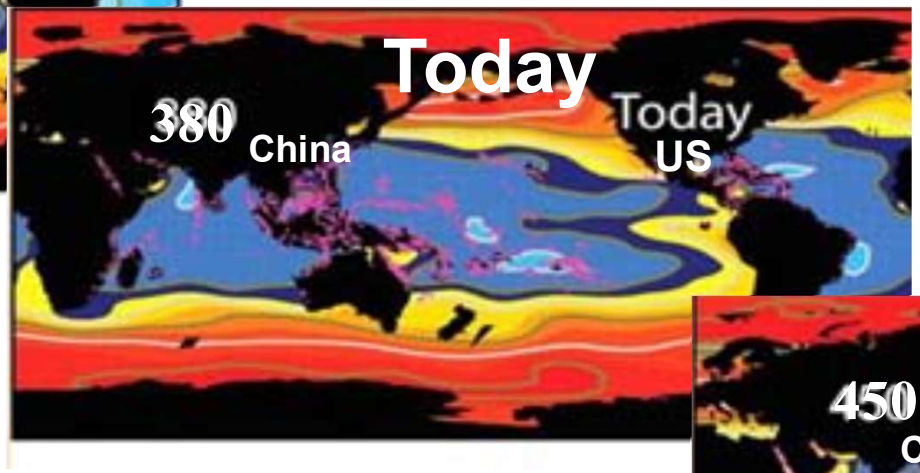
* Courtesy of GE Global Technology Center

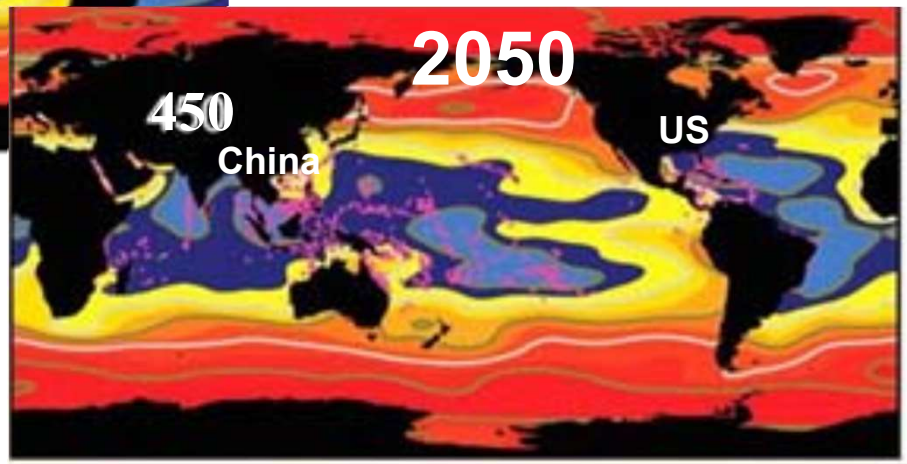
Statement of Ocean Acidification



Before Industry Revolution

Signed by the Academies of Science of 70 nations, June 1, 2009



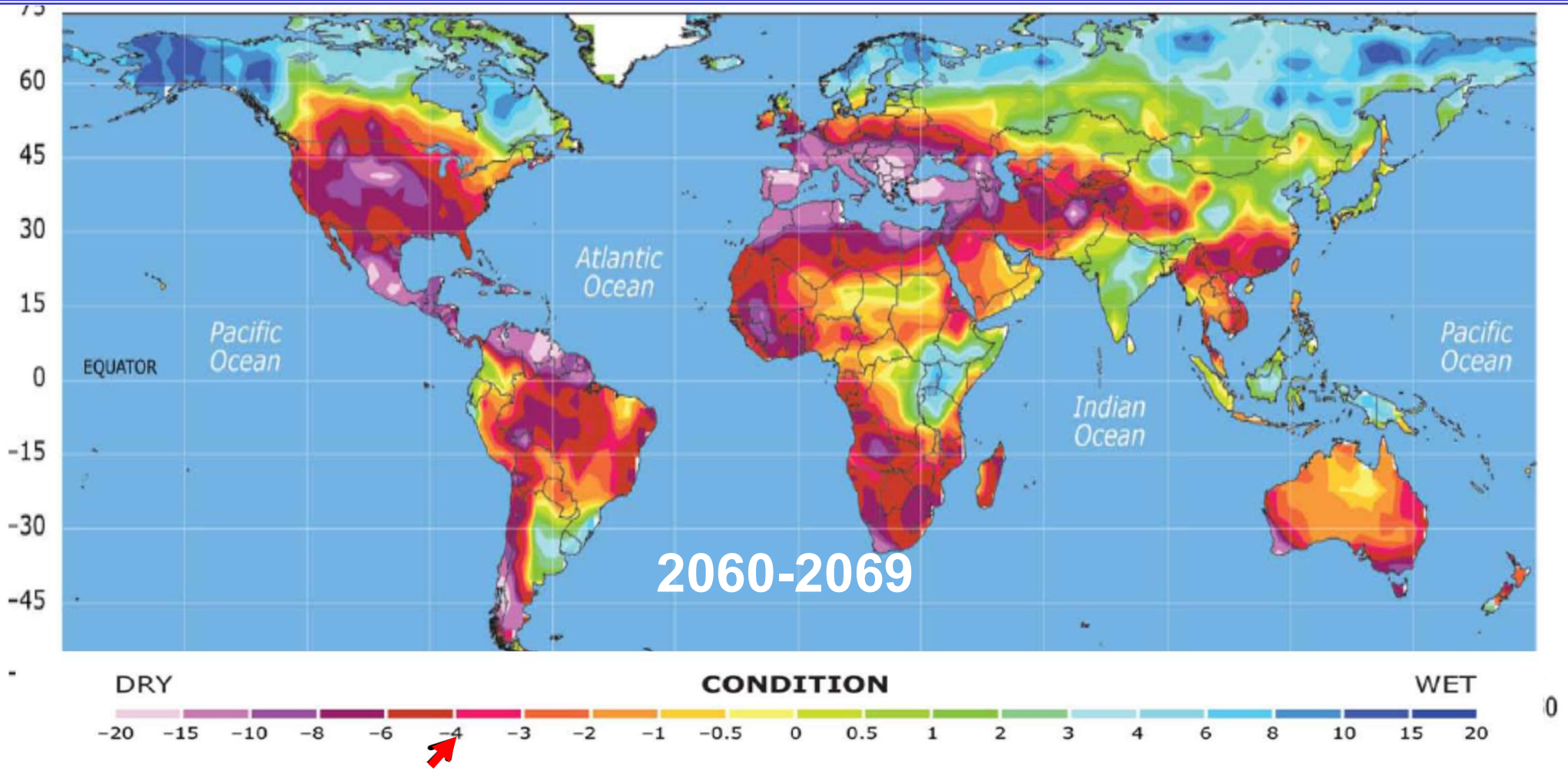


Courtesy from Sam Baldwin, Chief Scientist

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Source: Hoegh-Guldberg, et al, Science,V.318,pp.1737,14 Dec. 2007

Global Warming



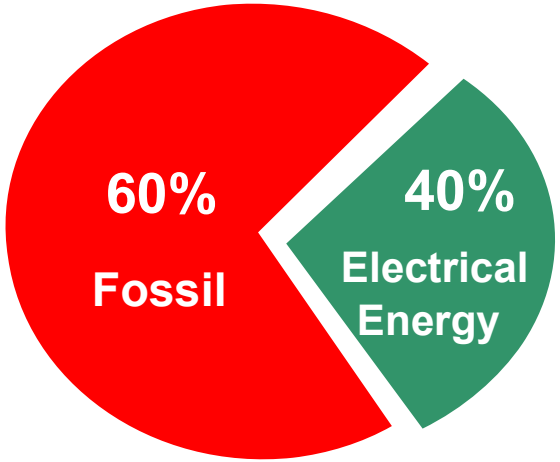
Extreme Drought

Aiguo Dai, "Drought under global warming: a review", Wiley InterDisciplinary Review: Climate Change, 2010; http://onlinelibrary.wiley.com/doi/10.1002/wcc.81/pdf

Energy Consumption Worldwide

Today

Total Energy Consumption



***Total electrical energy consumption in 2018:**

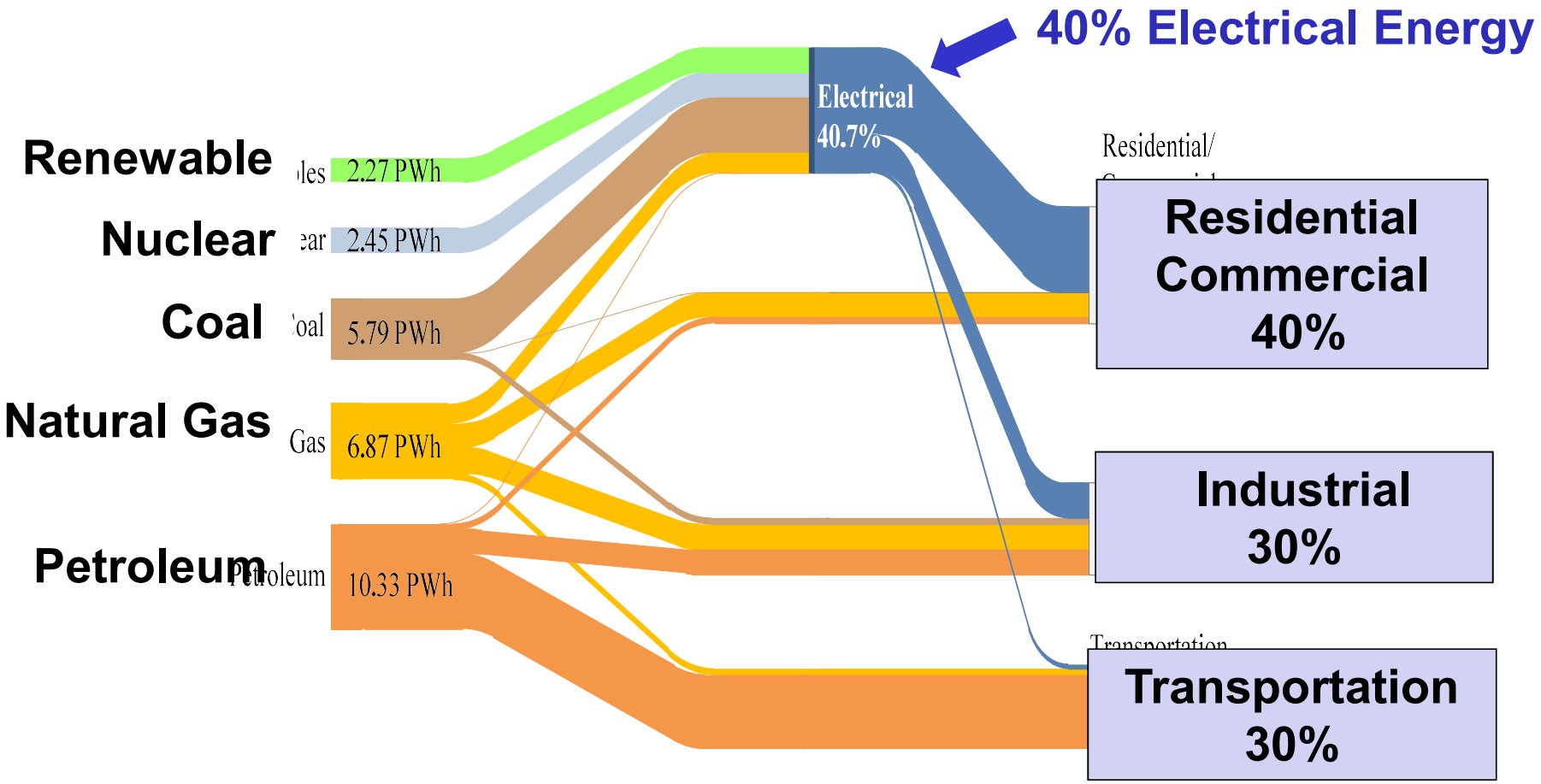
21,800TWH

Equivalent to 3257 Nuclear Power Plants
Each at 1GW capacity with annual production of 7 TWH

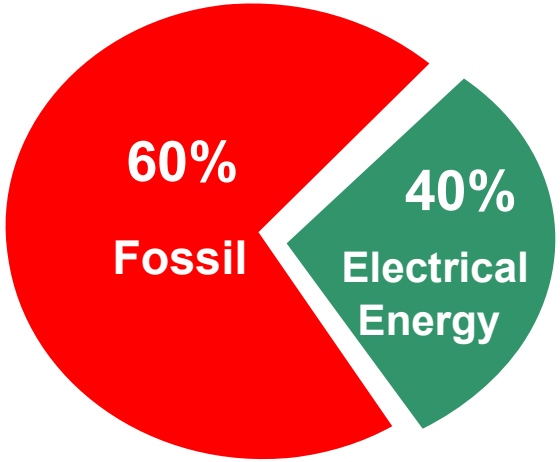
Electrical Energy Consumption

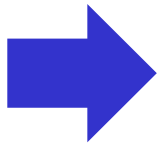
China: 6,167 TWH
US: 3,971
India: 1,243
Japan: 1,020
Russia: 929
S. Korea: 563
Canada: 529
Germany: 529
Brazil: 524
France:441
UK: 307
Italy: 303

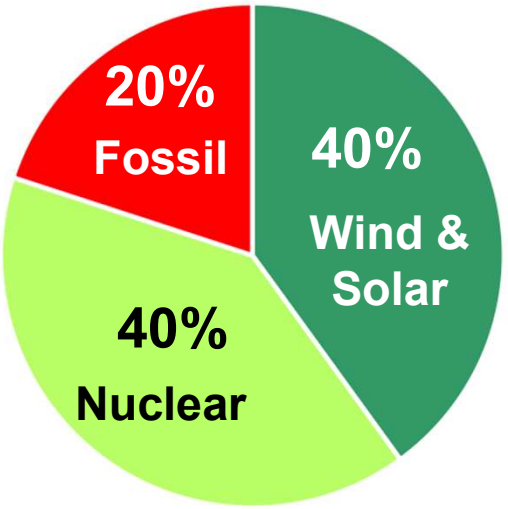
US Energy Consumption



Target Sustainable Energy





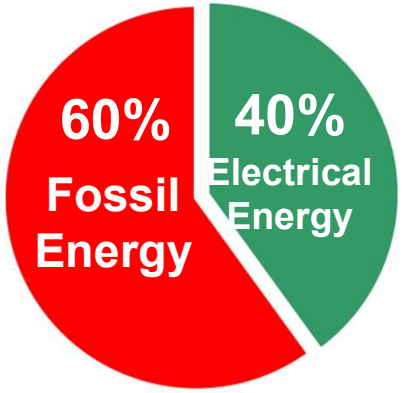


?

Energy Consumption Worldwide by 2050

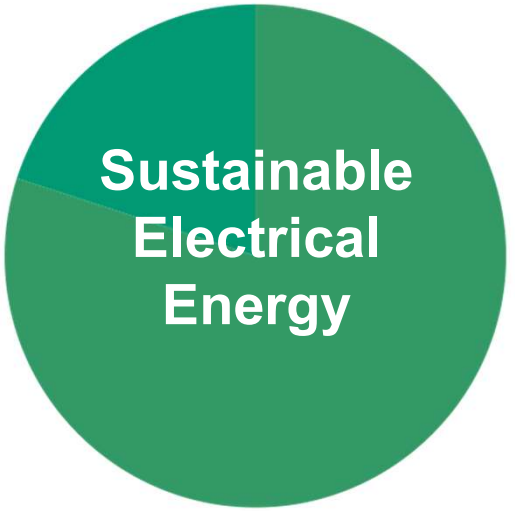
Paris Accord (2016): to keep the global temperature rise below +1.5º C

Today's Energy



Electrical Energy:
3,257 NPP

2050
2X Energy

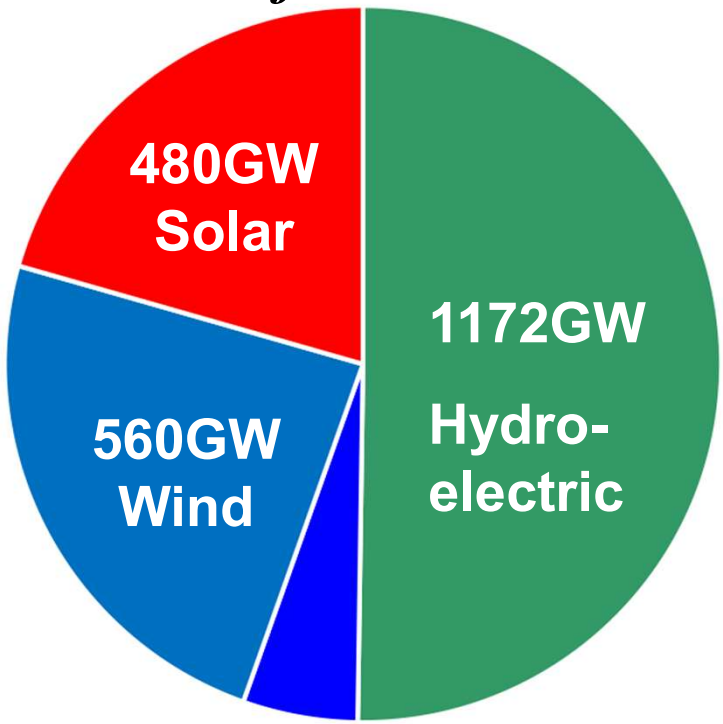


Electrical Energy:
16,000 NPP

Global Renewable Energy

Total of renewable energy 2018 : 2351GW

- about 1/3 of total electrical Energy



121GW
Bio-energy Geothermal
Marine-energy

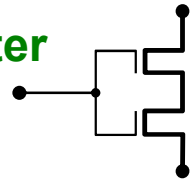
2050
Renewable energy
need to increase
17 X
of current capacity

Is it Doable ?

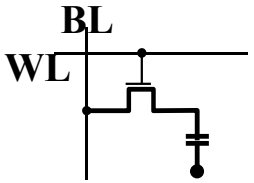
What is Power Electronics?

Micro Electronics

Inverter



BL
WL

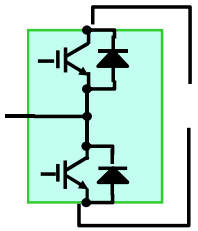


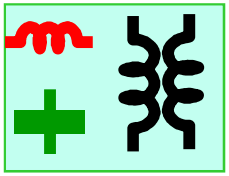
DRAM

Audio/Video → A-to-D Conv. → Number Crunching → D-to-A Conv. → Audio/Video

Power Electronics

PV





A-to-D → Modulation → D-to-A

60 Hz

Evolution of Power Electronics

CPES *EPRI

Transistor

Thyristor

MOSFET IGBT

SiC GaN ?

1960 1970 1980 1990 2000 2010 2020

1st Decade 2nd Decade 3rd Decade 4th Decade 5th Decade 6th Decade

Roles of Power Electronics

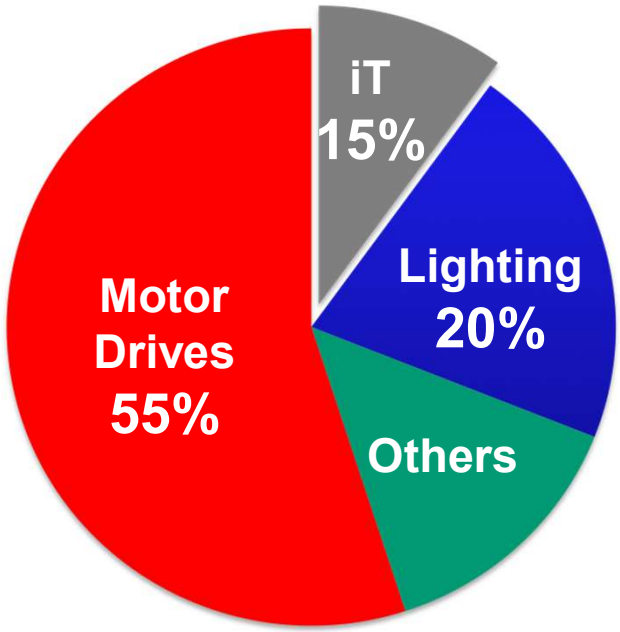
Roles of Power Electronics

1. Renewable Energy

2. Energy Conservation

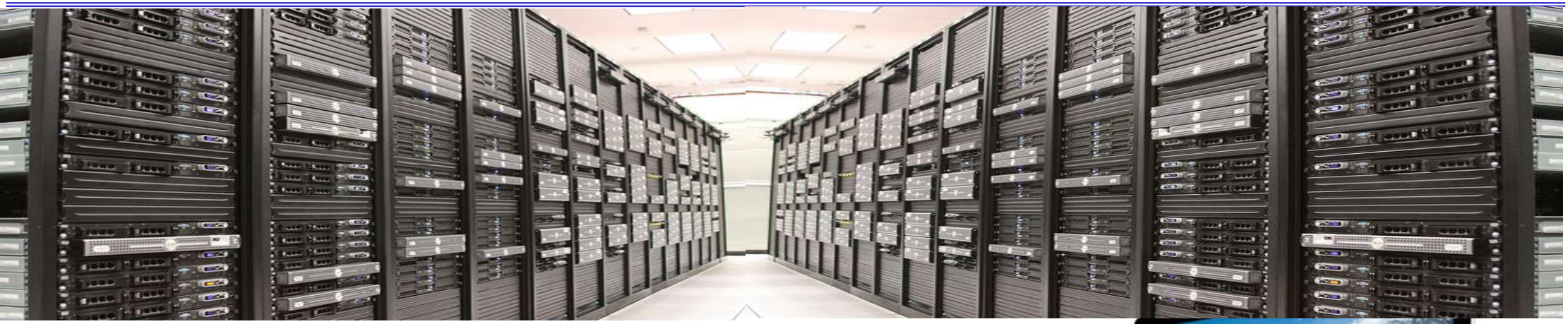
Role of Power Electronics

Impact of Power Electronics to Energy Conservation



Assuming same percentage by 2050

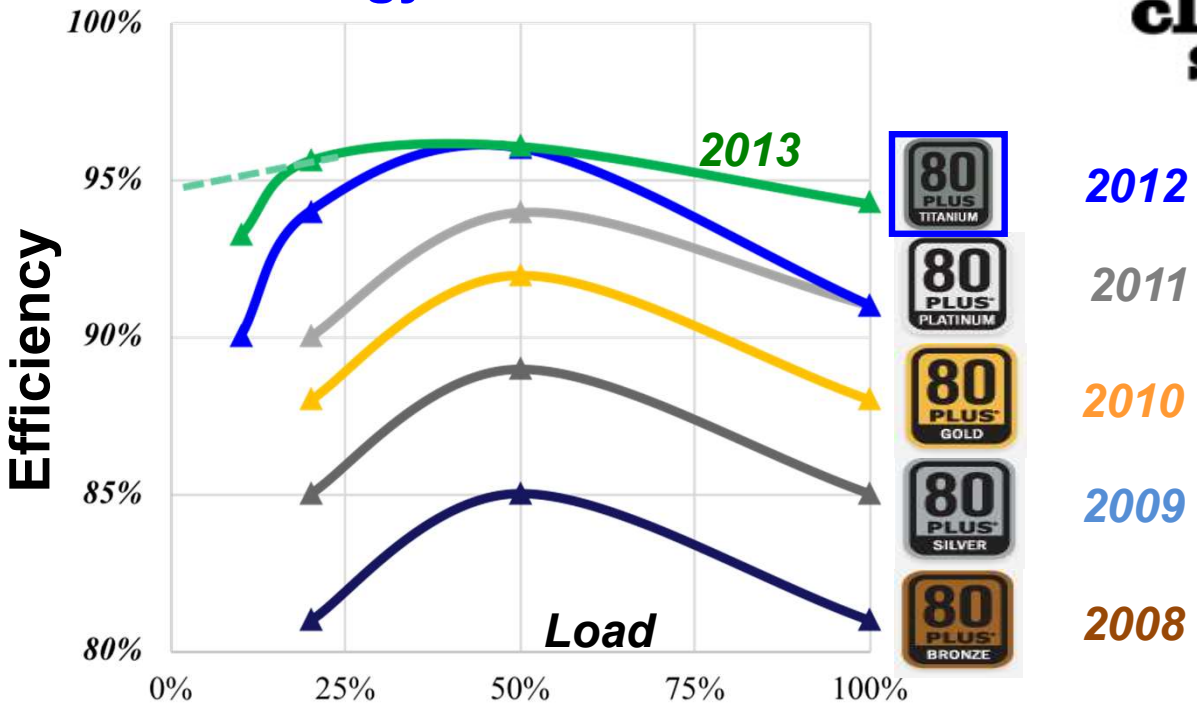
IT Industries and Consumer Electronics



Trend: Higher performance devices with more compact designs

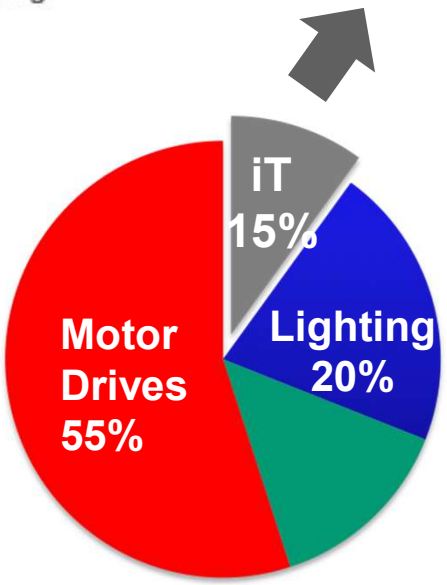
Efficiency Improvement

Energy Star Initiatives



climate savers smart computing™

245 NPP (2050)



Efficiency: from 70% to 95% to 99%

Energy Saving in Lighting

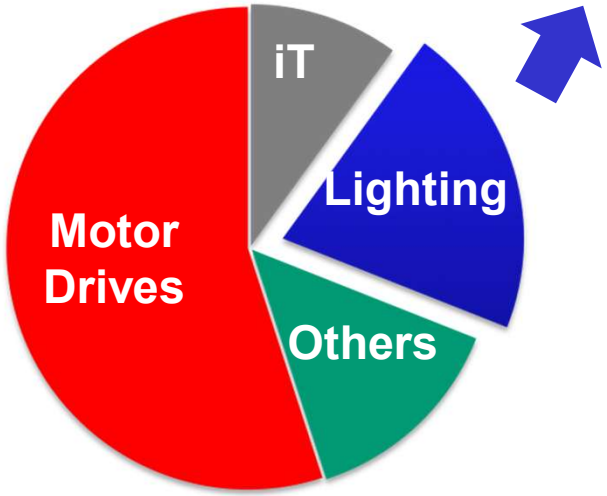
Electronics Ballast

LED driver

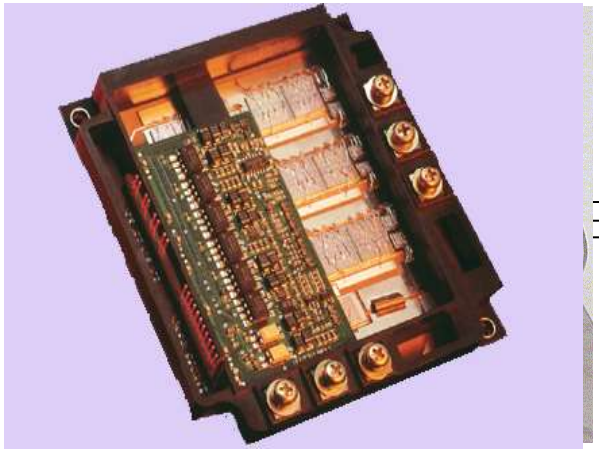
Fluorescent

LED

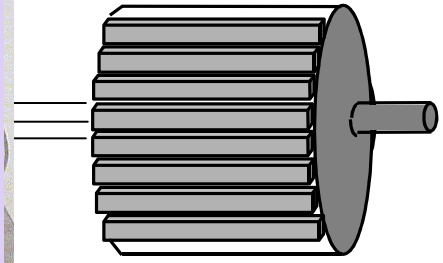
325 NPP (2050)

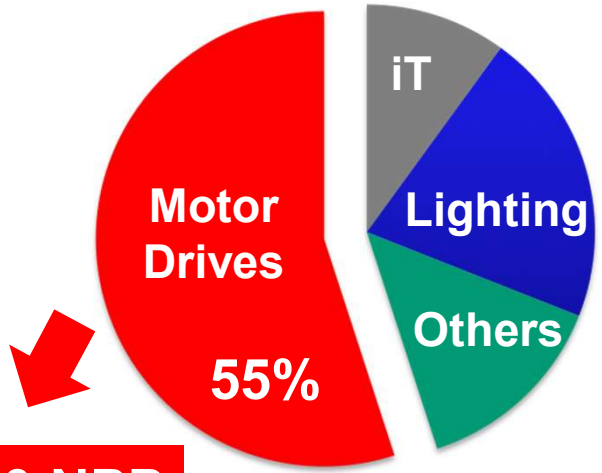


Variable Speed Motor Drives



Adjustable Speed Drive



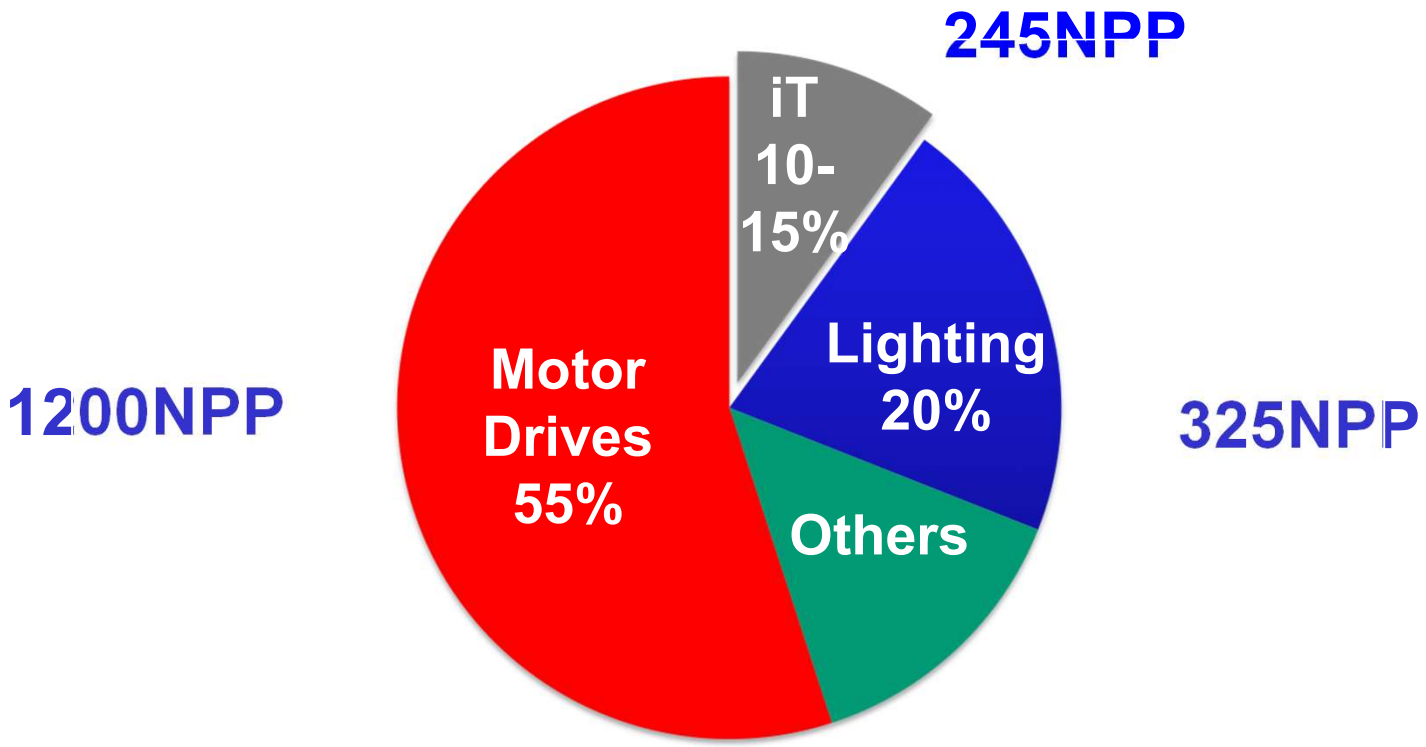


1200 NPP (2050)

+ Industrial drives

Challenge: More Cost Effective Power Electronics Solution

Energy Conservation via Power Electronics (by 2050)



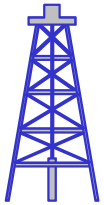
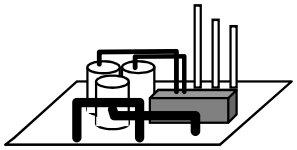
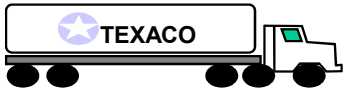
(11%)

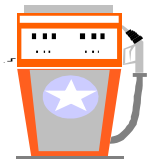
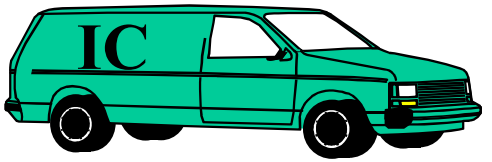
Potential Energy Saving though power electronics = 1770NPP

Examples of Game Changing Technologies

1. Electrical Vehicles
2. LED
3. Microprocessors
4. Data Center
5. Wide Bandgap Power Semiconductor Devices

1. Impact of Electric Vehicles

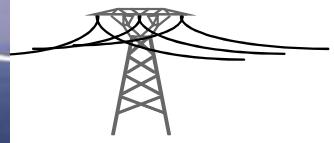
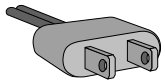
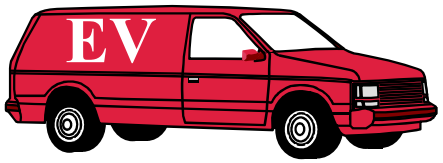



1.0 x 0.87 x 0.95 x 0.16 =

9000 Btu per mile

670 miles per barrel

*EPRI

1.0 x 0.32 x 0.92 x 0.80 x 0.90 =

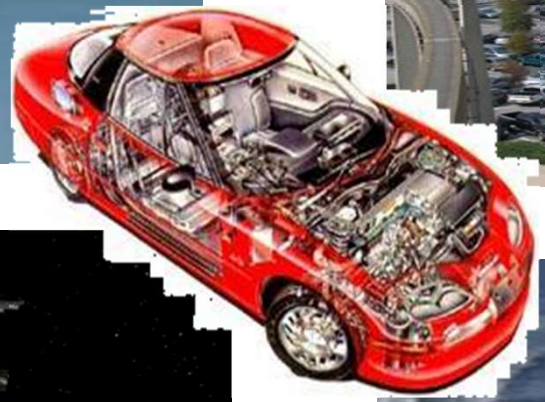
5400 Btu per mile

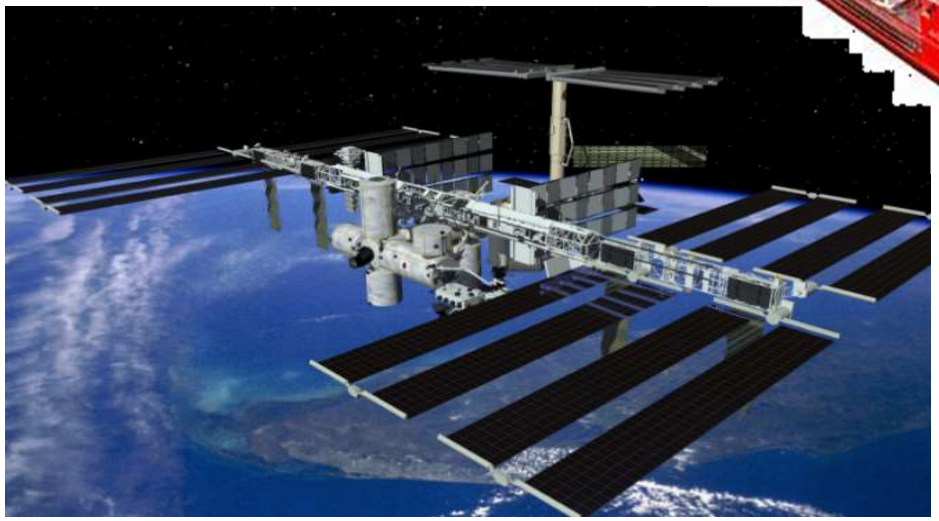
1100 miles per barrel

40% energy saving

Assuming EV consumes 20% of electrical energy by 2050, energy saving > 1280 NPP

Electrification of Transportation Systems





2. Impact of LED Lighting

Incandescent

LED

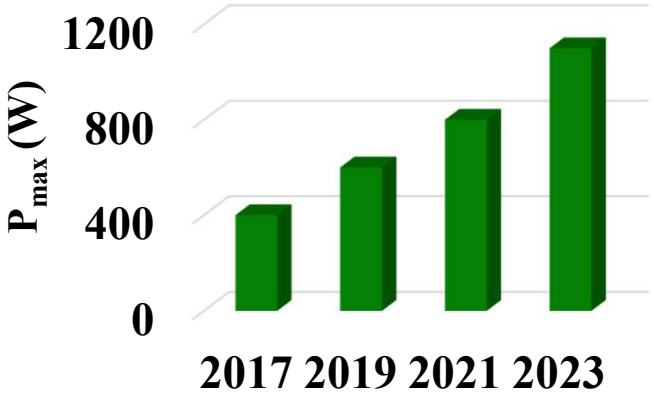
4 X

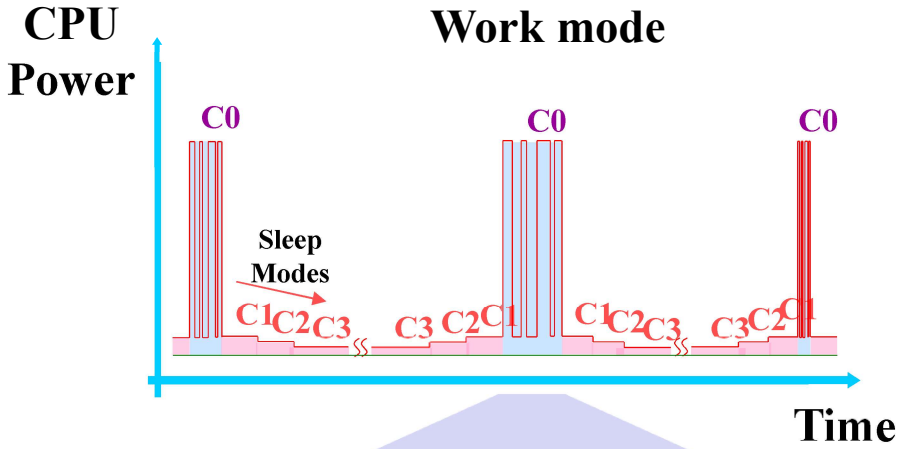
Energy Saving

Energy saving (2050) = 980 NPP

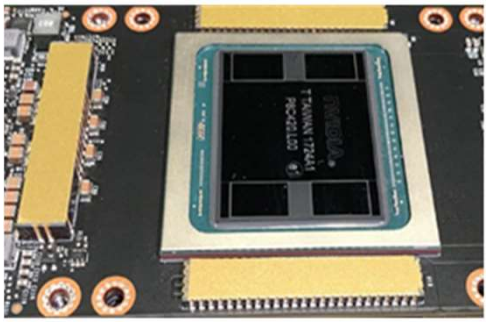
3. Impact of Next Generation Microprocessors

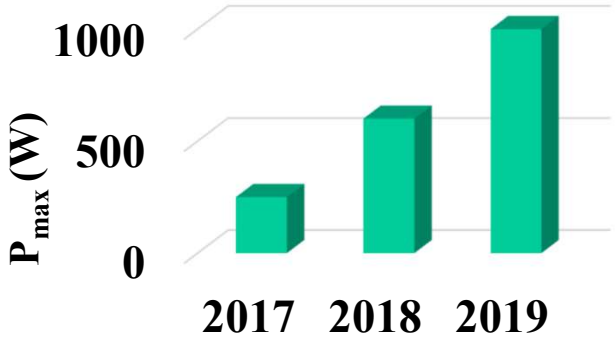
CPU (28 Cores)

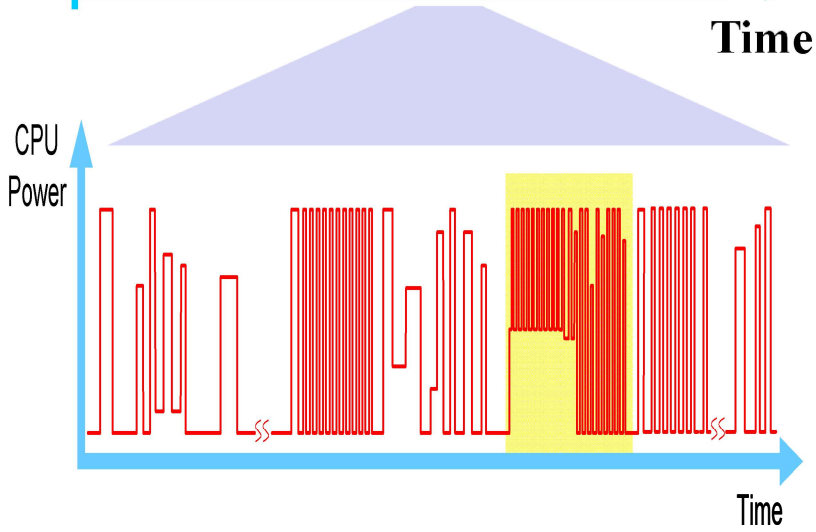




GPU (600 Cores)

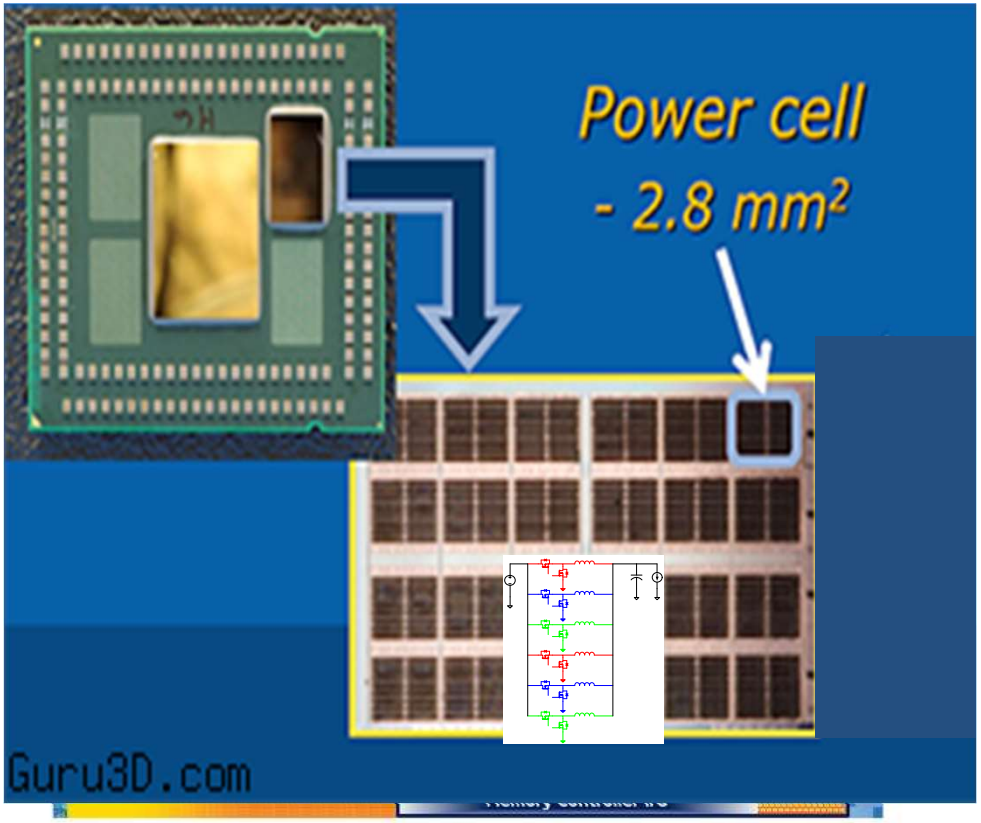




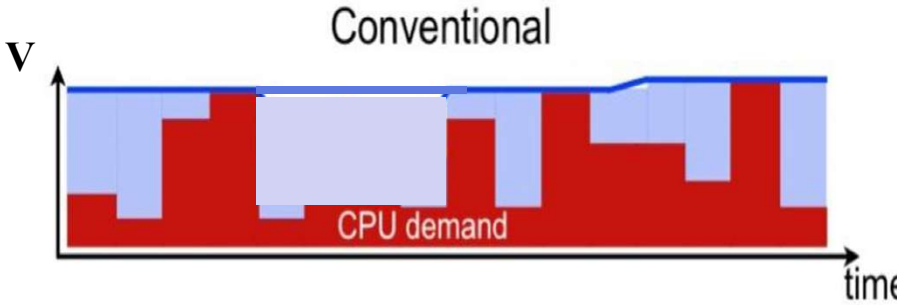


Intel's Integrated VR (iVR)

Integrated voltage regulators with f_s >100MHz; Input: 2.4V ; Output: 0.4V-1.4V



Ivy Bridge Core U-series processors



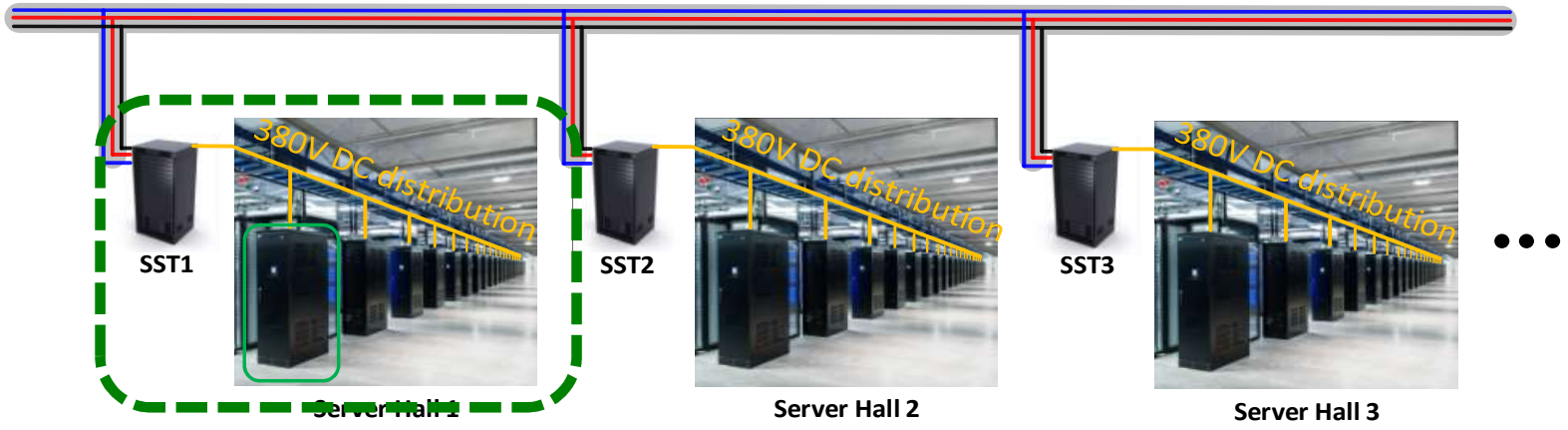
50% energy saving (2050) = 245 NPP

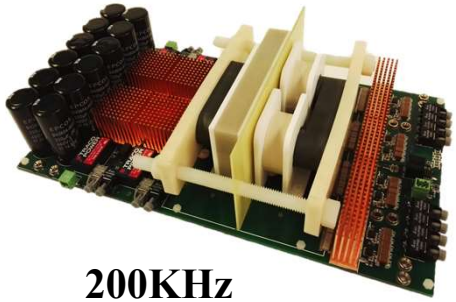
4. Impact of Data Center Power Architecture

Data centers will consume 10% of electricity by 2020

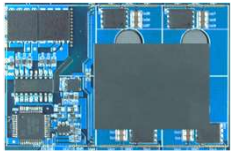
Next Generation Data Center

13.8KV utility Service





200KHz



>1MHz

13.8KV

SST

98%

380VDC

DC/DC

6 V DC

VR

VR

VR

PSU

98%

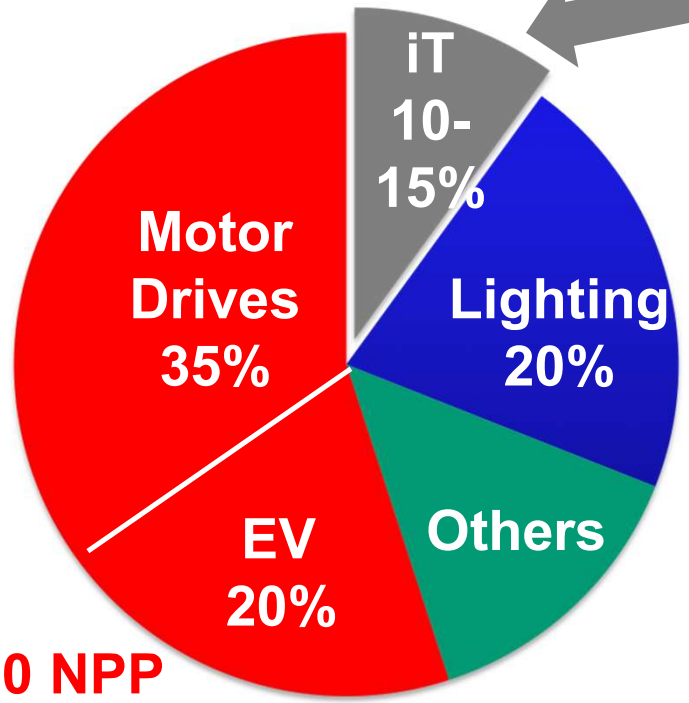
94%

90%

Energy saving: 110 NPP (2050)

Impact of Game Changing Technologies (2050)

Disruptive Technologies:
1. EV
2. LED
3. uP
4. Data Center



245NPP + 110 NPP

(uP) (Power Architecture)

980 NPP

(LED)

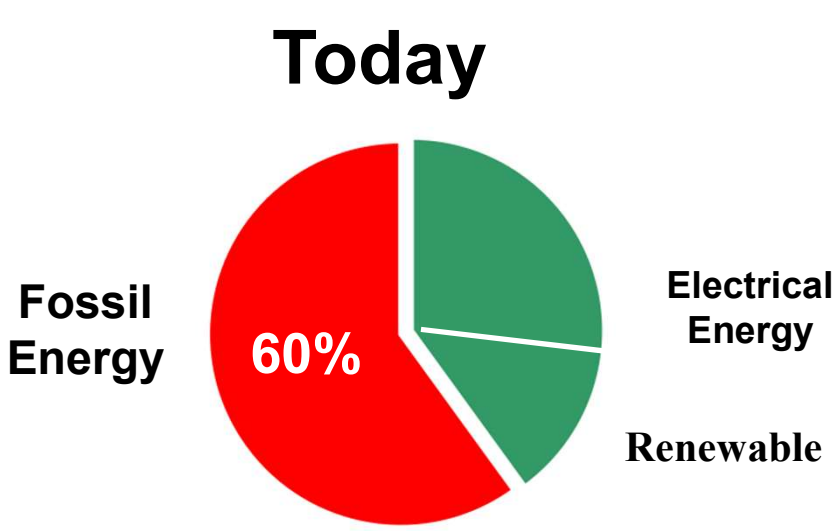
1280 NPP

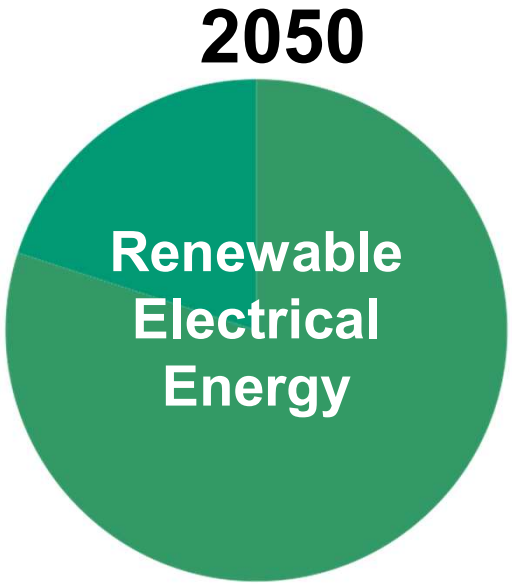
(EV)

(16% 0f 16000 NPP)

Total Energy Saving (2050): 2615 NPP

Is It Doable?





2351GW renewable energy
- *about 1/3 of total electrical Energy*

It is not inconceivable !

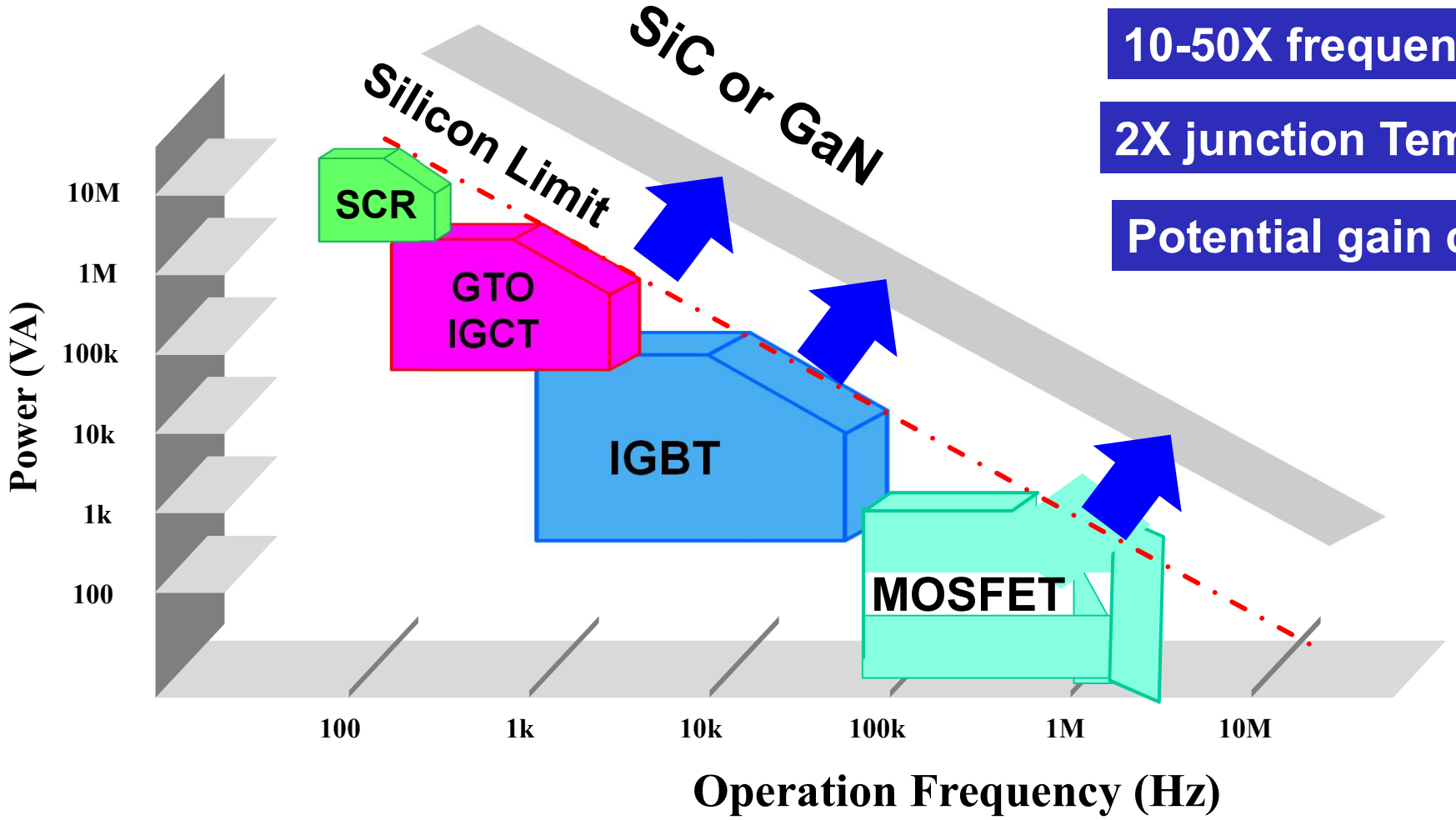
11% saving from Conservation

17X

16% saving from game changing technologies

10X increase from today's installed capacity

5. WBG Power Semiconductor Devices



10-50X frequency

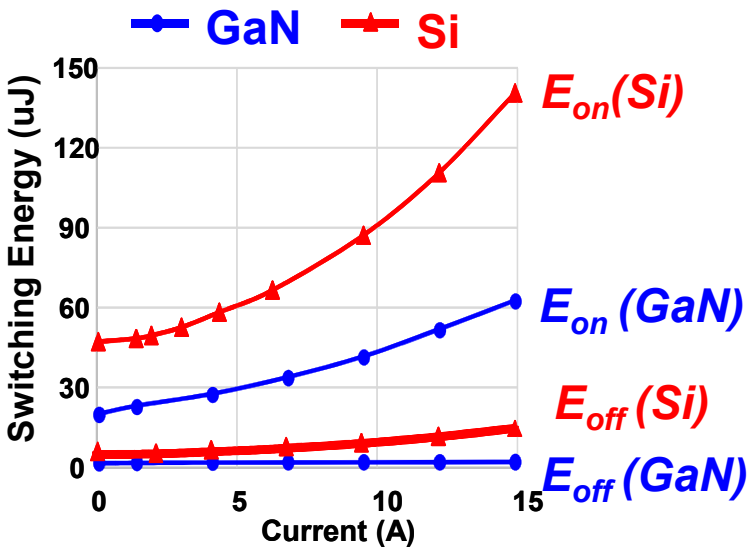
2X junction Temperature

Potential gain changing

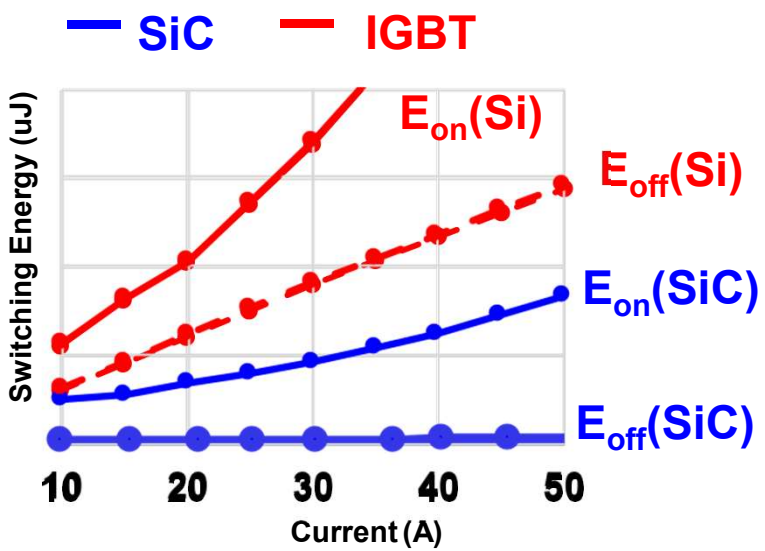
* Modified from application note of Powerex Inc.

Wide-Bandgap vs Silicon in Switching losses

GaN v.s. Silicon (MOSFET)



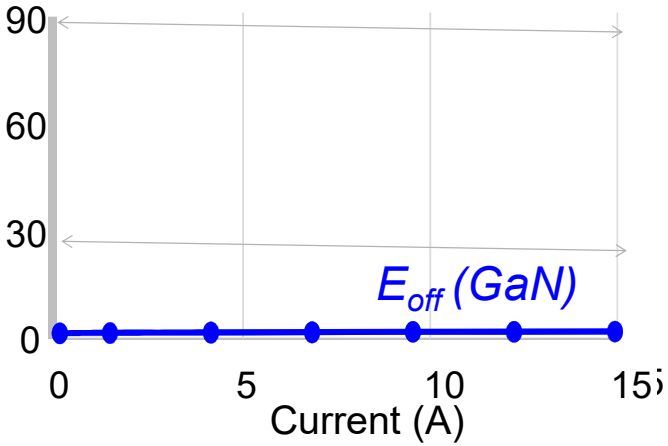
SiC v.s. Silicon (IGBT)



Conventional wisdom

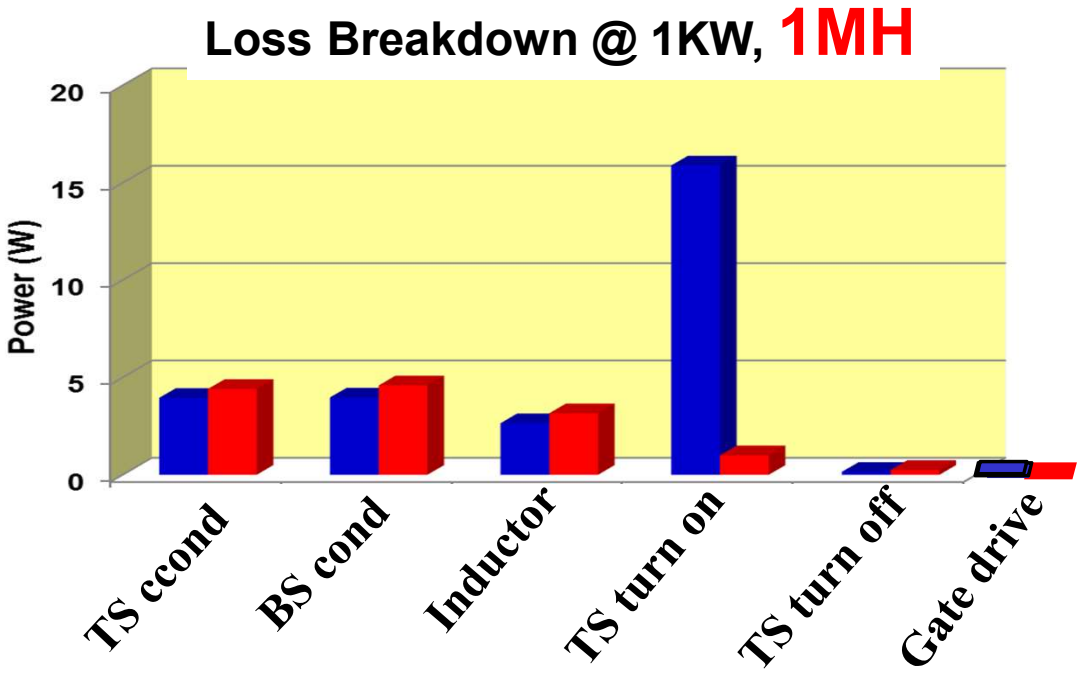
WBGs are about 2-3 X better than their silicon counter parts

GaN: Loss Breakdown



1 KW @ 1MHz

ZVS + **Negligible turn-off loss**



Switching losses are negligible

What do you do with it ?

Power Electronics Technologies & Applications

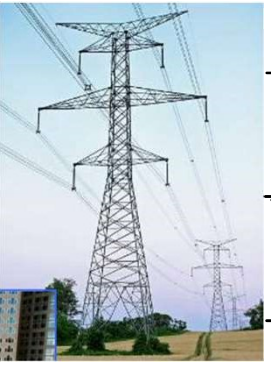
High Voltage | Medium Voltage | Low Voltage | POL (12V)

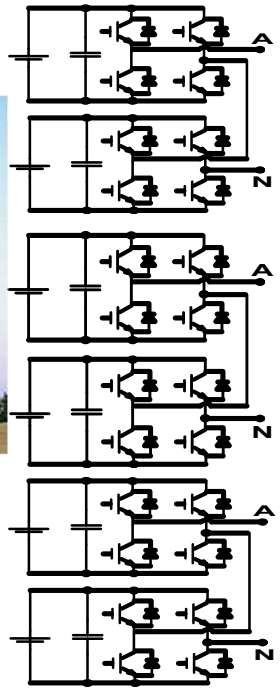
> 100KV

100KV> MV>1K

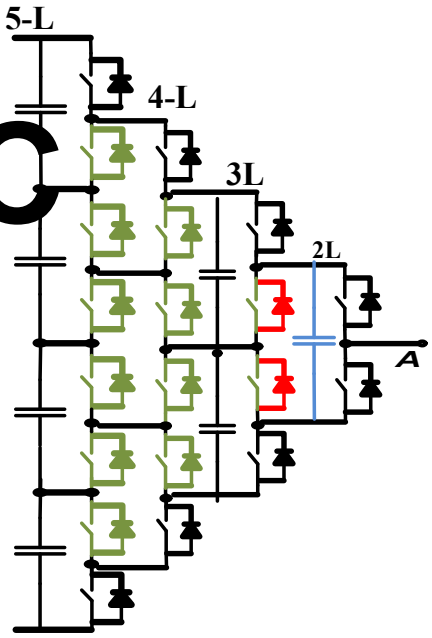
< 1KV

12V/1000A





SiC

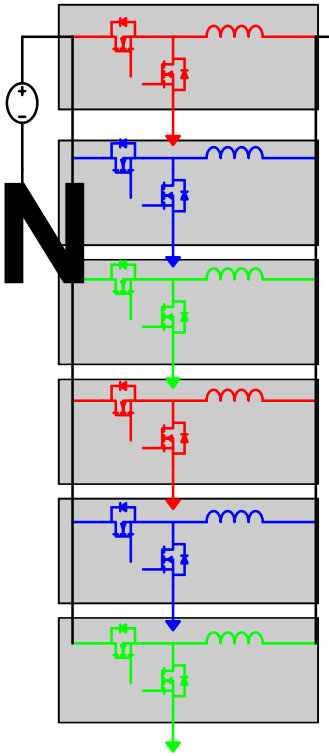


High volume, A large variety of topologies available

IT Consumer

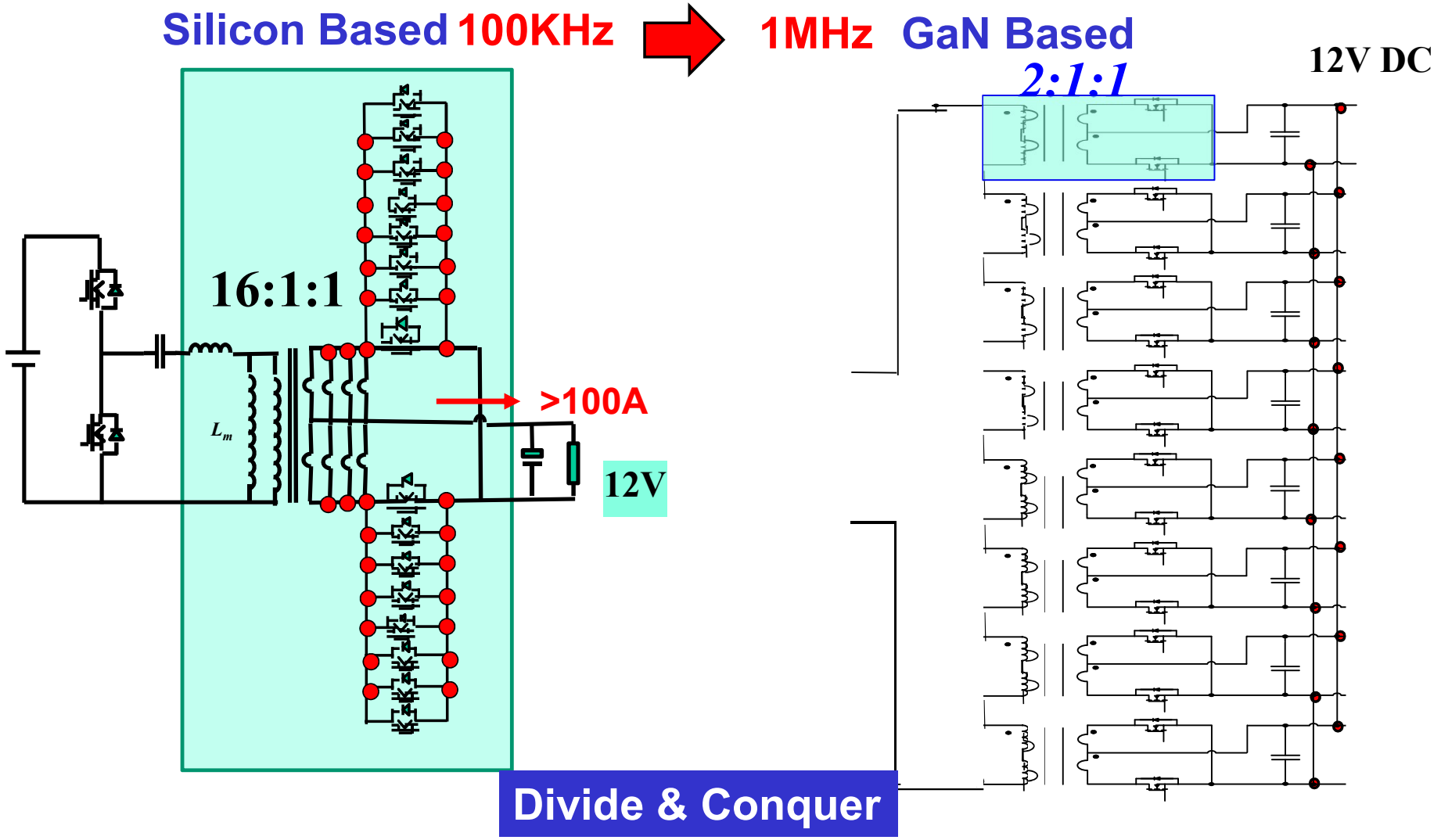
?

GaN



Standard Modular Approaches at all Level, except…,

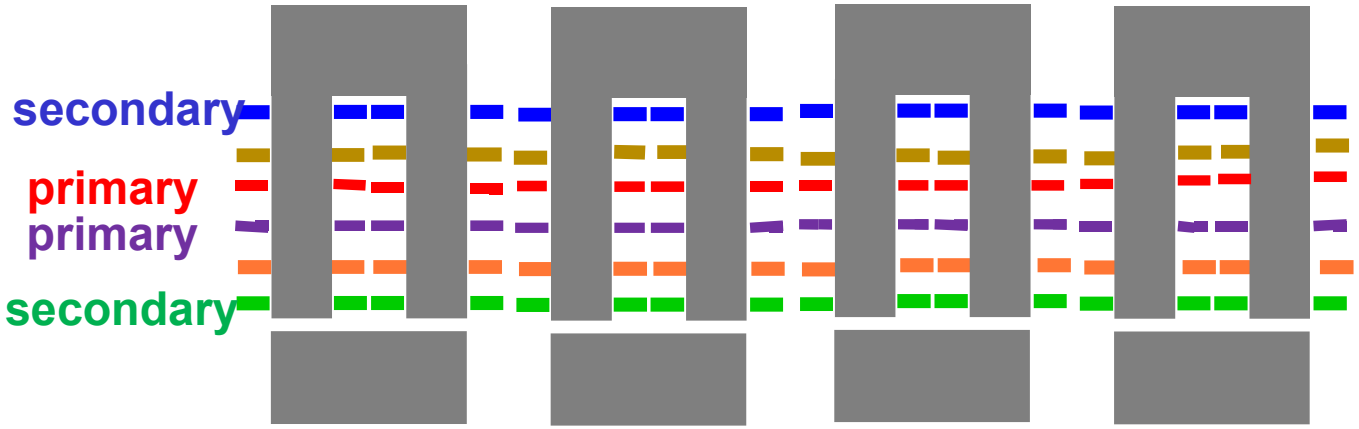
GaN Based DC/DC Converter for Data Center



Matrix Transformer with CM Noise Shielding

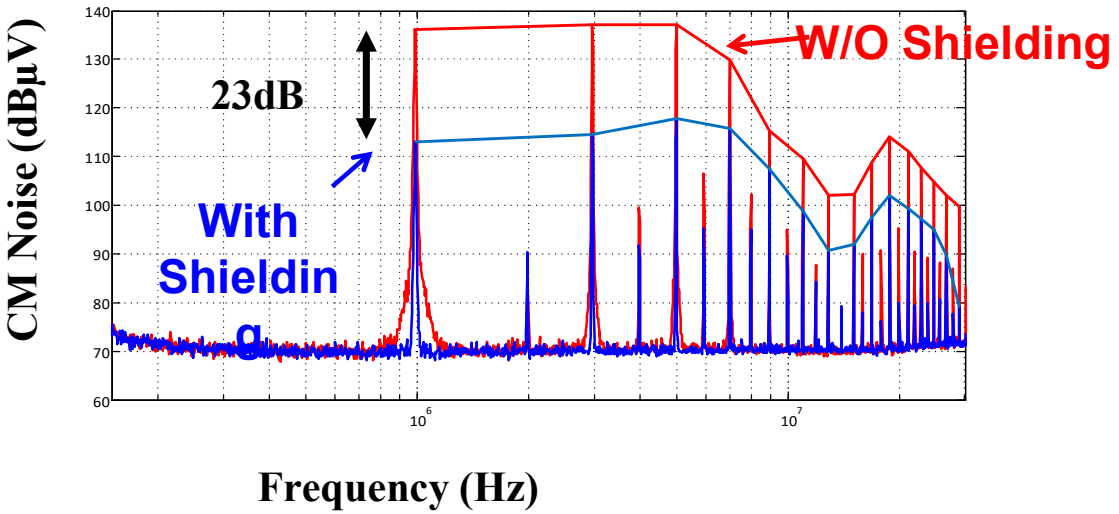
DC/DC Converter

6-layer PCB



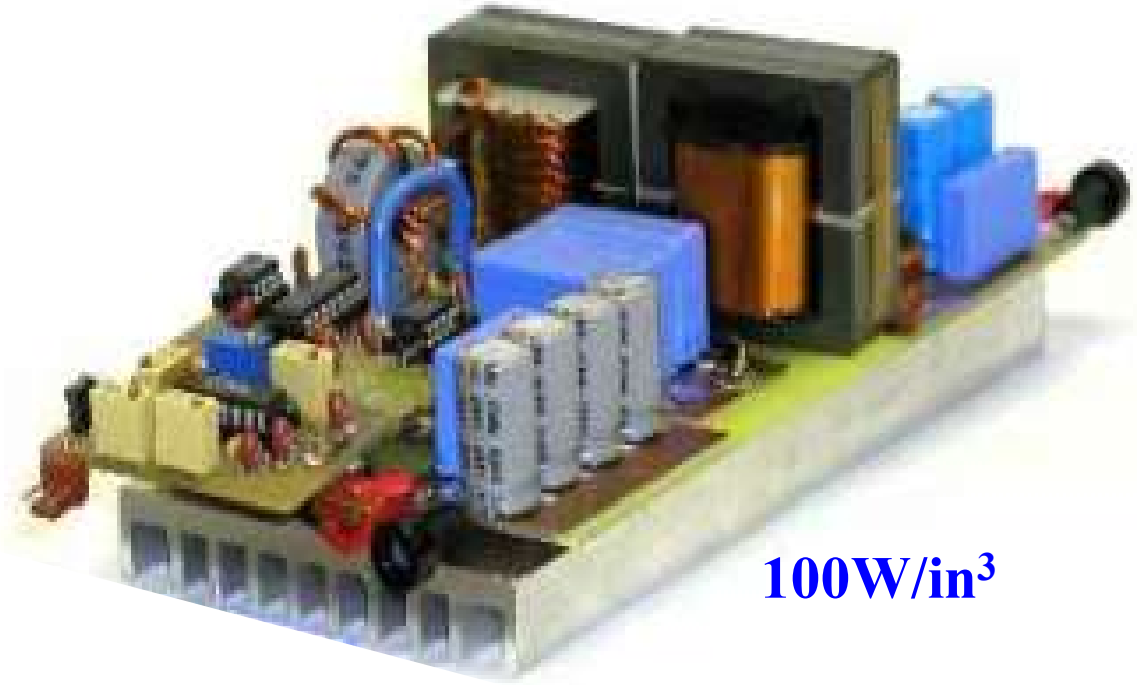
1MHz

700W/in^3

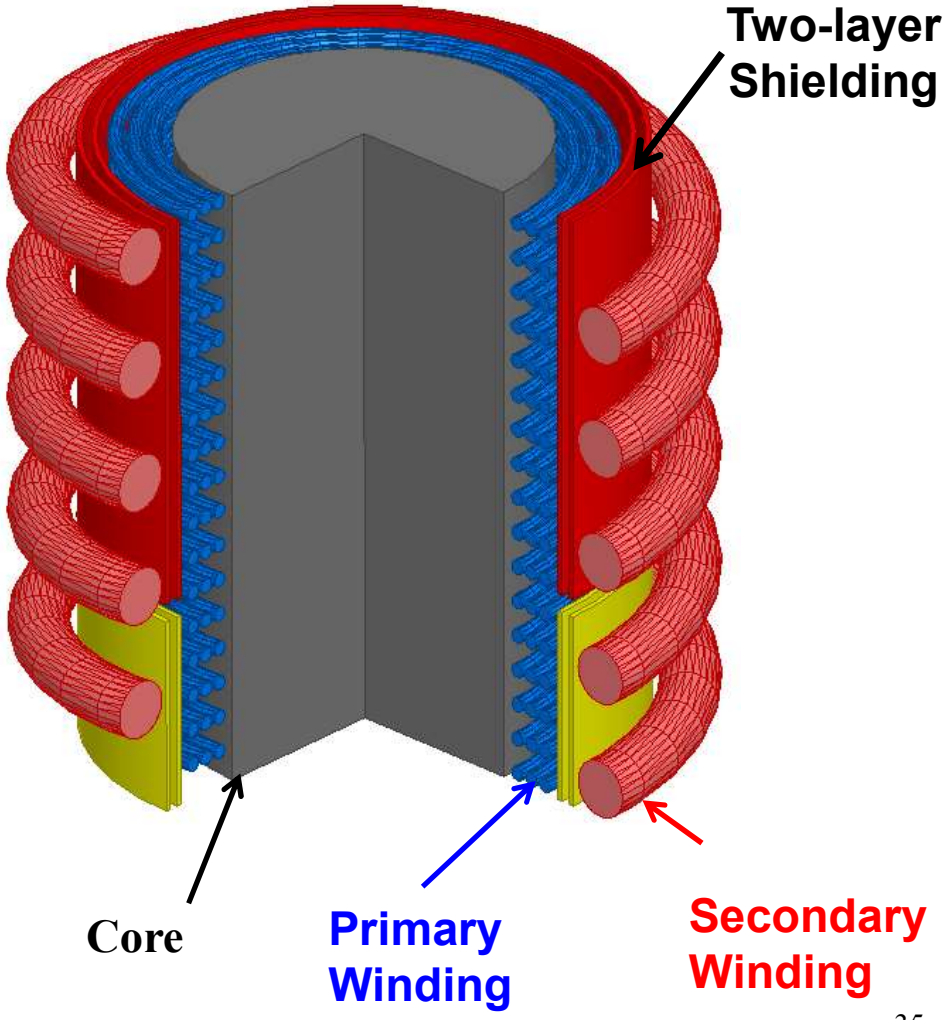


Silicon Based Design

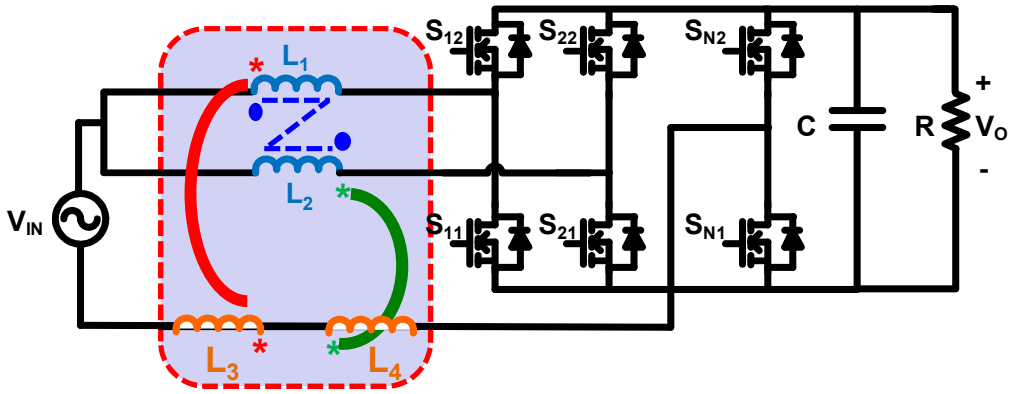
Silicon: 100KHz

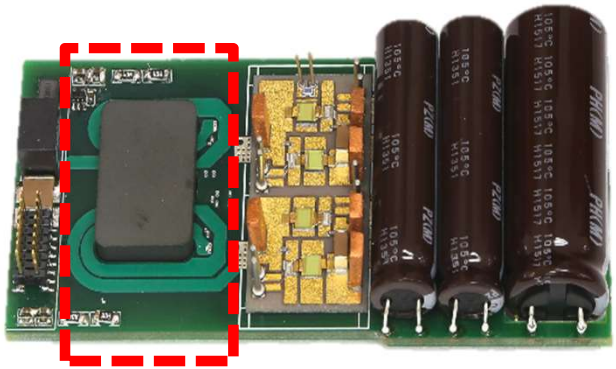


100W/in^3



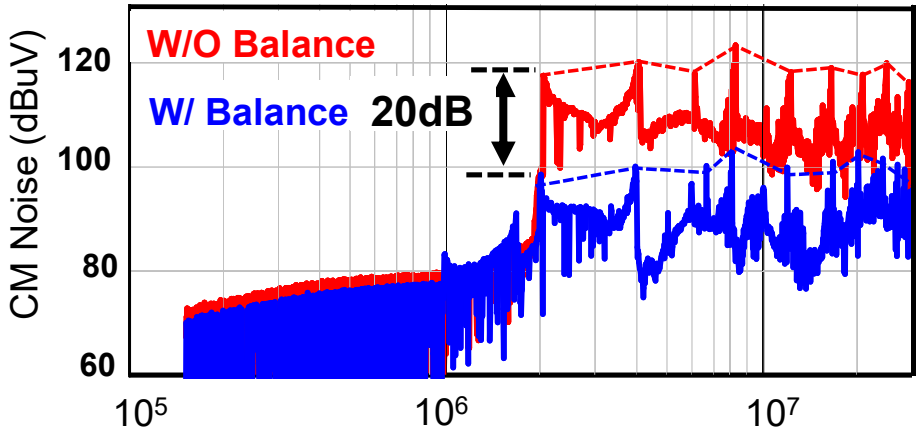
PFC with Integrated Magnetics

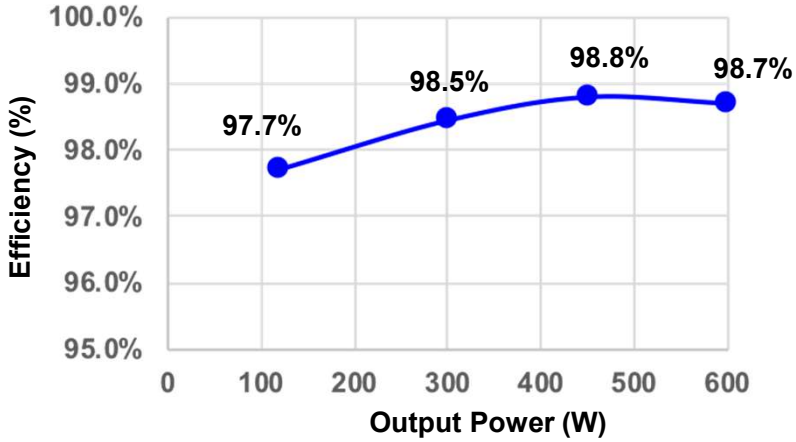




Interleaving for DM reduction
Balance for CM reduction

Fs > 1MHz

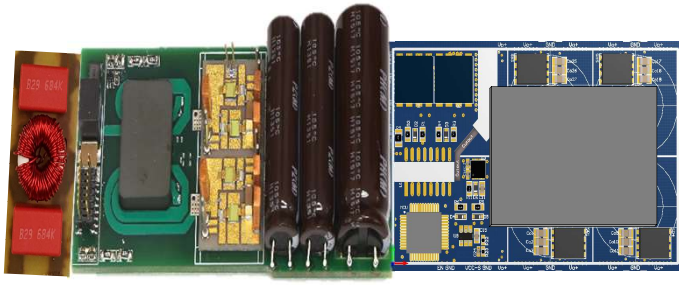




Wide-Bandgap Based design

1MHz

400 W/in^3



Improved Efficiency

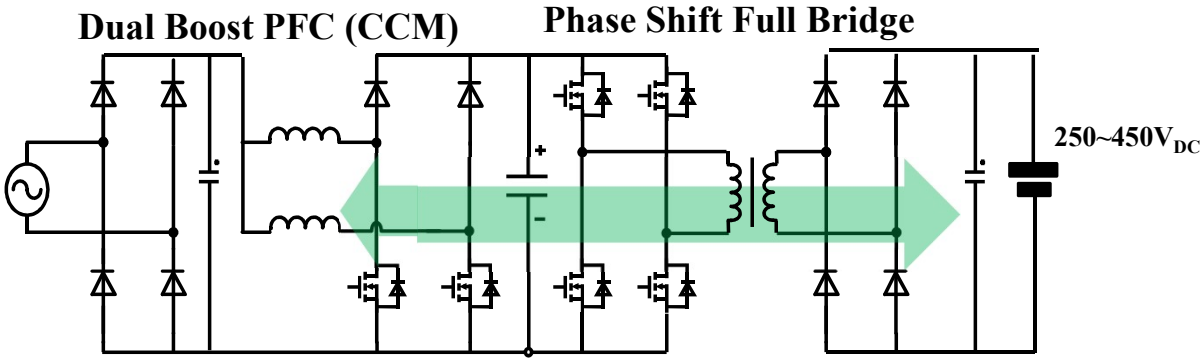
Improved Power density

Improved EMI

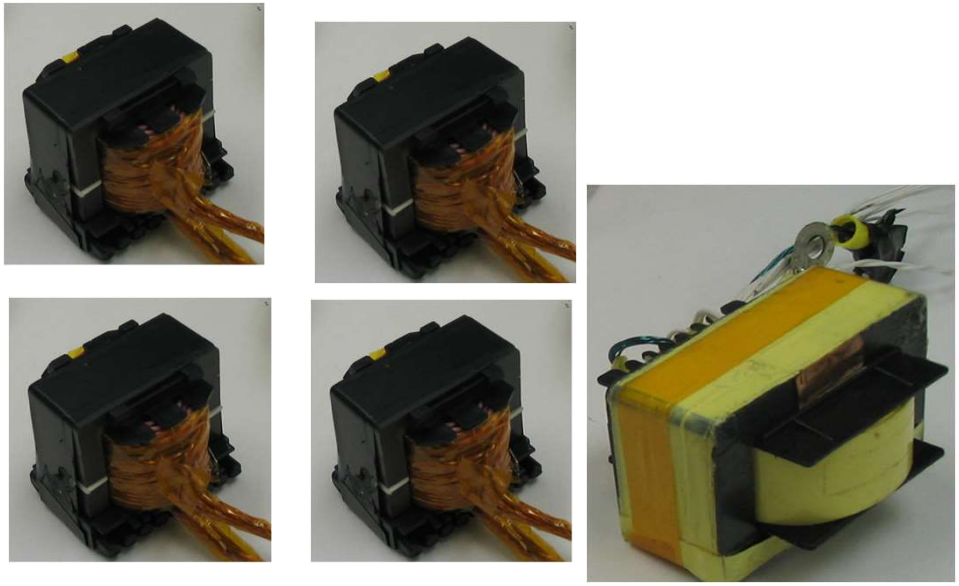
Improved manufacturability

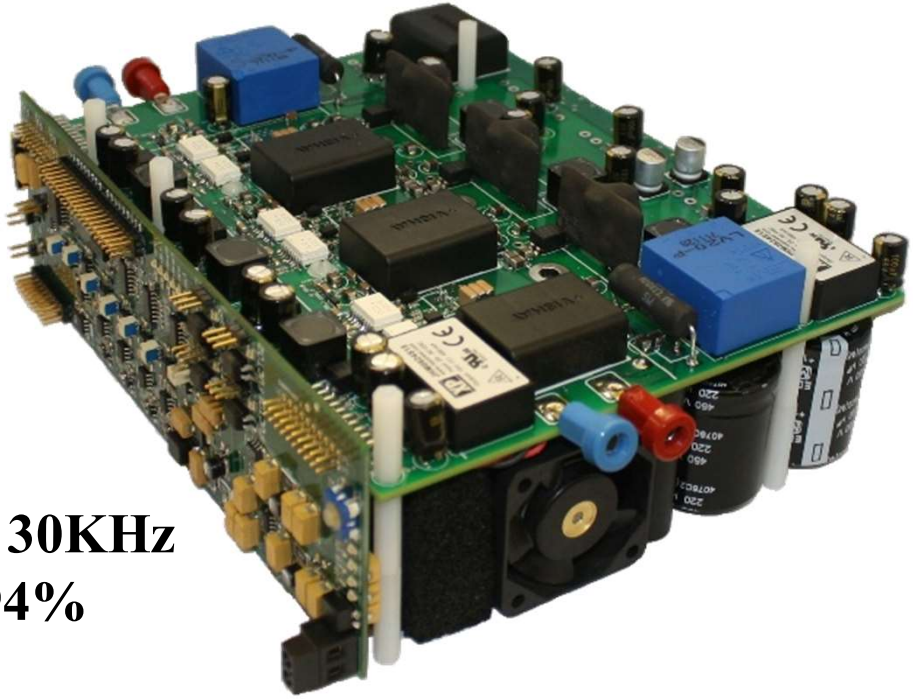
New Design & Manufacturing Paradigm

6.8KW Bidirectional On-Board Charger



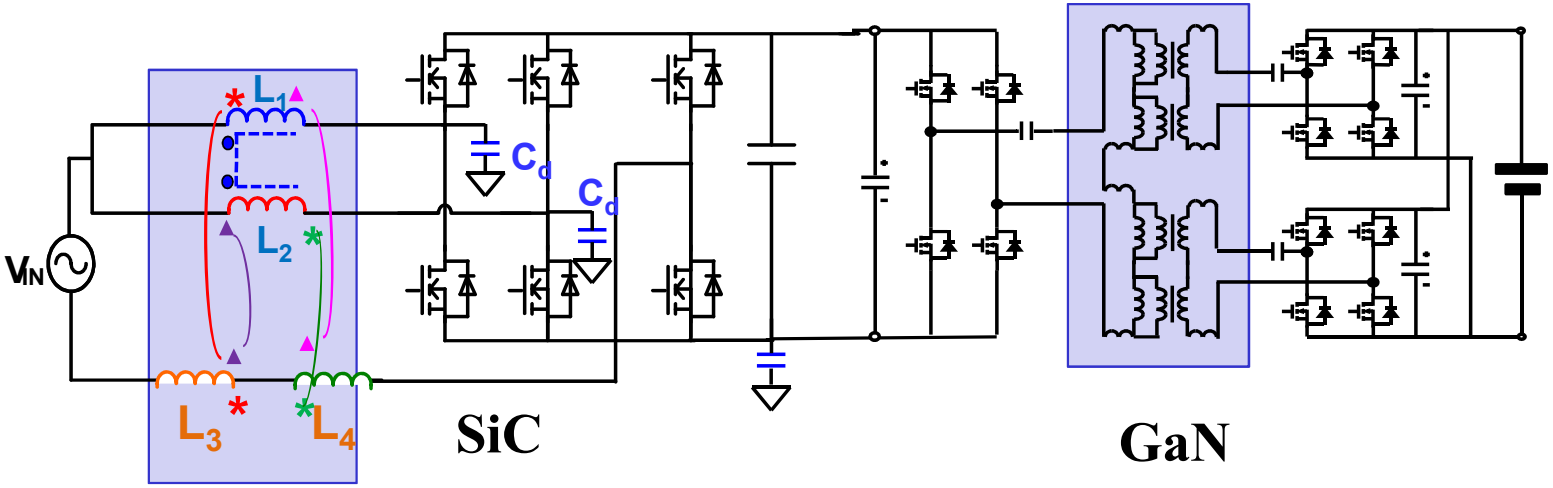
Silicon Based





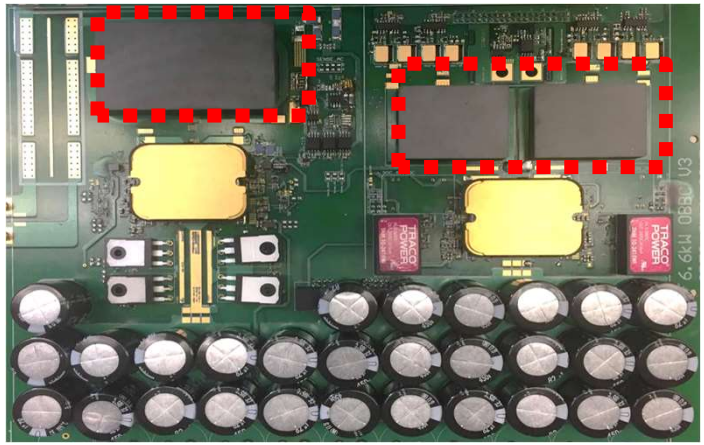
20 - 30KHz
94%

WBG Bases OBC Integrated Magnetics



300KHZ PFC

500KHz CLLC DC/DC



6-layer PCB

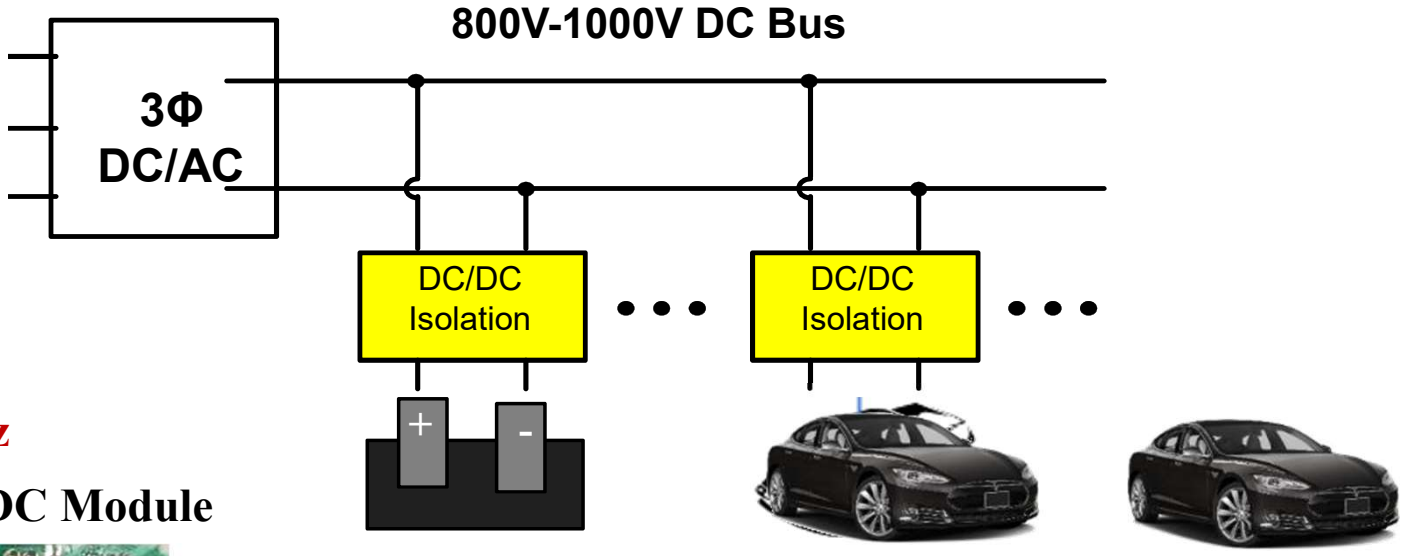
> 96%

3X Power density

43W/in^3

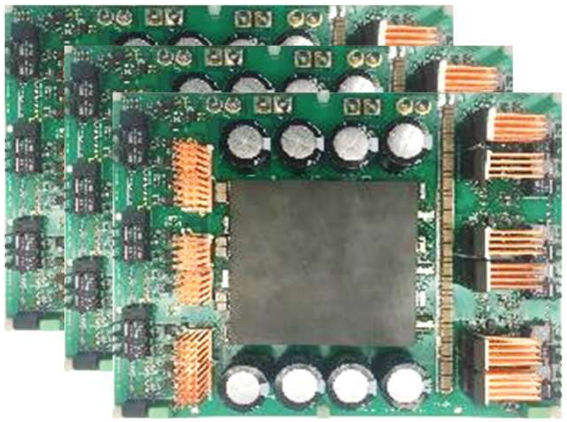
EV Charge Station

3Φ-Grid



500KHz

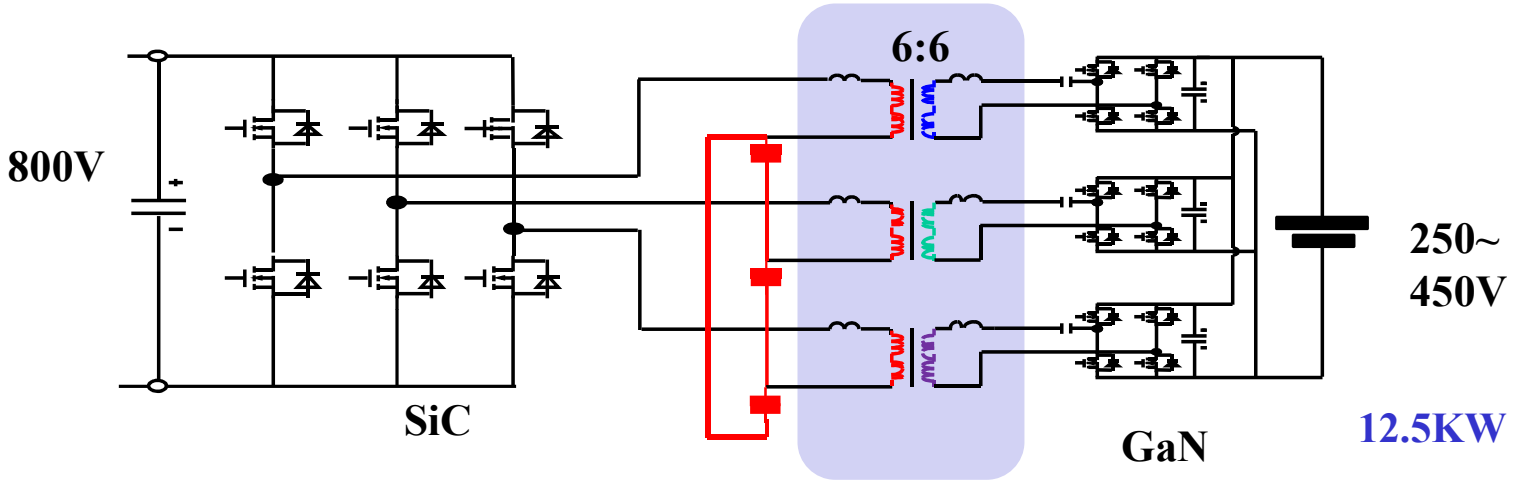
12.5kW DC/DC Module

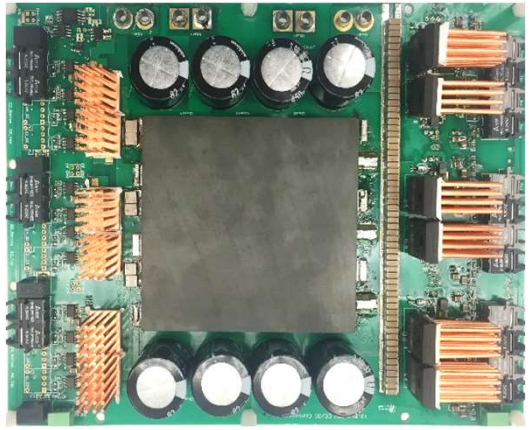


Battery

Eff. > 97%
500KHz

3-Phase Interleaved
Bi-Directional CLLC Converter





Eff. > 97%
@ 500KHz

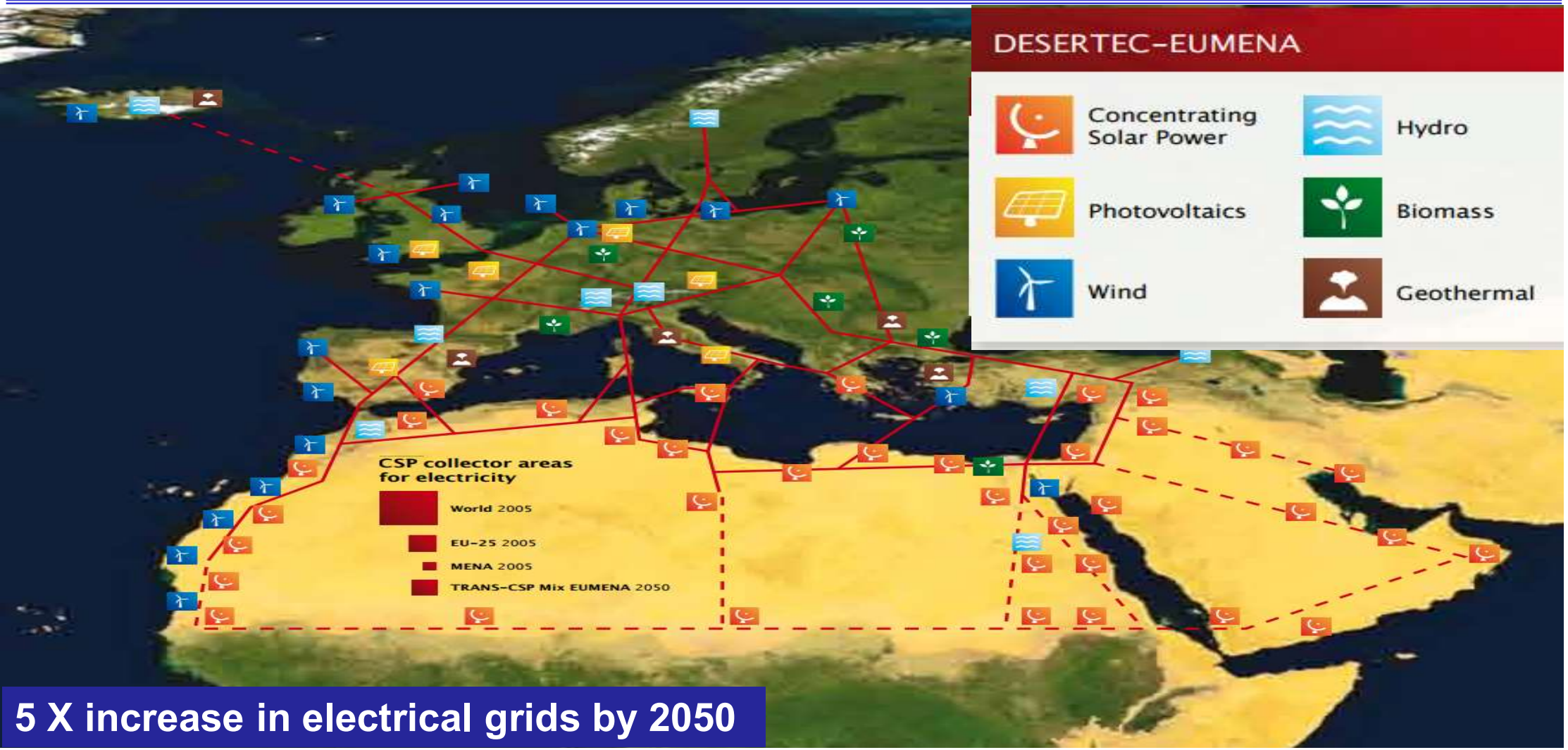
154W/in^3
(9.4kW/L)

6 L & 3 T

Major Challenges for Power Electronics

- More Affordable
- EMI/EMC
- Integration of Renewable Energy into the Electrical Grids seamlessly

Future: Europe Super Grid

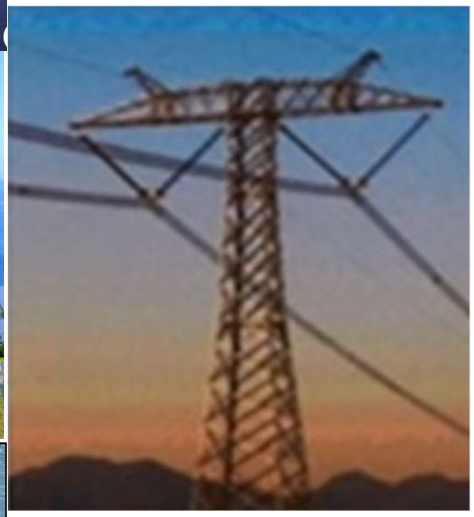


5 X increase in electrical grids by 2050

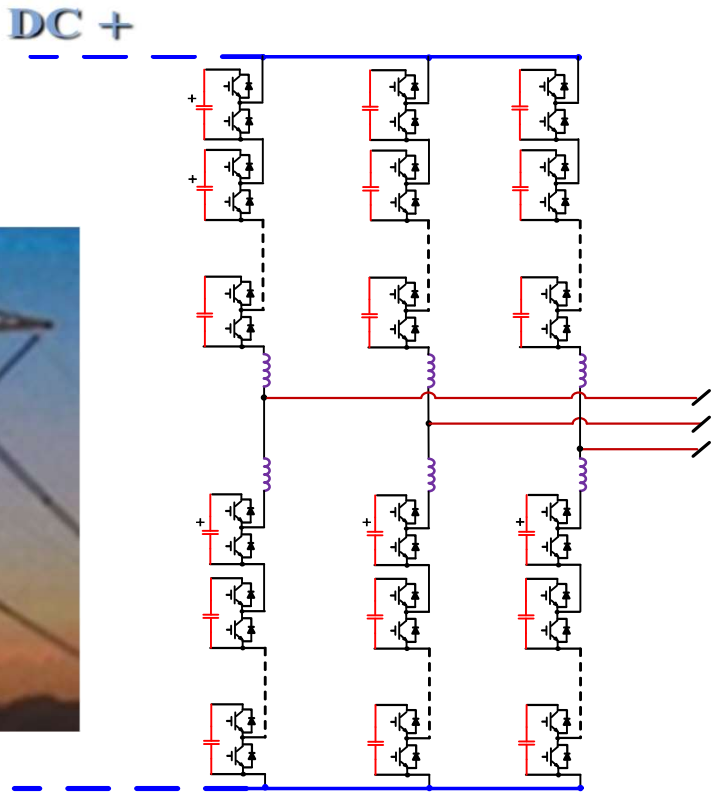
[5] Europe super gird, http://en.Wikipedia.org/ [6] The WhiteBook for DESERTEC in EU-MENA, http://www.desertec.org/, 2007

Power Electronics & Renewable Energy

DC Grids



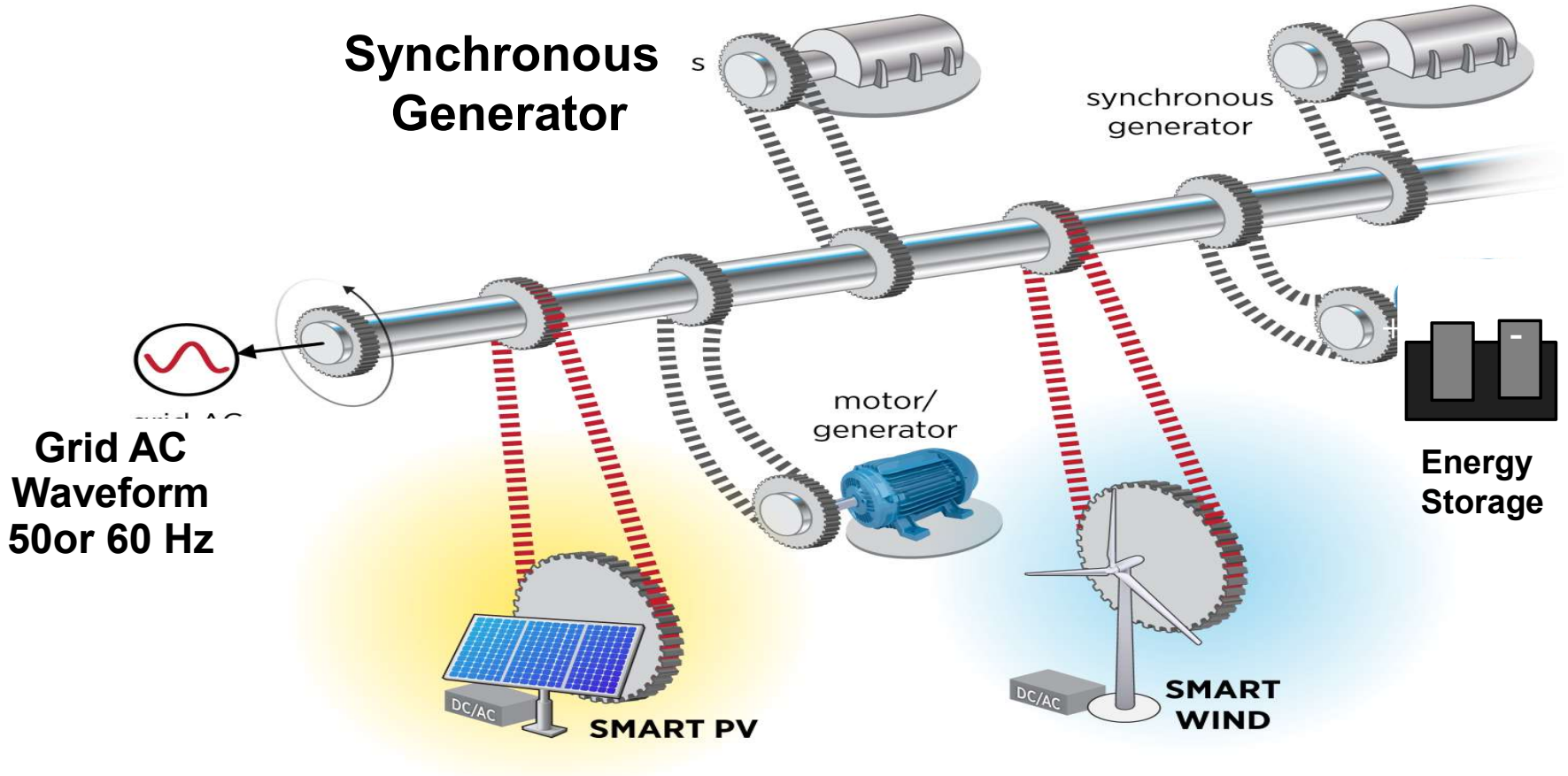
DC/AC



AC Grids

Power electronics is key to the generation, transmission and conversion

Paradigm Change in Power System Operation



Need advanced power control to integrate wind and solar

while maintaining grid stability and reliability

Thank You