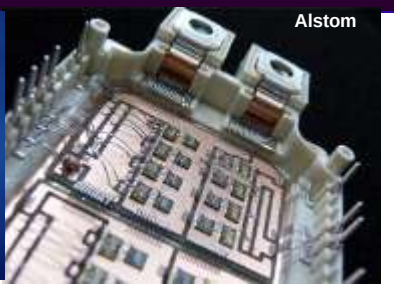
SiC: More devices, more business and more applications

Editorial Webcast. March 19th 2013

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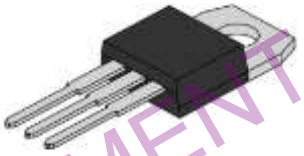
Overall power electronics industry outlook

Définitions

- **A power discrete, or component is a single-die packaged power device.**
  - **It is made of:**
    - **A semiconductor die (chip)**
    - **Interconnection**
    - **A lead frame (with 2, 3 or more pins)**
    - **A plastic package**
  - **It represents the largest part of power market.**
  - **Semiconductor devices are mostly transistors (MOSFETS, IGBT, BJT…) and Diodes.**



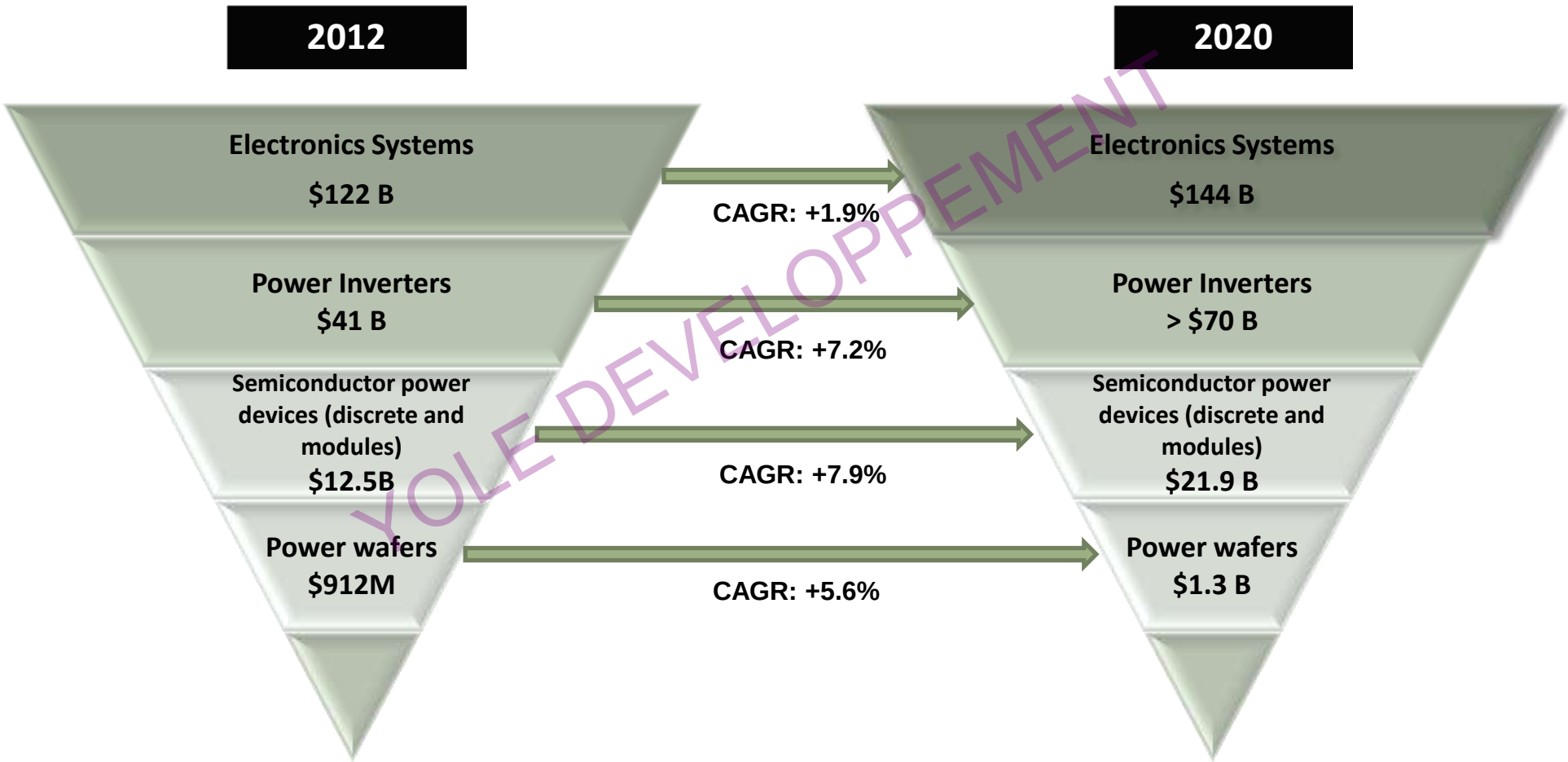
- **A power module is the assembly of several power semiconductor dies in one package.**
  - **It is made of:**
    - **Several semiconductor dies (chip)**
    - **Interconnections**
    - **Large substrate (usually DBC)**
    - **Gel filling**
    - **A plastic package**
  - **It is a more and more common type of device since enhances the switching/temperature/weight/cost performance.**
  - **Semiconductor devices are mostly IGBTs or MOSFET (Regular or Super-Junction)**

Source: Semikron

- **Power converter, also called Inverter is the assembly of several power modules as well as passives (Capacitors, Inductors, resistors…), logic and control circuits, protection devices, cooling systems and connectors.**

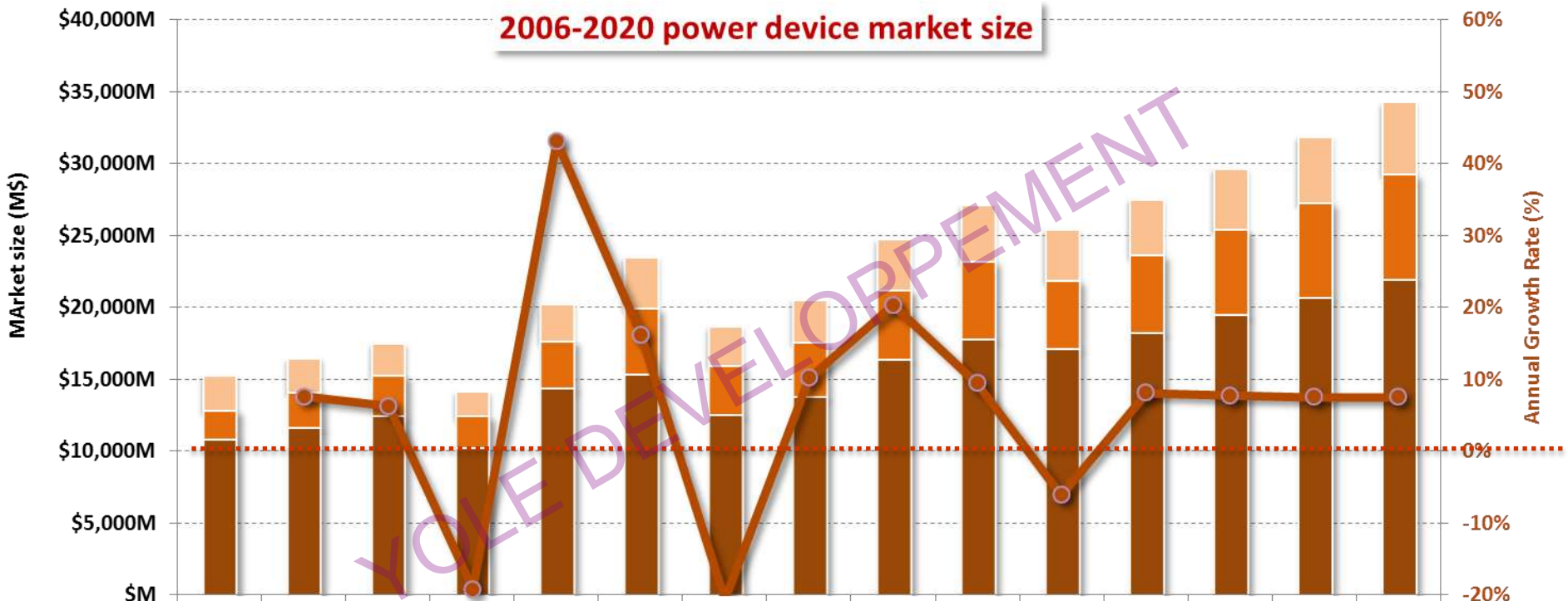
Power Electronics

2012 – 2020 value chain analysis: wafer, device, system



Power electronics market metrics

2006-2020 overall PE market size, split by device type



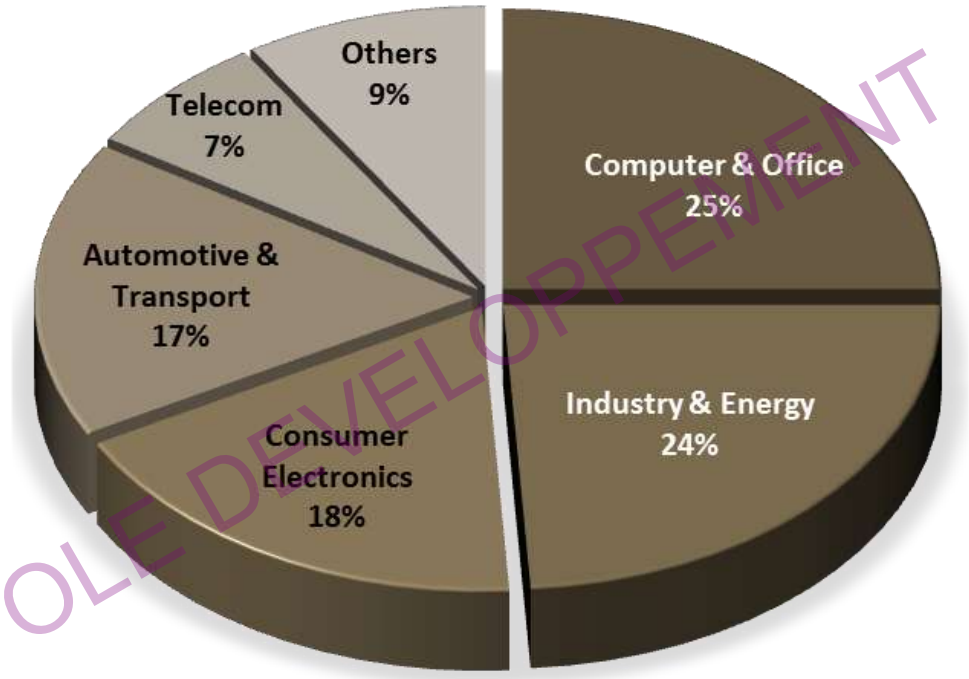
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Power IC	$2,458M	$2,335M	$2,218M	$1,708M	$2,562M	$3,587M	$2,690M	$2,986M	$3,554M	$3,873M	$3,564M	$3,884M	$4,234M	$4,615M	$5,030M
Power Modules (M$)	$1,973M	$2,506M	$2,842M	$2,188M	$3,283M	$4,596M	$3,447M	$3,826M	$4,820M	$5,447M	$4,739M	$5,355M	$5,944M	$6,598M	$7,324M
Discretes (M$)	$10,839M	$11,598M	$12,410M	$10,226M	$14,375M	$15,320M	$12,515M	$13,742M	$16,371M	$17,762M	$17,129M	$18,258M	$19,457M	$20,649M	$21,910M
Growth rate (%)		7.7%	6.3%	-19.2%	43.2%	16.2%	-20.6%	10.2%	20.4%	9.4%	-6.1%	8.1%	7.8%	7.5%	7.5%

It includes:

- **Power discretes: MOSFET, rectifier, IGBT, Bipolar….**
- **Power modules: IGBT, diode or MOSFET modules, IPM**
- **Power IC: power management IC: mainly voltage regulators (POL) and drivers**

Source: Yole Développement

2012 power electronics market by application and main expectations to 2015



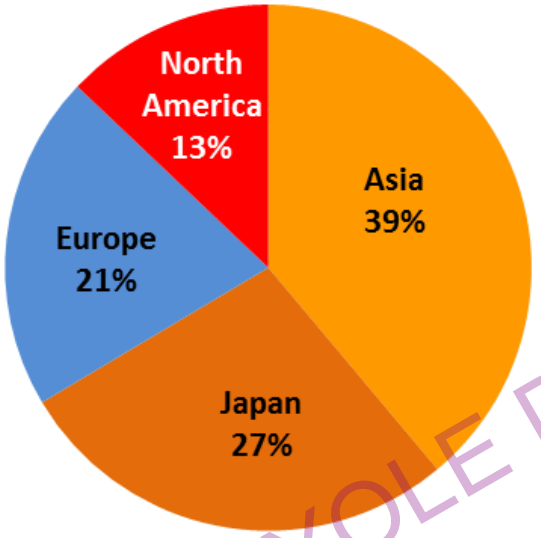
Overall Power Electronics Market by Applications

Expected 2013-2015 main trends are:

- **Significant increase of Automotive sector following EV and HEV ramp-up**
- **Renewable energies and smart-grid implementation will drive industry sector ramp-up.**
- **Steady erosion of Consumer segment due to pressure on price (However, volumes (units) will keep on increase)**

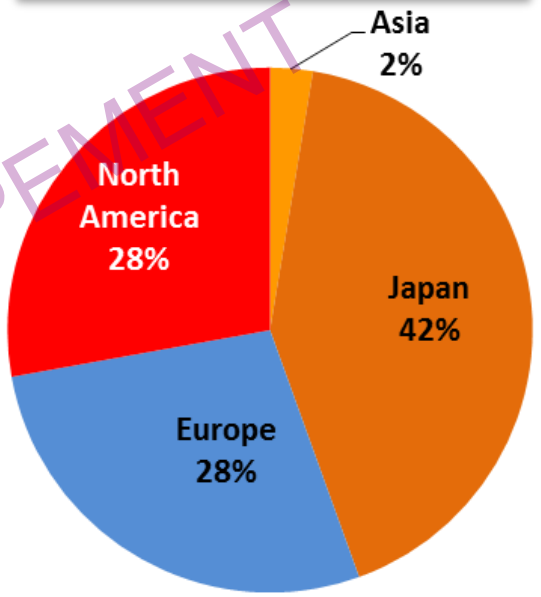
Regional analysis

2011 Power Device sales by region



- Overall Asia is still the landing-field for more than 65% of power products. Indeed, most of the integrators are located in China, Japan or Korea.
- Europe is very dynamic as well with top players in traction, grid, PV inverter, motor control…

2011 revenues by company headquarter location

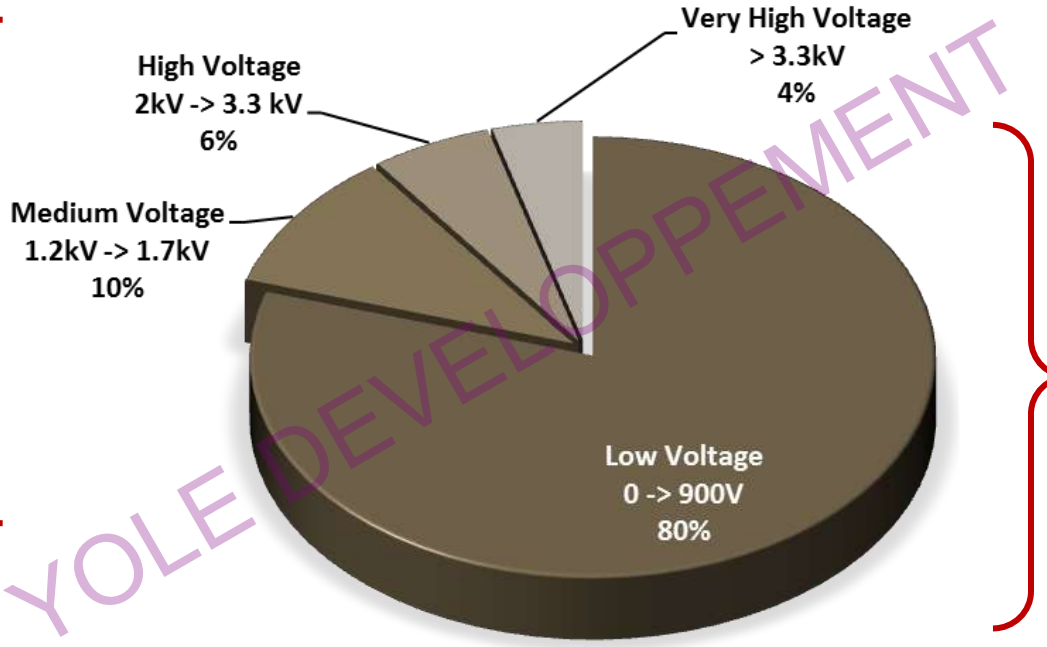


- The big-names of the power electronics industry are historically from Japan. 9 companies of the TOP-20 are Japanese.
- Very few power manufacturers in Asia except in Japan
- Europe and US are sharing 4 of the TOP-5 companies

What TAM for SiC (& GaN)?

Market size, split by voltage range

More comfortable area for SiC. Apps are less cost-driven and SiC added value is obvious



Strong competition with traditional Silicon technologies, SJ MOSFET and GaN. Cost driven apps

Power electronics market split by voltage range

Source: Yole Développement

Breakdown *over* a total market size of ~$18.6B in 2012

SiC Industry Outlook

The New Entrants and The Exits Since 2010

- **The new entrants**
  - **Material:**
    - Epiworld (CN): www.epiworld.cn is proposing epi services for 3", 4" and 6". They are equipped with Aixtron G4 6x6" and several pieces of inspection equipment
    - SiCC (CN). www.sicc.cc is proposing 2, 3 and 4" n-type and S.I. SiC epi-ready wafers. Established since late 2010 as a spin-off of Shandong Univ.
    - TYSTC (CN): www.sicty.com Tianyu Semiconductor Technology Co., Ltd. founded in Jan 2009, produces and markets SiC epi-wafers. They have 3 epi-reactors running (Aixtron).
  - **Devices:**
    - Kingway Technology Co. Ltd., (CN) www.thekingway.com a high-tech enterprise located in Beijing, China, was founded in 2010 by a group of veterans with Ph.D. Degrees and solid industrial experiences back from the US. Kingway focuses on epitaxial growth of SiC and GaN materials, design / fabrication of high power, high voltage devices and modules.
    - Anvil Semiconductors Ltd., (UK) a developer of small power converters using SiC power semiconductor switches.
    - Widetronix Inc. (US) is a manufacturer of high voltage SiC epitaxial wafers and power conversion devices. The company is located in Ithaca, New York.
    - Ascatron (SW), a spin-off from ACREO is dedicated to fabrication of SiC semiconductors, from epi to diced wafers.
    - IBS (FR) http://www.ion-beam-services.com/ who is positioned as an SiC foundry service provider
    - Fraunhofer IISB. Since 2012, IISB propose a foundry service for SiC devices, from epi to packaged chips
- **The Exits**
  - **Material:**
    - NeoSemiTech (Kr) has stopped its SiC activities, keeping focused on GaAS and Si for solar.
    - Caracal (US) who went bankruptcy
  - **Devices: SemiSouth who closed down late 2012**
- **The M&A**
  - Crysband (Kr) has been acquired by SKC (Kr)
  - SiCed (D) that is now 100% Infineon
  - Fairchild has acquired TranSiC (April 2011) for $17M

Power electronics SiC device manufacturing
Current business model in the SiC world

Size
(2012 sales)

Large

$5M

Medium

$1M

Small

Infineon
CREE
STMicroelectronics
ROHM SEMICONDUCTOR
Microsemi
CREE
MITSUBISHI ELECTRIC
Raytheon
Fraunhofer IISB
GeneSiC SEMICONDUCTOR
SET
TOSHIBA
HITACHI
SanRex
GLOBALPOWER DEVICE COMPANY
Raytheon
e-Front runners
ibs
ascatron
USCi
RENESAS
NORTHROP GRUMMAN
Panasonic
TOYOTA CENTRAL R&D LABS., INC.
FAIRCHILD SEMICONDUCTOR
JRC
BOSCH
DENSO

SiC Foundry service / contract manufacturer

Device maker - IDMs

System manufacturer with SiC capability

Business Model

SiC Switches. Who is active? Late 2012 status

Company	MOSFET	JFET			BJT	IGBT	Thyristor	IC
		Normally-on	Normally-off	Cascode				
ACREO (SW)	X							
Cissoid (B)	X							
CREE (US)	X	X			X	X	X	
DENSO (J)	X							
Fairchild (SW)					X			
Fuji (J)	X					X		
GE (US)	X							
GeneSiC (US)					X		X	
Global Power Device (US)	X							
Hitachi (J)	X					X		
Infineon (D)		X		X (hybrid Si-SiC)				
MicroSemi (US)		X	X	X (full SiC)	X			
Mitsubishi Electric (J)	X					X		
Nissan Motor (J)	X							
Northrop Grumman (US)	X	X	X	X (full-SiC)				
Panasonic (J)	X							
Raytheon (UK)		X						X
Rockwell (US)		X						
Rohm (J)	X					X		
Shindengen (J)					X			
Sumitomo SEI (J)		X						
Toshiba (J)	X	X						
United Silicon Carbide (US)	X	X	X		X		X	X

Commercially available

Tentative BoM analysis of WBG devices use in PV Inverters Case study with SiC devices

Solar Market Segment

- **Photovoltaic plants' nominal power depends on the application:**
  - **Residential: Home building installations**
    - **Typically around 3 kW of nominal power**
  - **Industrial and Commercial building installations**
    - **From 10kW to 100kW of nominal power**
  - **Solar farms**
    - **Up to 10 MW of nominal power**

Picture: Example of a solar farm power plant

PV inverters commercial products with SiC
Full-SiC products

- **SMA and RefuSol inverters are today's only inverters with Full-SiC**
  - **SMA is using JFET**
    - **JFET power modules**
    - **3 Level circuit topology**
  - **RefuSol**
    - **3 Level circuit topology**
- **No specific modifications of inverter architecture is observed yet**
  - **All passives are still of the same type and size, more or less**
  - **Conditions of operation are similar: standard temperature, voltage, frequency…**
  - **Topology modification are also possible using Silicon devices**
  - **The objective was only to bring higher efficiency**

RefuSol 20kW SiC inverter
Model: 020K SCI

SMA Tri-power 20kW SiC inverter
Model: 20000TL HE

PV inverters commercial products with SiC
Hybrid Si/SiC products (1/2)

- **2 examples of hybrid products:**
  - **Enphase (US): M215 micro-inverter**
    - **2 SiC diodes 1200V/5A**

ENPHASE M215 Main Characteristics	
Input (DC)	• Max power 260W • Max Voltage 45V • Max Current 10.5A
Output (AC)	• Max power 215W • Nominal Current 0.9A (at 240Vac / single phase) to 1A (at 208Vac / three-phase) • Frequency 60Hz • Utilization : Single phase or Three-phase
CEC efficiency	• 96.0%
Cooling concept	• Natural convection, no fan
Interfaces	• Power Line Communications (PLC) • Status LED

Enphase M215 micro-inverter

  - **Power One (US): Aurora Trio 10KW inverter (PVI-10.0-TL)**
    - **2 SiC diodes 1200V/22A (TO247) for DC-DC boost converter stage**
    - **Input:**
      - **Max voltage: 900V**
      - **Max current: 36 Amp**
    - **Max. efficiency: 97.8%**
    - **Transformer-less topology**

PowerOne Aurora Trio 10kW inverter

PV inverters commercial products with SiC
Hybrid Si/SiC products (2/2)

– **Power One (US): Aurora Micro-inverter 205W (Micro-0.25-I-OUTD-230)**
  - **2 CREE SiC diodes 1200V/5A (TO263) + 2 CREE diodes 600V/4A (TO252)**

Power-One Aurora Micro-0.25-I Main Characteristics	
Input (DC)	• Max power 265W • Max Voltage 65V • Max Current 10.5A
Output (AC)	• Max power 250W @ 65°C • Rated AC Grid Voltage 230V • Max AC Output Current 1,3A • Frequency 50Hz • Utilization : Single phase
CEC efficiency	• 96.5%
Cooling concept	• Natural convection, no fan
Interfaces	• Wireless Communications

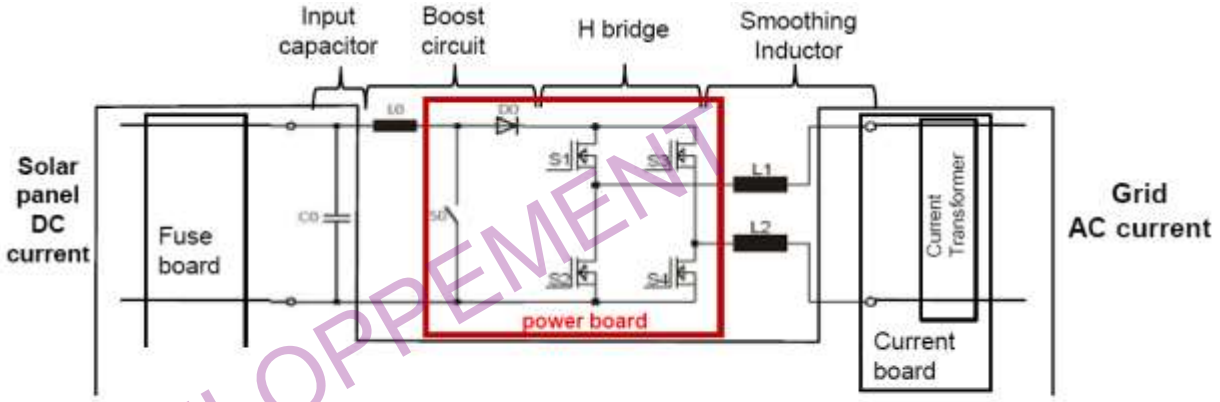
Courtesy of System+ Consulting

CREE Inc.
C3D04060E
DIODE SCHOT 600V 4A
ZREC SiC TO252-2
Marking C3D04060 (x2)

CREE Inc.
C2D05120E
DIODE SCHOT 1200V 5A
ZREC SiC TO263-2
Marking C2D05120 (x2)

Bill of Material comparison Si vs. SiC Hypothesis. Transformer-less topology

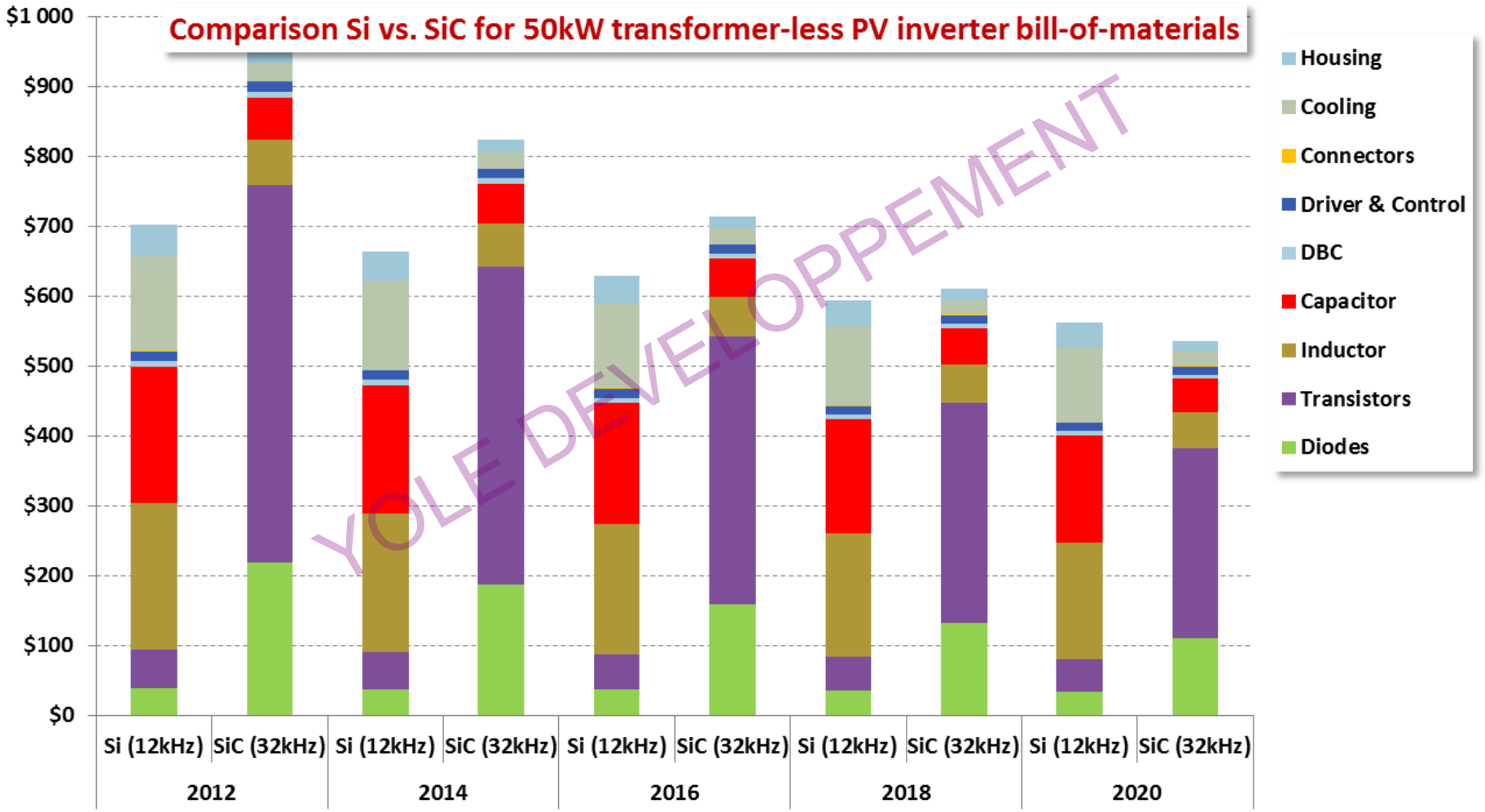
- **5kW PV inverter single-phase**
  - DC-DC boost converter + H-bridge DC-AC Inverter
  - Imax=30A. Vin max=280V
  - Boost converter: 1 diode chip + 1 transistor chips. Each are 600V/50Amp
  - H-bridge Inverter: 4 diode chips + 4 transistor chips. Each are 600V/50Amp
- **20kW PV inverter 3-phase**
  - DC-DC boost converter + 3-leg DC-AC Inverter
  - Imax=35A Vin max=800V
  - DC-DC boost converter : 1 diode chips + 1 transistor chips. Each are 1200V/50Amp
  - 3-leg Inverter: 6 diode chips + 6 transistor chips. Each are 1200V/50Amp
- **50kW PV inverter 3-phase**
  - DC-DC boost converter + 3-leg DC-AC Inverter
  - Imax=90A Vin max=800V
  - DC-DC boost converter : 2 diode chips + 2 transistor chips. Each are 1200V/50Amp
  - 3-leg Inverter: 12 diode chips + 12 transistor chips. Each are 1200V/50Amp



Proposed PV inverter single-phase topology including DC-DC boost converter and 2-leg DC-AC inverter. SMA Sunny-boy model

- Only power conversion parts and transformer are considered. Fuse, interface, screen, logic, buttons, memories, multimedia, final housing are not analyzed here
- BoM is calculated as for an integrator buying components from off-the-shelf at market price
- All component prices, expect power devices, are eroding -3%/year

Bill of Material comparison Si vs. SiC Results for 50kW 3-phase



Payback time estimation

How SiC moves the fundamental economics of a PV inverter

- **When moving from Si to SiC, 3 parameters dramatically change the fundamental economics of a PV inverter:**

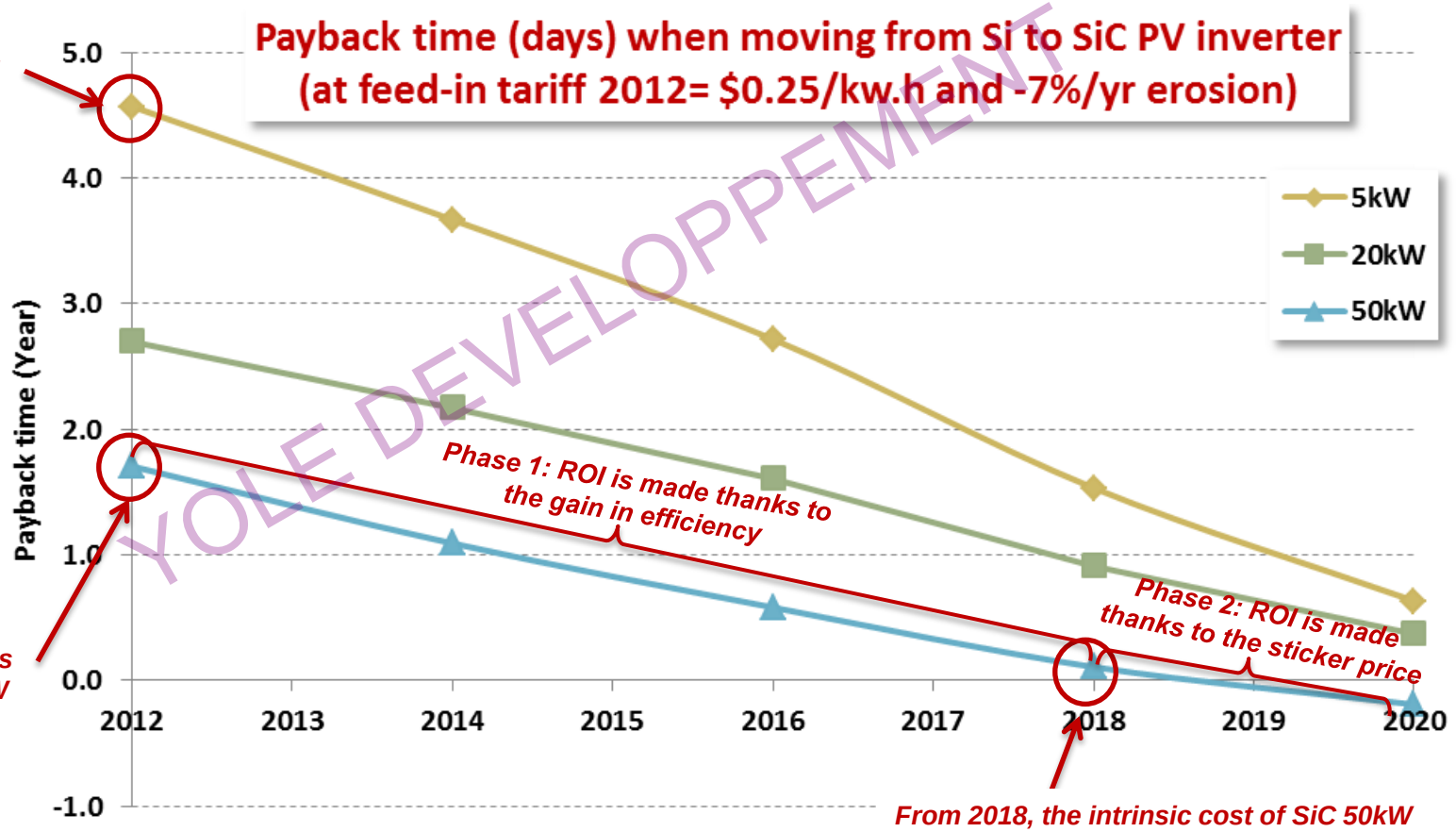
SiC devices (chips) are (and will probably remain) more expensive than Silicon ones. The Bill-of-Material of the power module core will mechanically increase when using SiC

SiC will allow gaining +1.3 points on the European efficiency with a maximum that could reach 96.7% (compared to 95.4% with Silicon). Money will be saved when selling the electricity production at local feed-in tariff

SiC will allow running the inverter at a higher switching frequency (typically 32kHz, instead of 12kHz). Such a high frequency will dramatically decrease the size and so the cost of surrounding passive devices (inductors and capacitors)

Payback time estimation
Overall results

It would take almost 4.5 years to absorb full-SiC 5kW PV inverter extra cost



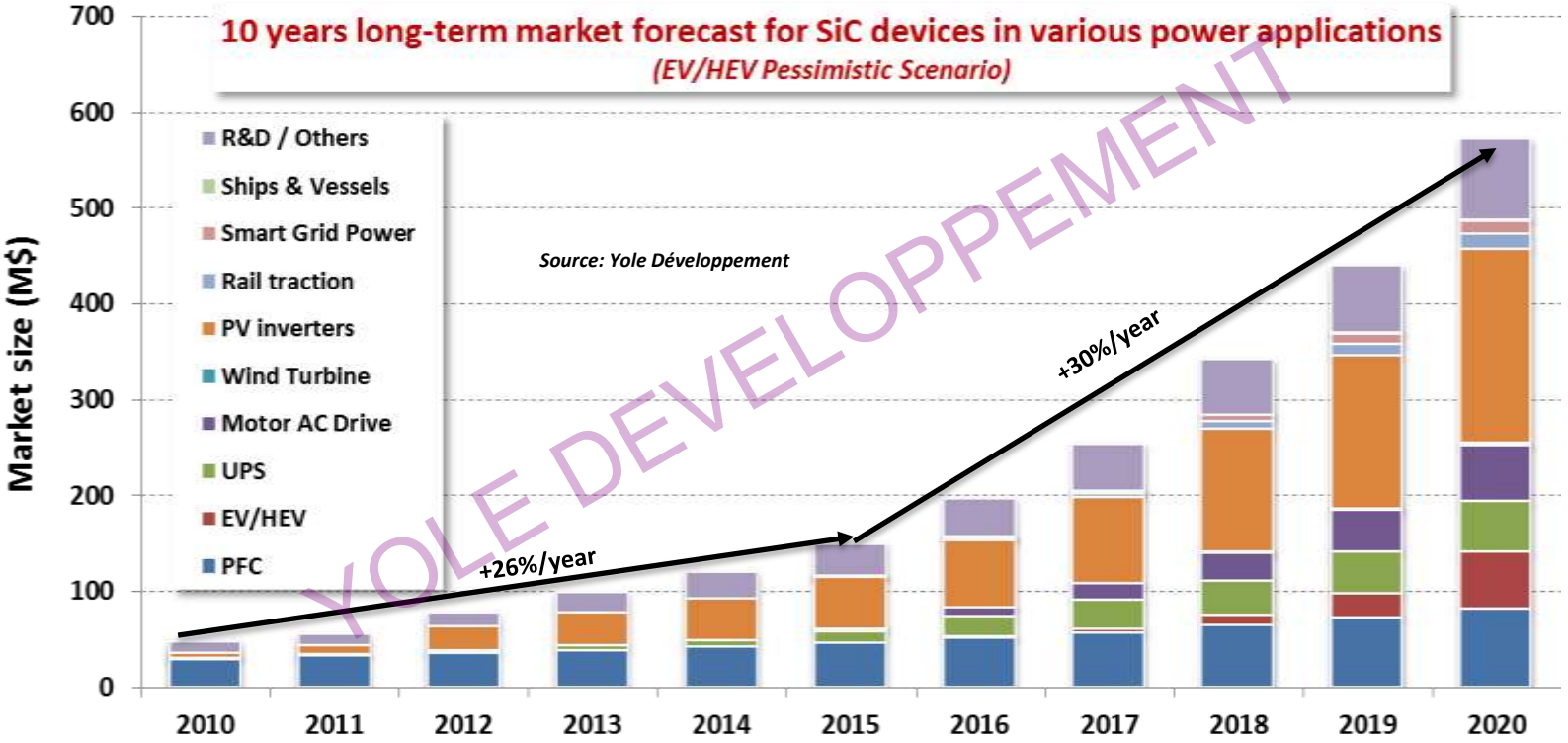
It takes only ~20 months to absorb full-SiC 50 kW PV inverter extra cost

From 2018, the intrinsic cost of SiC 50kW inverter will become cheaper than the silicon version. Whatever the feed-in tariff, SiC solution will be competitive vs. Silicon

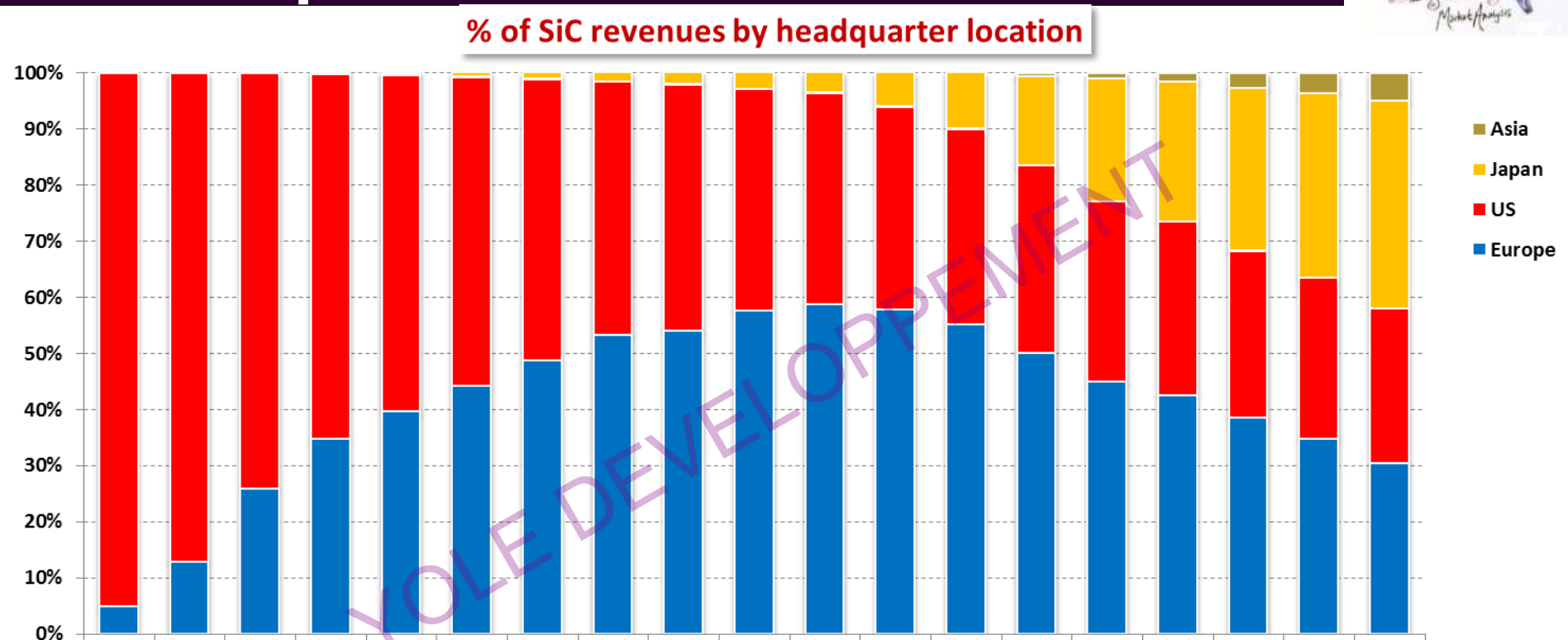
SiC Market Penetration
The 2 scenarios for EV/HEV

- **In order to take into account the uncertainty of the implementation of SiC devices in EV/HEV segment, we have defined 2 scenarios with different market dynamics:**
  - **Nominal scenario: The implementation of SiC devices will start from 2015 followed by a ramp-up of SiC adoption that will take up to 11% shares over Si IGBT by 2020**
  - **Pessimistic scenario: Here the SiC will take off by 2016 with only a slow ramp-up in production to reach only 2.5% of usage by 2020**
- **Another "worst scenario" could have also been defined where SiC is totally excluded from EV/HEV. However, we stay confident that SiC will have a roll to play in EV/HEV before 2020**

10-year Projection of SiC Power Device Market Size (EV pessimistic scenario)



% of SiC revenues by company headquarter location. 2002-2020



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Asia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.9%	1.5%	2.7%	3.5%	5.0%
Japan	0.0%	0.0%	0.0%	0.1%	0.3%	0.7%	1.1%	1.6%	2.0%	2.9%	3.5%	6.0%	10.0%	16.0%	22.0%	25.0%	29.0%	33.0%	37.0%
US	95.0%	87.0%	74.0%	65.0%	60.0%	55.0%	50.0%	45.0%	43.9%	39.1%	37.6%	36.2%	34.8%	33.4%	32.1%	30.9%	29.7%	28.6%	27.5%
Europe	5.0%	13.0%	26.0%	34.9%	39.7%	44.3%	48.9%	53.4%	54.1%	57.4%	58.9%	57.8%	55.2%	50.1%	45.0%	42.6%	38.6%	34.9%	30.5%

CREE domination

Infineon then STMicro ramp-up

Japan to catch-up

Other Asians starting
Japan takes the lead

Conclusions

- SiC is now implemented in several power systems and is gaining momentum and credibility.
- We stay convinced that the most pertinent market for SiC lands in high and very high voltage (> 1.2kV), where applications are less cost-driven and where few incumbent technologies can't compete in performance. This transition is on its way as several device/module makers have already planned such products at short term.
- Thus, even though EV/HEV skips SiC, industry could expand among other apps. Now, the only question remains: Is there enough business to make so many contenders live decently ? Probably yes as green-techs are also expanding fast, strongly requesting SiC. But, any new comers should carefully manage its strategy and properly size its capex according to the market size…

Thank you for your attention !

… and don't miss these 2 events:

- **International SiC Power Electronics Applications Workshop. ISiCPEAW 2013. June 9 to 11, 2013 – Stockholm, Sweden**
- **Focus → The latest results and innovations on the use of SiC technology in power electronics applications.**
- **Format → 3 days event including conferences, exhibition and b2b meetings.**

  In 2012, 200+ attendees.
- **Organized by → The Swedish SiC Power Center, and Yole Développement and Enterprise Europe Network**

- **Yole Développement and Serma Technologies have combined their industry knowledge to create Successful Semiconductor Fabless 2013 (SSF 2013) taking place in Paris, from April 10 - 12. We would like to invite you to join and exchange with industry leaders about today's Fabless business model.**
- **SPEAKERS: Amkor Technology, FEI Europe, GaN Systems, imec, Nanium and poLight … as well as plenty of constructive debates and invaluable networking time.**