Empowering the Electronics Industry
A Power Technology Roadmap

Power Sources Manufacturers Association (PSMA)

2017 PTR Co-Chairs:

Dhaval Dalal, ON Semiconductor

Conor Quinn, Artesyn Embedded Technologies

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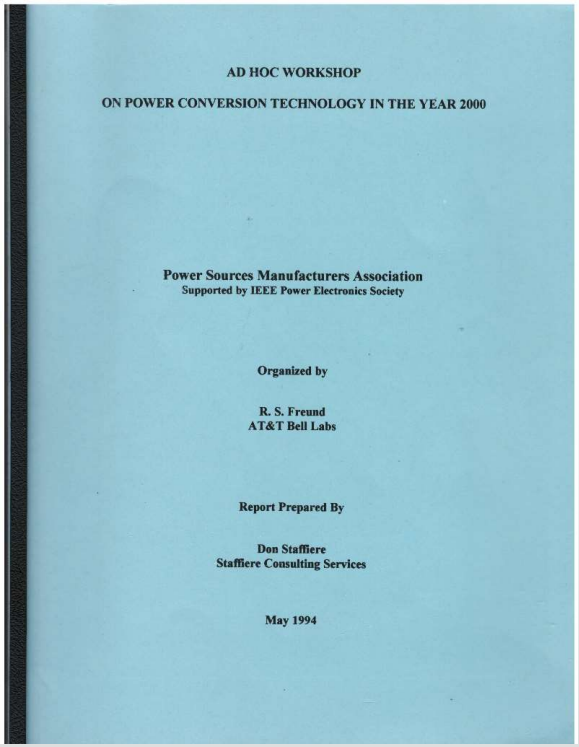
A Power Technology Roadmap

Technology Roadmap, as assessed by our Industry …

Power Technology Roadmap since 1994


AD HOC WORKSHOP

ON POWER CONVERSION TECHNOLOGY IN THE YEAR 2000

Power Sources Manufacturers Association
Supported by IEEE Power Electronics Society

Organized by

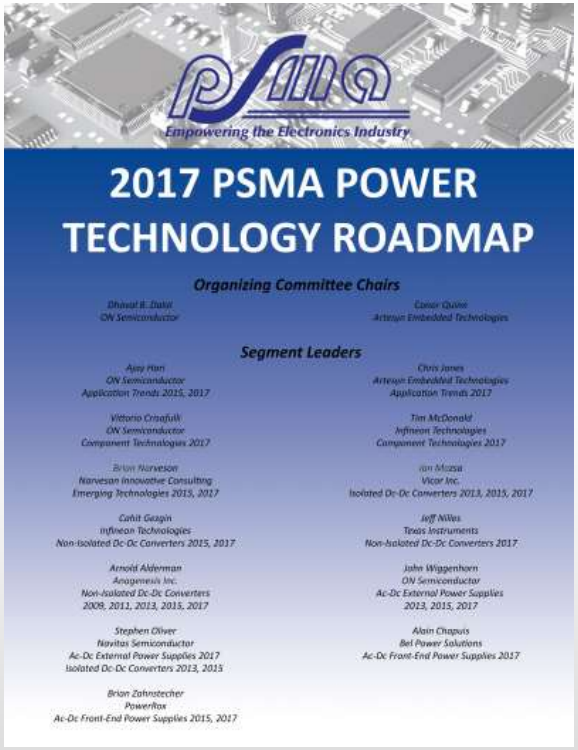
R. S. Freund
AT&T Bell Labs

Report Prepared By

Don Staffiere
Staffiere Consulting Services

May 1994

	1994	2017
Methodology		
	1 day	18 months
	Ad-hoc	Scheduled
Participants		
	18	82+
Focus		
	Product	Product
		Applications
		Components
Pages		
	21	537



Outline

- Who we are and what we do
- What remains consistent with previous roadmaps
- What has changed in this roadmap cycle

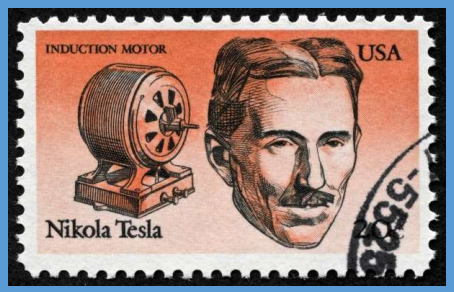
Who are we and what do we do ?

What society thinks I do

What my children think I do

What my parents think I do

What my boss thinks I do



What I think I do

What I do

What do we really do? Power stuff efficiently

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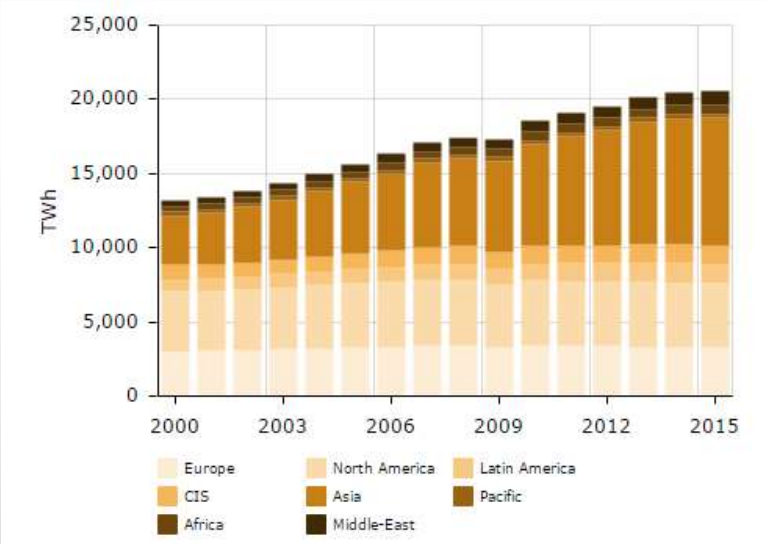
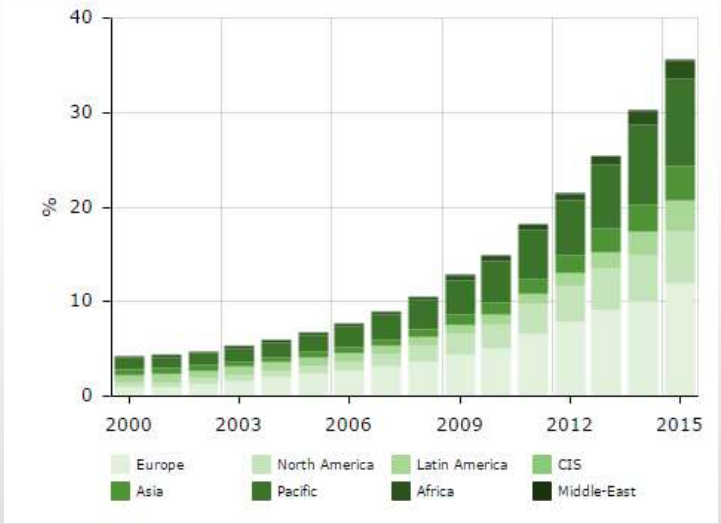
Electric Energy Consumption Patterns

Worldwide Consumption Increases ✗



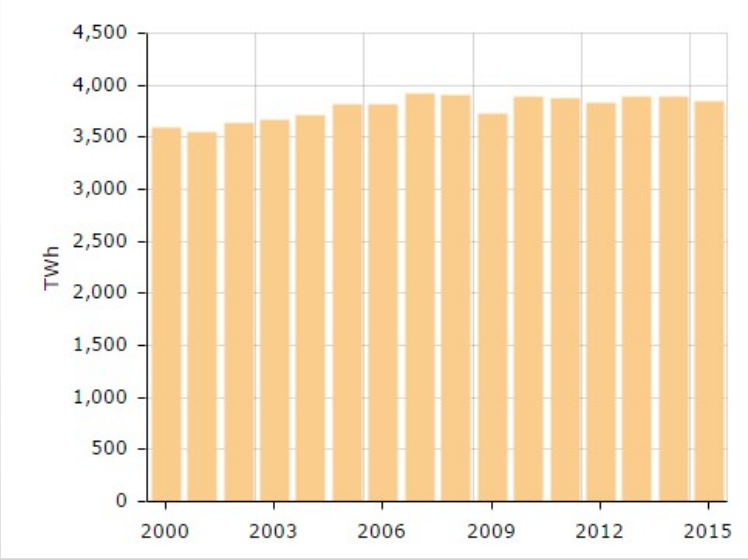
Worldwide Wind and Solar Increases faster ✓



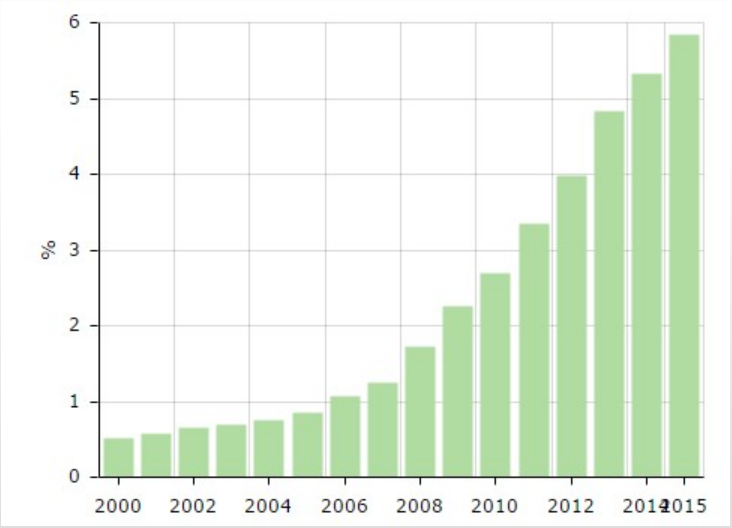
Source: https://yearbook.enerdata.net/#energy-consumption-data.html

Electric Energy Consumption Patterns

US Consumption Flat ✓

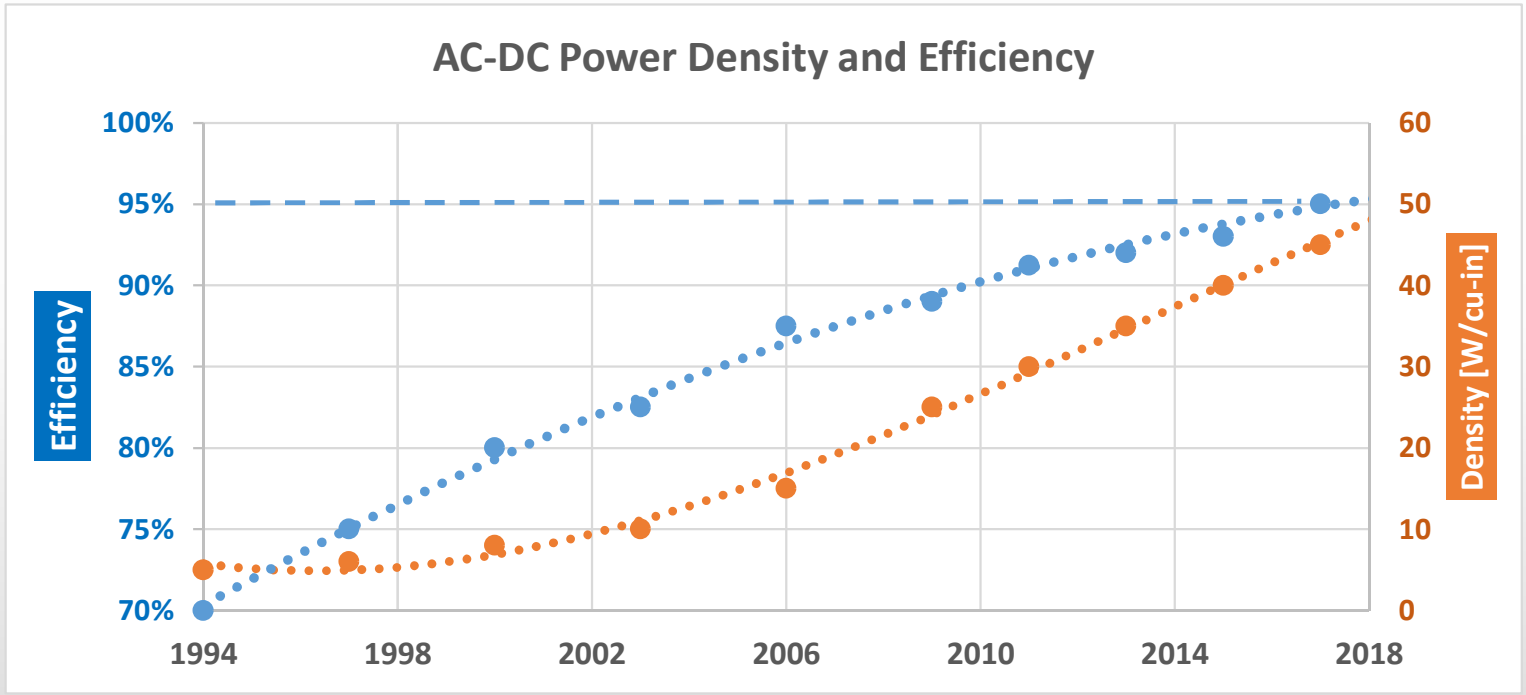


US Wind and Solar Increases faster ✓
but much lower than worldwide penetration ✗



Source: https://yearbook.enerdata.net/#energy-consumption-data.html

We've come a long way …



While cost has fallen by a factor of 5 or 10 !

Source: PSMA Roadmap Data and Industry Datasheets

Datacenters: Successfully bending the curve

~ 70 billion kWhrs annually in US

~ 2% of US Electricity Consumption

Electricity usage slowed to 4% per year

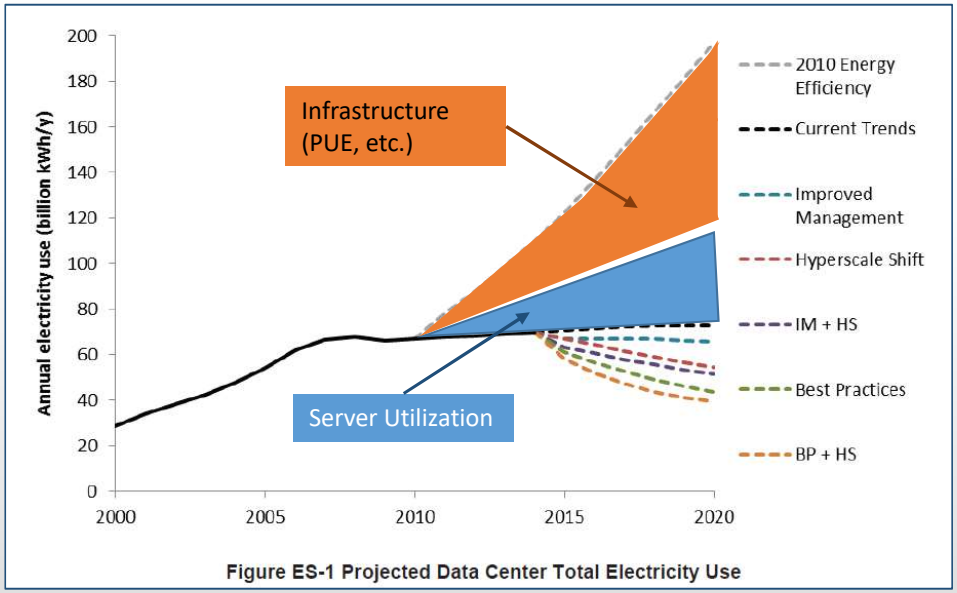


Figure ES-1 Projected Data Center Total Electricity Use

Source: LBNL-1005775 (June 2016)

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Need to keep bending the curve

- Energy Usage in Legal Cultivation
  - 2012: 1.0% of US Electricity Usage
  - 2016: 2.0% in Denver, CO

  Compare with Datacenters at 1.8%

- Will only continue to grow
  - In 2012, cultivation was legal in 15 states plus District of Columbia
  - In 2016, 28 states had legalized in some form

Sources: Evan Mills, Elsevier Energy Policy 46 (2012) 58-67
http://www.theguardian.com/us-news/2016/feb/27/marijuana-industry-huge-energy-footprint

Roadmap Methodology

- The cube

- Webinar Series
- Trend Working Groups / Leaders
  - Power Supply and Converters
  - Applications
  - Components
  - Emerging Technologies
- Online Survey
- Report Consolidation and Editing

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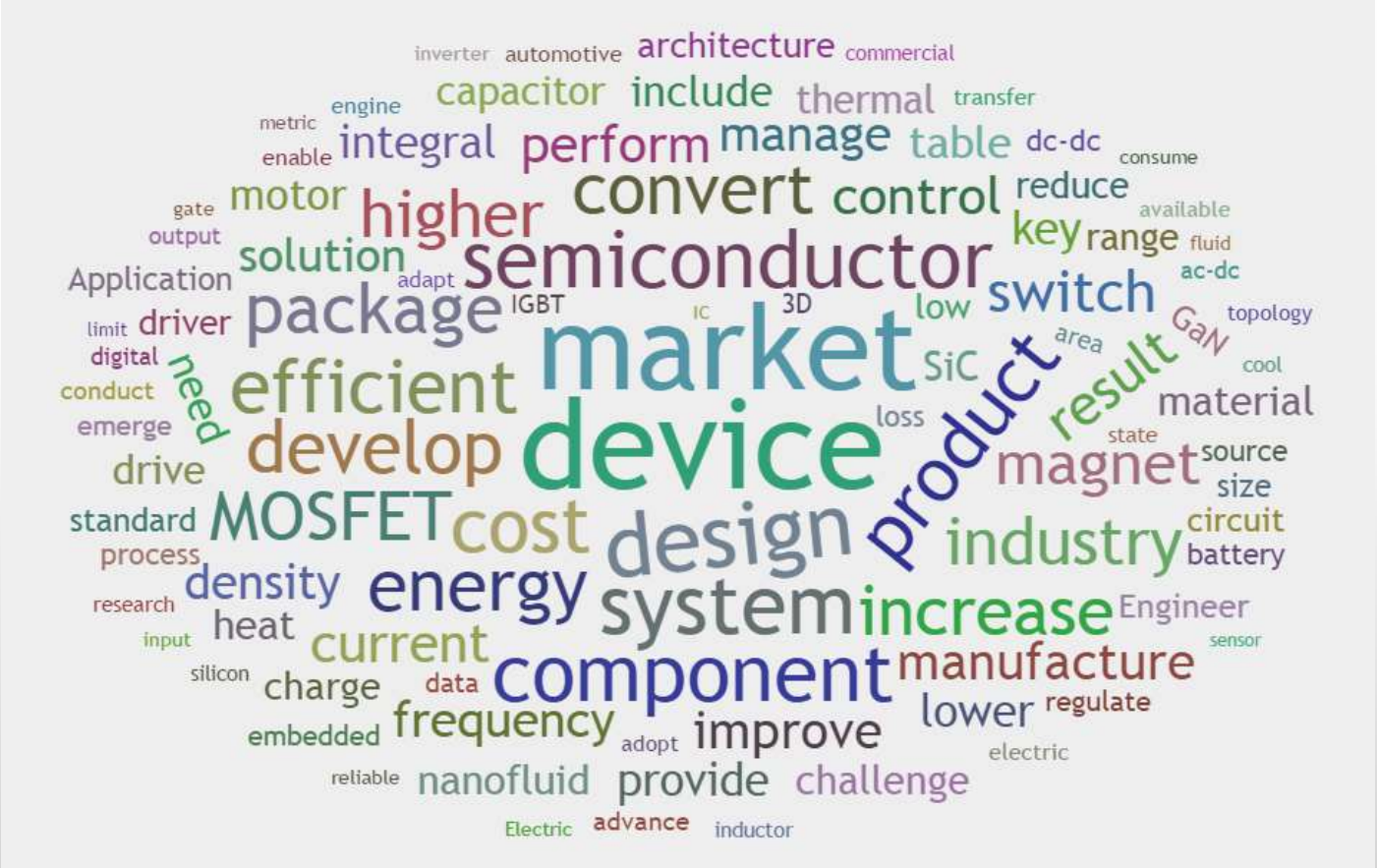
What's hot?


inverter
automotive
architecture
commercial
capacitor
include
thermal
transfer
engine
metric
integral
perform
manage
table
dc-dc
consume
enable
motor
higher
convert
control
reduce
gate
available
output
solution
semiconductor
key
range
fluid
Application
adapt
ac-dc
package
IGBT
IC
3D
low
switch
topology
limit
driver
area
GaN
digital
need
efficient
market
SiC
product
result
cool
conduct
material
emerge
loss
state
develop
device
magnet
source
drive
size
standard
MOSFET
cost
design
industry
circuit
process
battery
density
energy
system
increase
Engineer
research
heat
input
current
sensor
component
manufacture
silicon
charge
data
lower
regulate
embedded
frequency
improve
adopt
electric
reliable
nanofluid
provide
challenge
Electric
advance
inductor

Takeaway: Shift in Perceptions

Nothing has changed !

Technology Responsive

- Commoditization of AC-DC Power Supplies and DC-DC Converters continues
- Smaller, Faster, Cheaper Technology Treadmill

Everything is different !

Technology Shaping

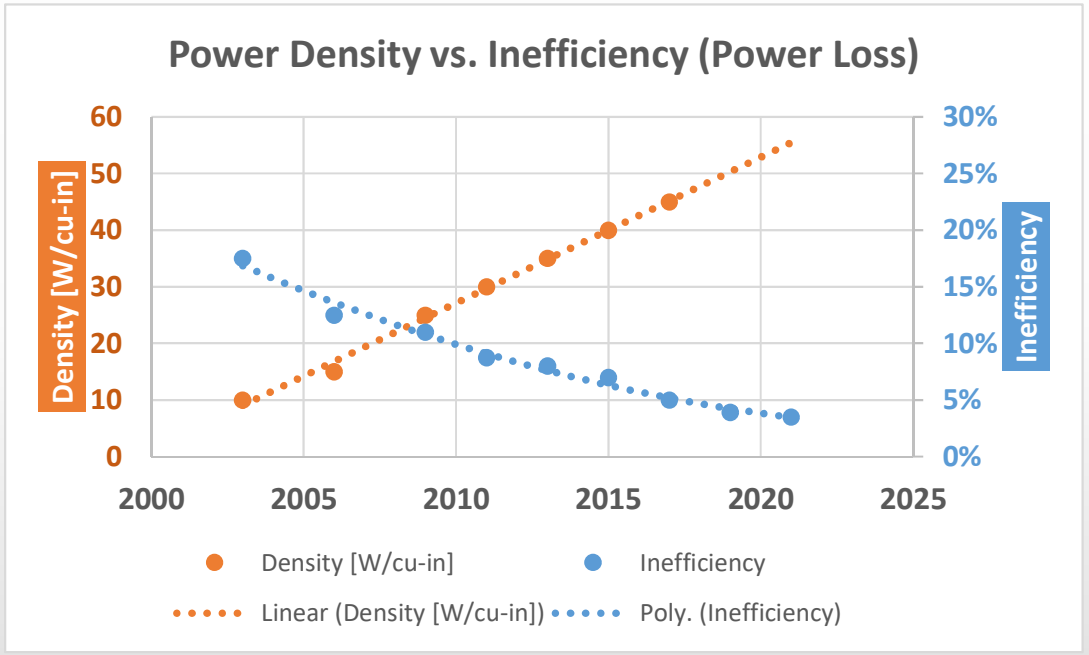
- We are now shaping the future and the public are (somewhat) familiar with our products
- Opportunities for self-promotion, should we want to

Nothing has changed

- SMALLER ✓
  - Power Density Trends
- FASTER ?
- CHEAPER ✓
  - Cost and commoditization of the traditional products covered

Nothing has changed

- SMALLER ✓
  - Power Density Trends
  - Enabled by significant reduction in power losses
  - Not approaching the limits



NOTE: This has been mostly achieved without increases in switching frequency

Source: PSMA Roadmap Data and Industry Datasheets

Nothing has changed

- CHEAPER ✓
  - Cost and commoditization in <u>all 4</u> Power Supply and Converter sections

Parameter/Metric	2019 Est. (PTR 2015)	2017	2019	2021
Key Design Goal (In Order of Importance): (Answer those with which you are familiar.) Score 1 to 4 where 1 = Most Important and 4 = Least Important		1 = Most 4 = Least	1 = Most 4 = Least	1 = Most 4 = Least
Server & Storage				
Efficiency	3	3	3	3
Cost	1	1	1	1
Power Density	4	4	4	4
Reliability	2	2	2	2

and switching losses. The semiconductor industry is racing to have the most cost effective solution. The adoption will hinge (as usual) on the cost vs. performance tradeoff related to the external pressures of the market. SiC and GaN products are n… …ificant volume in

the most cost effective solution

Estimated Industry Price Trend Compared to Today	% of Respondents in last report	Select One
-10% or more	2.3%	1.0%
Approx. -5%	91.7%	45.0%
Same	5.0%	43.0%
Approx. +5%	0.7%	11.0%
+10% or more	0.3%	0.0%
	Total: 100 %	100%

Demand for isolated dc-dc converter modules continues to be dominated by applications in the converged computing and telecommunications market segment as the integration of voice and data communication capabilities into the internet backbone is almost complete

steep commoditization trend

Expectation of across the board price reduction is tamed greatly when compared to past

Nothing has changed

- FASTER … Higher Switching Frequency ?

Ac-Dc Supplies, 200-2000 W – Design & Components: PFC Stage				
Parameter/Metric	**2019 Est. (PTR 2015)**	**2017**	**2019**	**2021**
Switching Frequency (per channel if interleaved)				
Fs <20-50 kHz>	3%	7%	3%	1%
Fs 50-100 kHz	67%	70%	67%	61%
Fs 100-150 kHz	15%	12%	15%	20%
>150 kHz	15%	11%	15%	18%
	Total: 100 %	**Total: 100 %**	**Total: 100 %**	**Total: 100 %**

Change Drivers / Enablers / Barriers

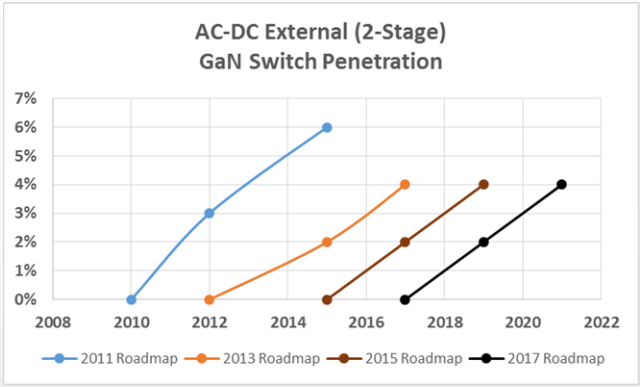
Note: Not seeing predicted increase in switching frequency due to continued limitations of emi, magnetics materials, etc.

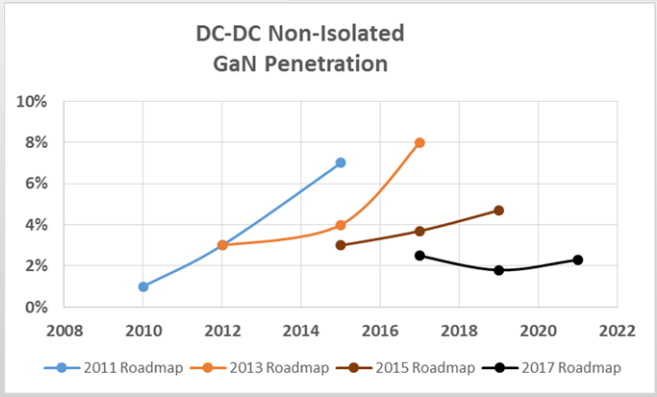
Or has something changed ?

- FASTER … Wide Bandgap devices begin to shift the discussion

EMI
Switching Losses
Size Reduction

Availability of Magnetics
Cost





Source: PSMA
Roadmap Data

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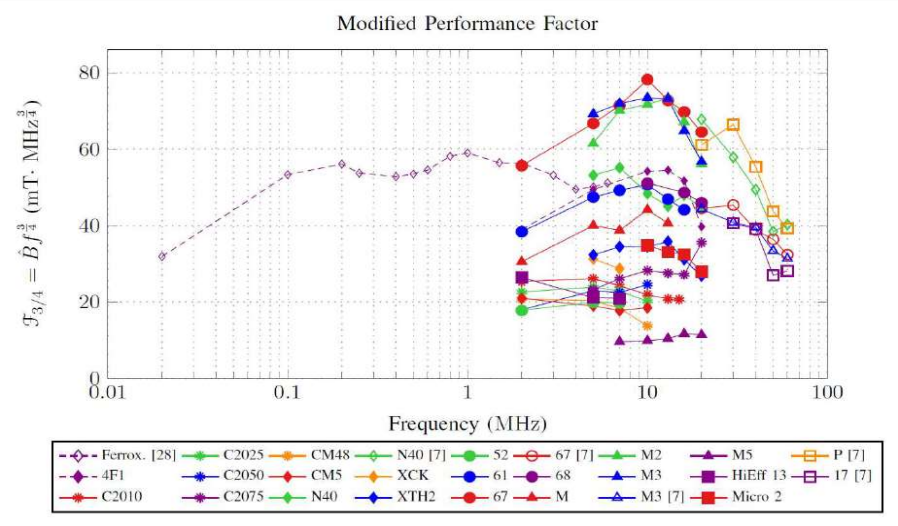
What still needs to change ?

- Magnetics, Magnetics, Magnetics
- Industry has acknowledged the limitations
- Included in the report
  - New materials, some from the RF domain
  - Industry initiatives to improve characterization
  - New techniques and processes
  - Appropriate topologies

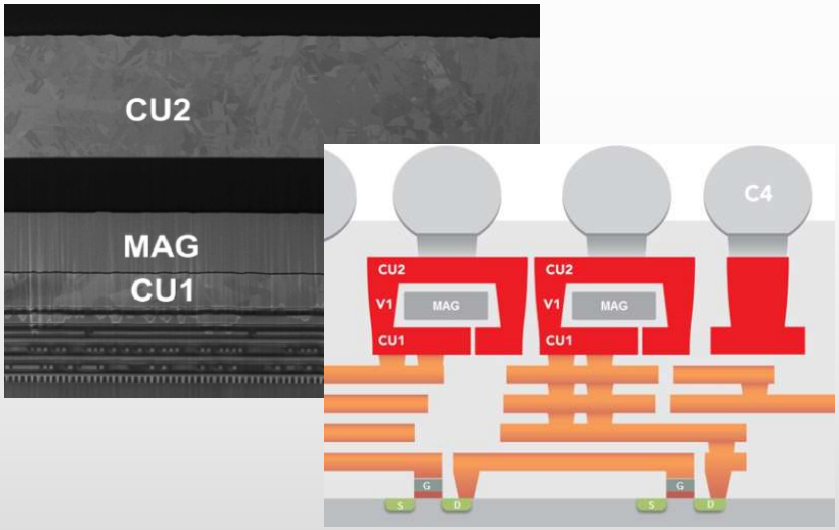
Magnetics Technology Examples

Core Materials for Multi-MHz



Source: PSMA Magnetics Workshop 2016, David Perrault MIT

Thin Film Magnetics



Source: Noah Sturcken, Ferric Inc.

Everything is Different

Noticeable change in tone from the power conversion industry
from Technology Responsive to now Shaping Technology

- From Very Low Power to High Power
- From Energy Generation and Distribution to Transportation
- And the Component and Packaging Technologies that enable these

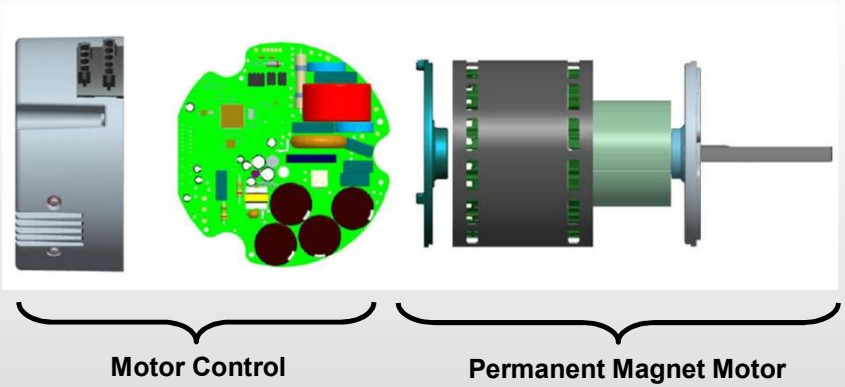
Shaping New and Improved Applications

Energy Harvesting

- As low as μW
- Kinetic, PV, Temperature, Humidity
- Sensors to Implantables

Indoor Climate Control

- Smart Controls
- Energy-saving Variable Speed Drive

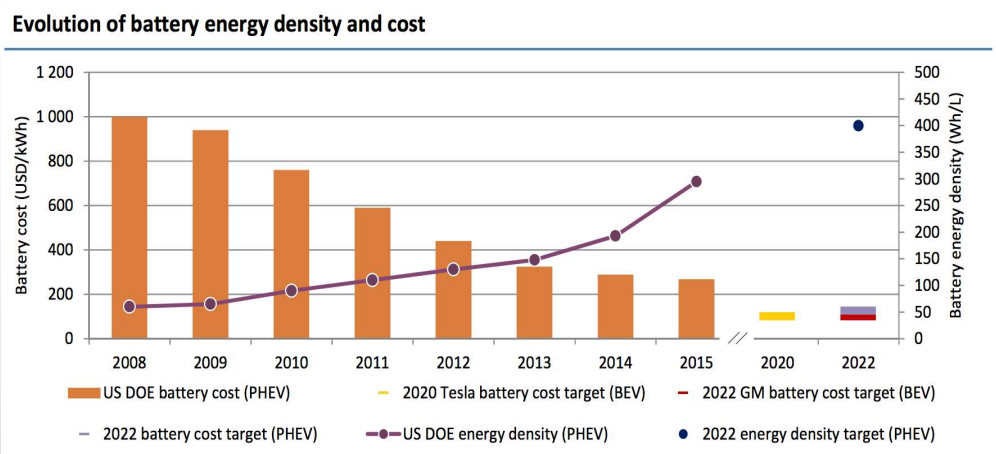


Sources: PSMA Energy Harvesting Committee
Nidec Motor Corporation

Shaping Electrification

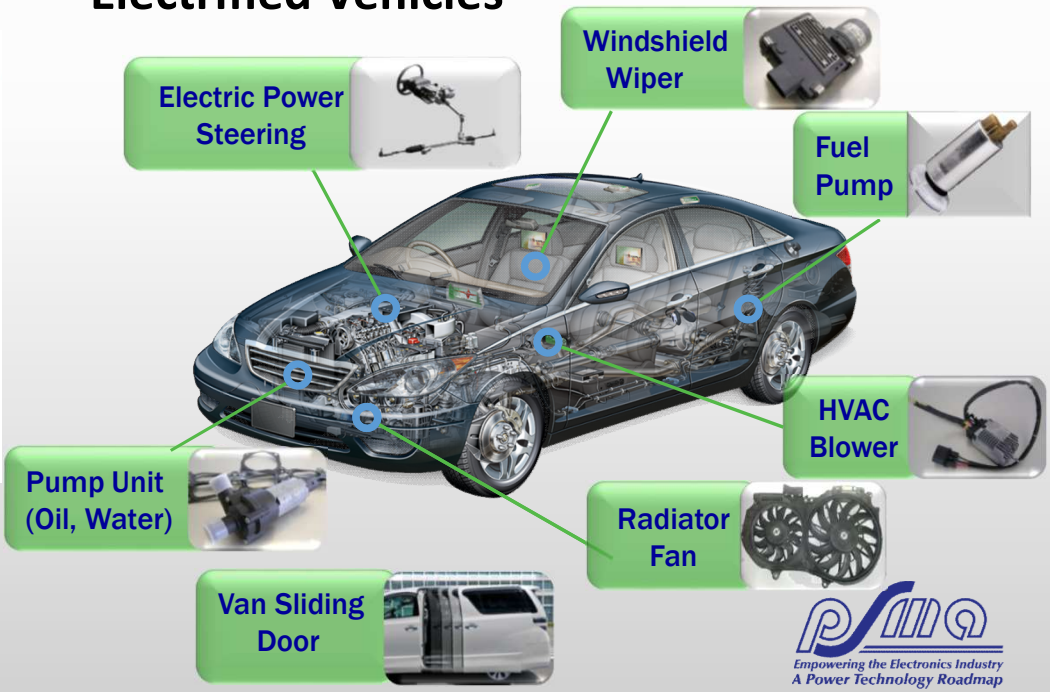
Generation and Distribution

- **PV and Wind**
- **Energy Storage Challenges**



Transportation

- **Electric Vehicles**
- **Electrified Vehicles**



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Sources: iNEMI 2017 Roadmap
ON Semiconductor

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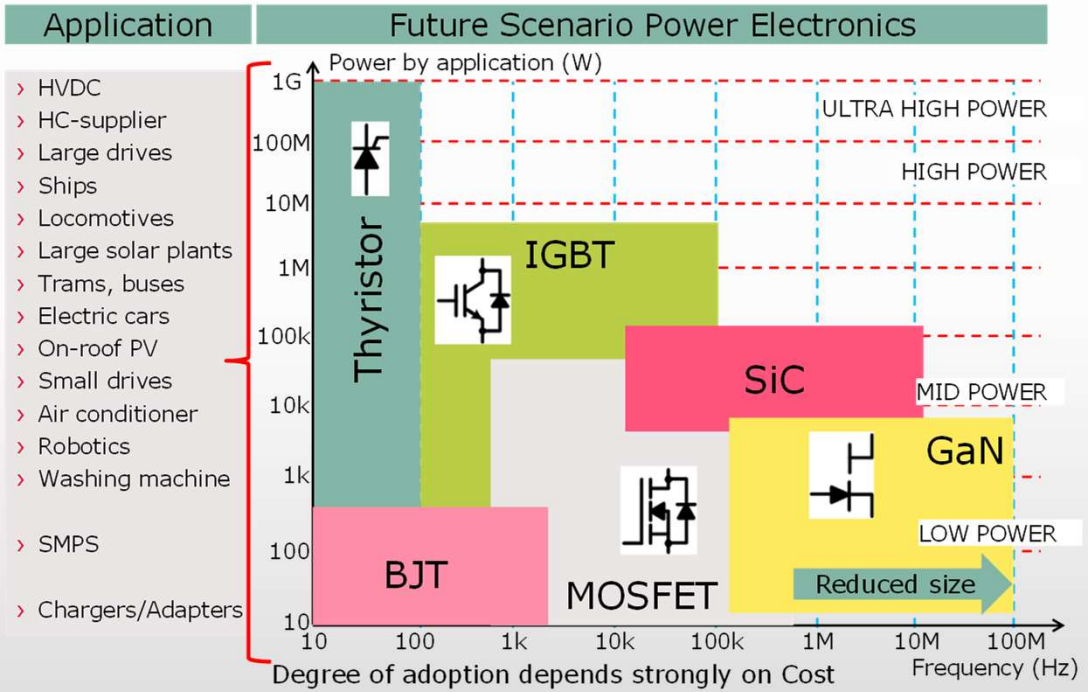
Component Technologies



Report covers

- IGBTs
- MOSFETs
- GaN
- SiC
- Controllers
- Passives

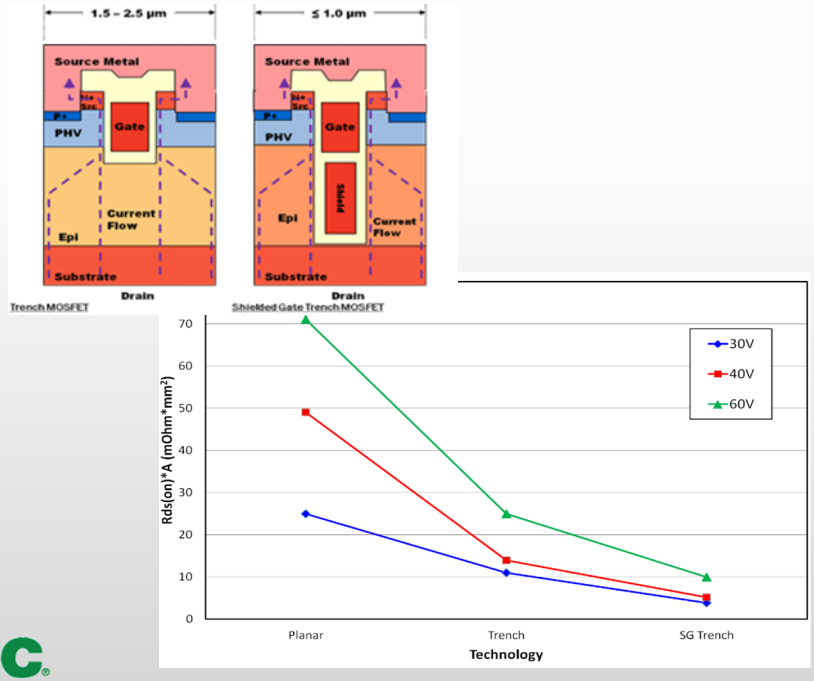
Detailed discussion of

- Market Drivers
- Key Metrics
- Trends
- Challenges

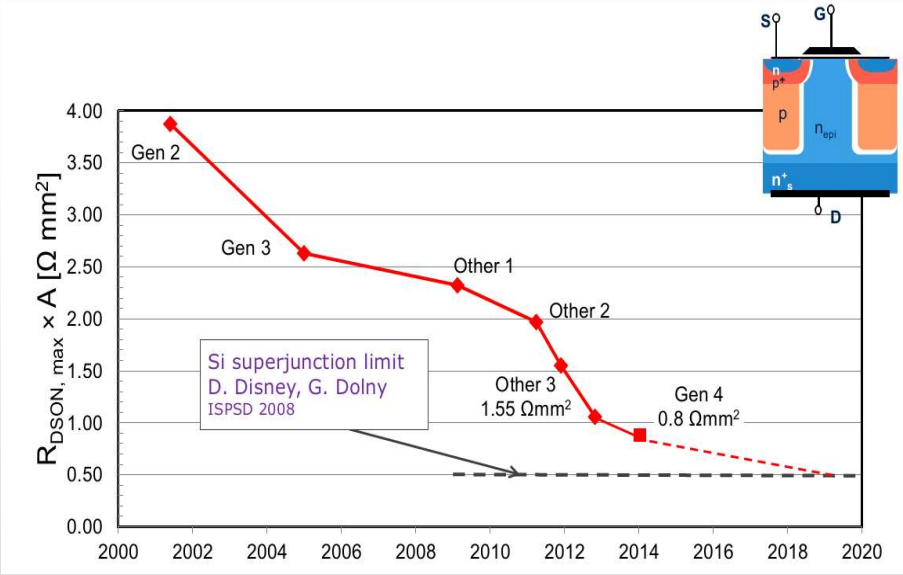
Source: Infineon Technologies

Component Technologies

Low Voltage FET Improvements



High Voltage FET Trends



Source: PSMA 2017 Roadmap

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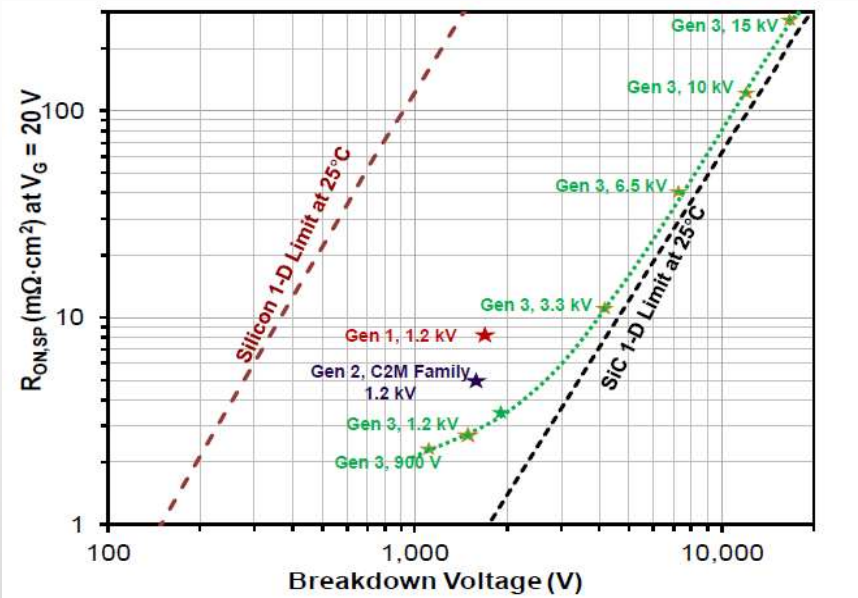
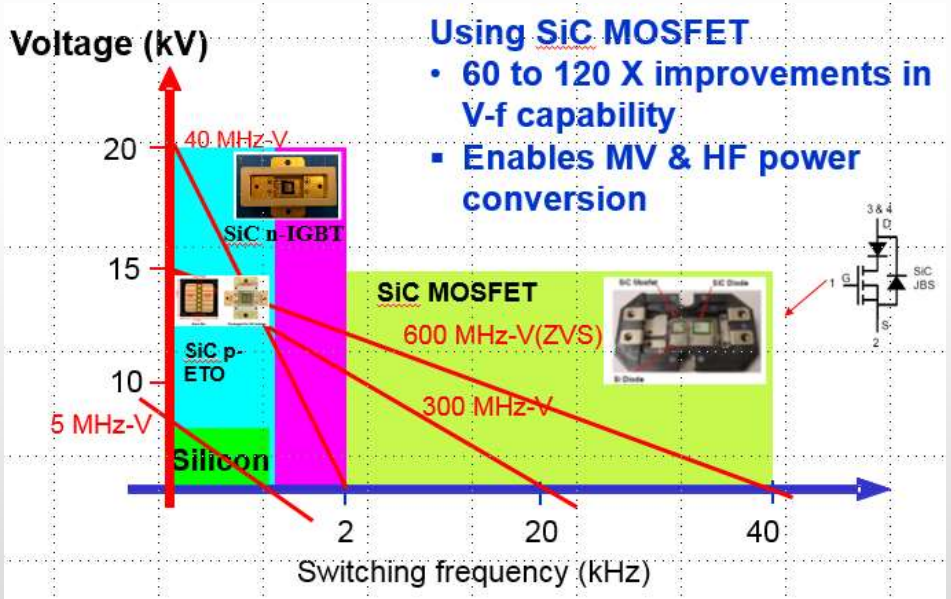
Component Technologies

SiC Trends



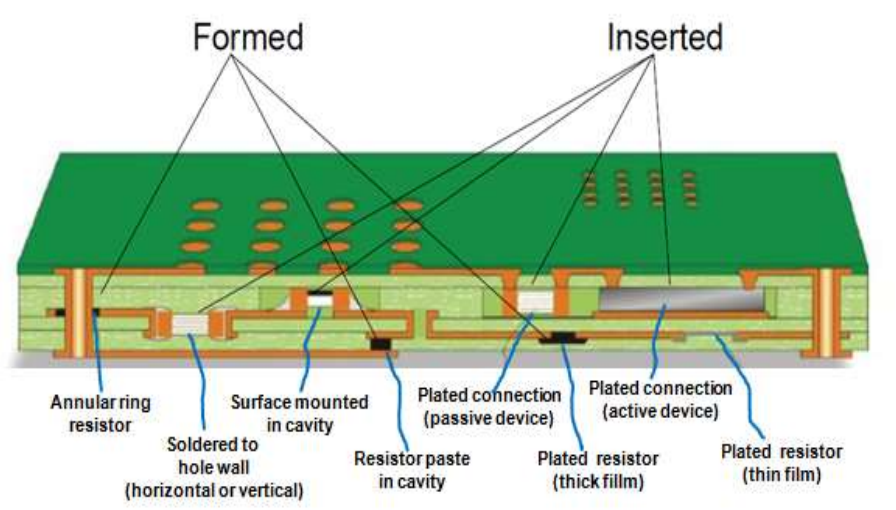
SiC for "Medium" Voltage



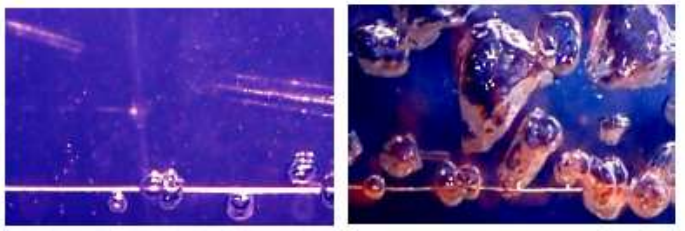
Sources: Wolfspeed
NC State

Emerging Technologies

Embedded Substrate



Nanofluids enhance Cooling



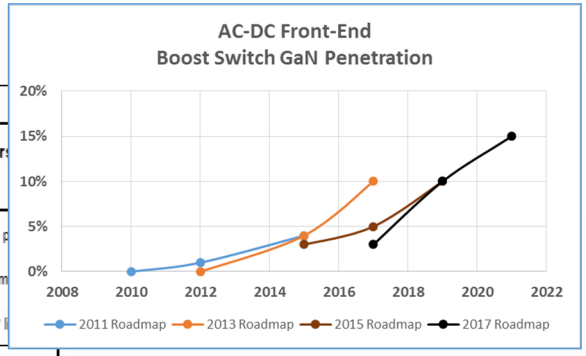
Type of Nanoparticle	Thermal Conductivity of Particle W/(m-K)	Size of Particle in Solution*	Amount of Solution*	Price of Unit (USD)**
Alumina (Al_2O_3)	30	30-60 nm	100.0 mL	$183.50
Copper Oxide (CuO)	401	<50 nm	25.0 g***	$73.10
Gold (Au)	310	10 nm	25.0 mL	$338.00-$362.00
Gold (Au) with Silica Coating	N/A	10 nm	5.0 mL	$318.50
Iron Oxide (Fe_2O3)	0.58	30 nm	5.0 mL	$240.00
Silver (Ag)	429	20 nm	25 mL	$114.50
Titanium Oxide (TiO_2)	22	21 nm	100.0 g	199.50

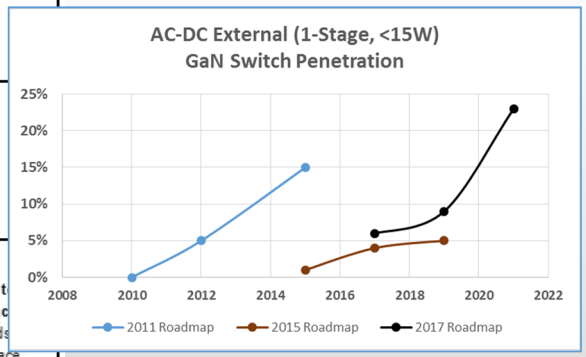
Sources: PSMA Packaging Committee
Advanced Thermal Solutions, Inc.

Quantitative Tables

I. Dc-Dc Converters, Isolated – General Requirements II

Parameter/Metric For each PARAMETER, identify the expected change in usage in your industry compared today's level of usage.	2015 Est. (PTR 2011)	2017 Est. (PTR 2013)	2019 Est. (PTR 2015)	2017	2019	2021	Change Drivers / Enablers Barriers
Output Voltage Regulation (%)							**Drivers**: Trade-off of eficiency vs. p density **Enablers**: Flexibility of downstream regulation **Barriers**: Confusion created by IP l
Totally Unregulated (DC Transformer)	18%	Same	15%	24%	22%	33%	
Semi-Regulated (Total Regulation Band ±2 % To ±10 %)	4%	More	32%	27%	26%	24%	
Well Regulated (Total Regulation Band ±2 % Or Better)	78%	Same	53%	49%	52%	43%	
	Total: 100 %			**Total: 100 %**	**Total: 100 %**	**Total: 100 %**	
Expected Efficiency - most economical (Eff%)							Wide breadth of responses; entry represents averaged response
48Vin - 3.3Vout (regulated)	93%	X	91%	85%	86%	87%	
48Vin - 12Vout (regulated)	94%	X	94%	89%	90%	94%	
48Vin - 12Vout (unregulated)			95%	91%	93%	94%	
380Vin - 12Vout (regulated)			92%	90%	90%	92%	
380Vin - 12Vout (unregulated)			94%	89%	90%	92%	
Expected Efficiency - most advanced (Eff%)							Wide breadth of responses; entry represents averaged response
48Vin - 3.3Vout (regulated)	97%	X	94%	88%	89%	91%	
48Vin - 12Vout (regulated)	98.0%	98.0%	96%	92%	94%	97%	
48Vin - 12Vout (unregulated)			98%	92%	95%	95%	
380Vin - 12Vout (regulated)			97%	92%	96%	96%	
380Vin - 12Vout (unregulated)			98%	92%	96%	96%	
Power Management Interface Technology (%)							**Drivers**: **Need for more control t improve overall system efficienc** **Enablers**: digital control easily adds capability for communications interface
None	80%	Same	30%	51%	44%	37%	
I2C	10%	Same	27%	13%	20%	23%	
PMBus			39%	16%	30%	40%	
Other	Trace	More	4%	20%	6%	0%	
	Total: 90 %			**Total: 100 %**	**Total: 100 %**	**Total: 100 %**	





Sources: PSMA Roadmap Data

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Print Version and USB Stick

USB Stick includes 13 Webinar Recordings by Industry Experts

Contact the PSMA at APEC or at power@psma.com

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The next roadmap cycle starts now

PTR Working Group Meeting

- Tuesday, Noon to 2pm
- Room 32, Convention Center

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Thank you !

Emerging Technologies

Brian Narveson
Ed Herbert
Noah Sturcken
Reza Azizian
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With support from

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Joe Horzepa
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Laurie House
Greg Evans
Mikhail Guz
Kevin Parmenter
Chuck Richardson
PSMA Technical Committees
And >100 Survey Responses

Product Trends

Alain Chapuis
Brian Zahnstecher
Ed Massey
Stephen Oliver
John Wiggenhorn
Cahit Gezgin
Jeff Nilles
Arnold Alderman
Ian Mazsa

Application Trends

Ajay Hari
Chris Jones
Upal Sengupta
John Vigars
Richard Caubang
Maeve Duffy
Michael Hayes
Anandan Velayutham
Prakash Shahi
Yong Ann Ang
Frazier Pruett
Jim Young
Brian Zahnstecher

Component Technologies

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Tim McDonald
Chris Bull
Davide Chiola
Michael Treu
Johannes Schoiswohl
Christophe Basso
Prasad Venkatraman
Tirthajyoti Sarkar
Jeff Casady
Ritu Sodhi
Ali Salih
Conor Quinn

Webinars

Ray Ridley
Brian Narveson
Siamak Abedinpour
Michael Hayes
Lorandt Fölkel
Ajinder Singh
Alex Huang
Stephen Oliver
Hans Stork
Brian O'Connell
Jeff Casady
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