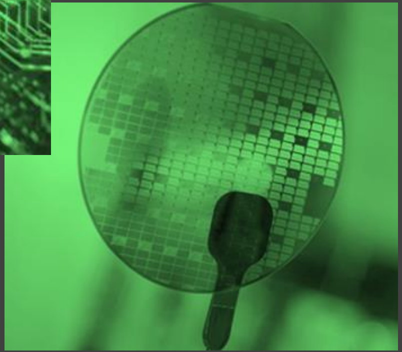


WHERE
TECHNOLOGY
IS AN ATTITUDE

WIDE BAND GAP semiconductors for power electronics applications

Amaia López de Heredia

10th June - 2022

ikerlan

MEMBER OF BASQUE RESEARCH
& TECHNOLOGY ALLIANCE

TABLE OF CONTENTS

WHERE TECHNOLOGY IS AN ATTITUDE

WHERE TECHNOLOGY IS AN ATTITUDE

Private not-for-profit Technological Research Centre

"OUR FINAL GOAL IS TO TRANSFER TECHNOLOGY TO OUR INDUSTRIAL CLIENTS"

ikerlan

MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

OVER 364 PEOPLE — READY FOR PRESENTAND FUTURE TECHNOLOGICAL CHALLENGES

25,4 M€ TOTAL INCOME FOR 2021

- 12,4M€ TRANSFERS TO COMPANIES
- 12,3 M€ IN RESEARCH PROJECTS IN 2021 (DFG, GV, AGE andH2020)
- 0,7 M€ OTHER INCOME

Sectors

32 %	TRANSPORT AND MOBILITY	9 %	AUTOMOTIVE
26 %	MANUFACTURING	1 %	HEALTH
17 %	ENERGY	1 %	AERONAUTICS
14%	SERVICES AND OTHER INDUSTRIES		

1. BASQUE COUNTRY
2. SANTANDER
3. OVIEDO
4. GIRONA
5. BARCELONA
6. VALENCIA
7. SEVILLE
8. SANTIAGO DE COMPOSTELA
9. PARIS
10. BESANÇON
11. GRENOBLE
12. LEUVEN
13. BRUSSELS
14. EDINBURGH
15. AACHEN
16. SIEGEN
17. ZURICH
18. VIENNA
19. LULEÅ
20. AALBORG
21. OLDENBURG
22. USA

"WE COLLABORATE WITH LEADING TECHNOLOGICAL CENTERS AND UNIVERSITIES IN A GLOBAL SCOPE"

WHERE
TECHNOLOGY
IS AN ATTITUDE

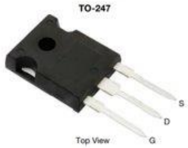
SEABAT project

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 963560.

H2020 (2021-2024)

- **WP4 (component development)**: Design and develop the components for a modular and flexible hybrid battery system towards low cost.
- Design: BMS, DC/DC converter, cooling system, control units, mechanical housing, system protections, etc.
- Currently: early stage of design.
- WP4 Milestone: **May 2023,** all components built.
- Modular topology: **12 modules connected in series to a 1kV DC bus**
- Only two strings in the prototype: **155A/string**
- **Each module**: DC/DC converter of 100V-155A
  - GaN: very high current, a lot of devices in parallel→ very expensive
  - SiC: very low voltage→ not appropriate
  - Si: lower cost, good enough performance → best balanced option

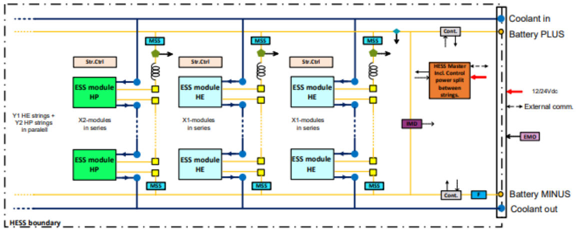
Si MOSFET 200V



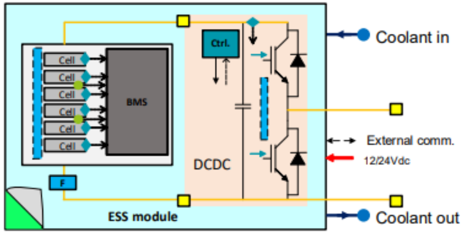
- Low conduction resistance
- Availability
- Cheap

www. seabat-h2020.eu

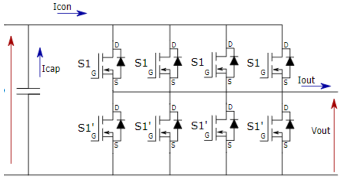
HESS system:



Each module:



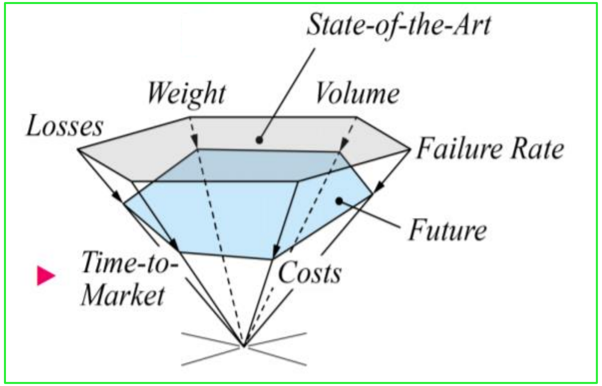
Each DC/DC converter:



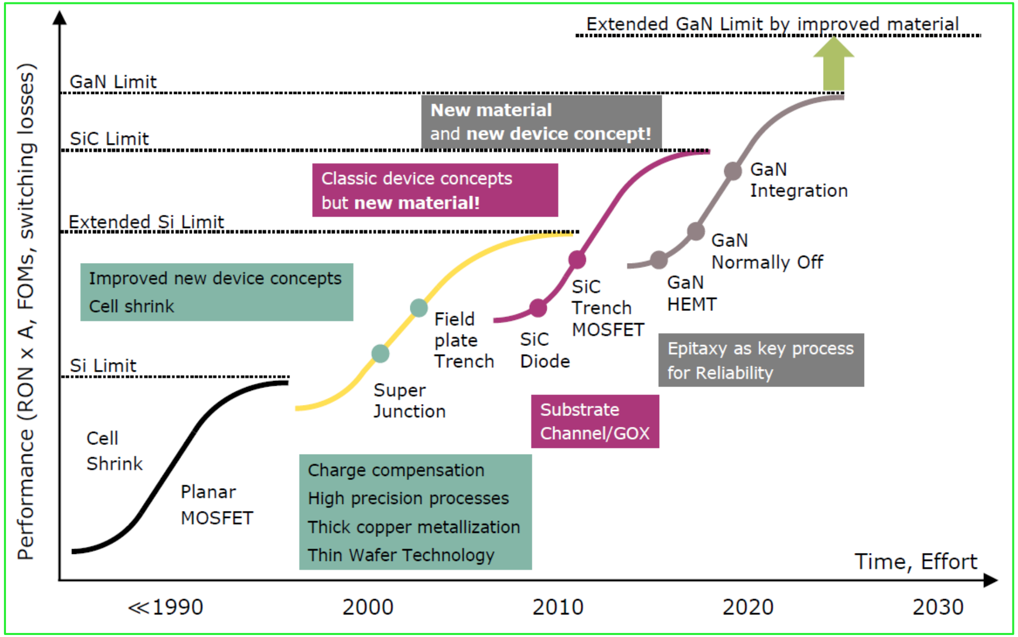
02.
New WBG semiconductors

New WBG semiconductors

CONVERTERS OBJECTIVE



SEMICONDUCTORS EVOLUTION

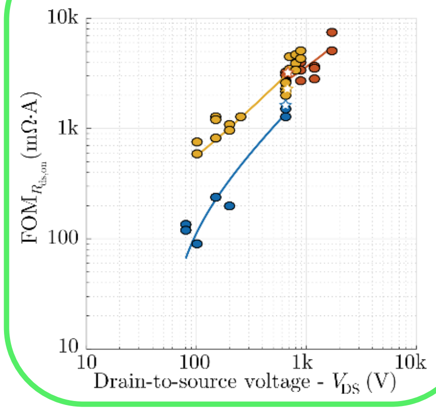


** Sources: O. Häberlen, Technical Challenges to Safeguard the Gallium Nitride Roadmap, Ultimate GaN Kick-off meeting, May 14, 2019*

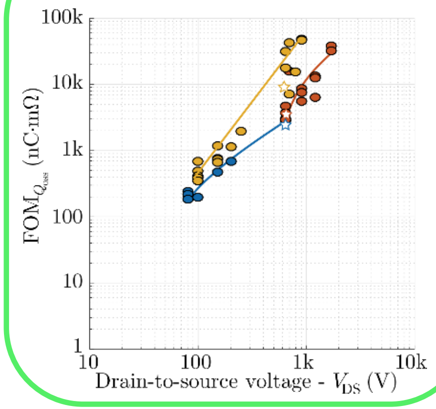
New WBG semiconductors

COMPARISON OF DIFFERENT SEMICONDUCTORS MAIN FEATURES

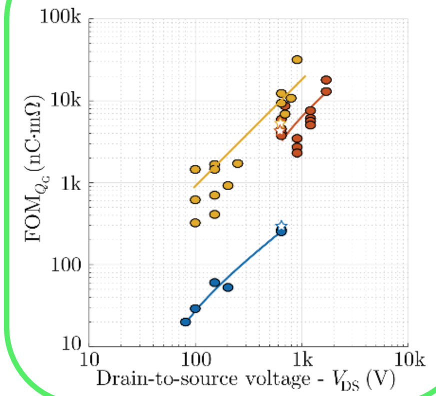
Conduction resistance



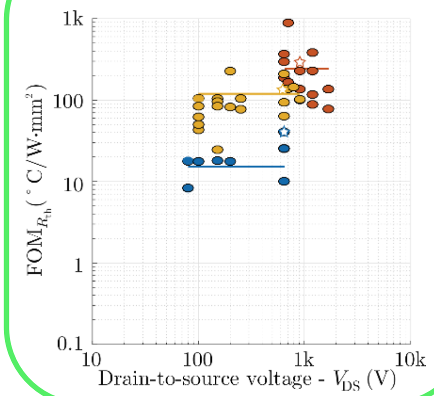
Output charge



Gate charge



Thermal charact.

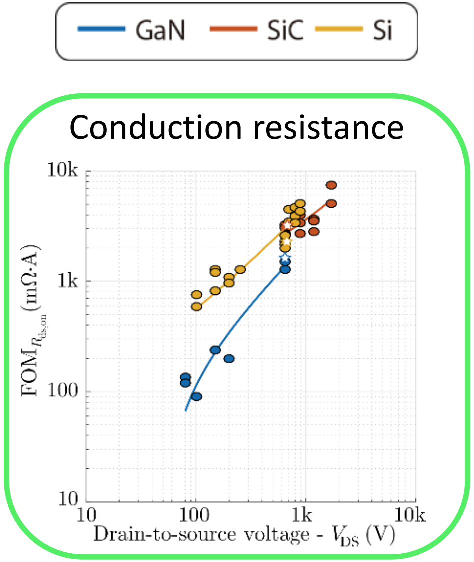


WHERE TECHNOLOGY IS AN ATTITUDE

New WBG semiconductors

ADVANTAGES WITH RESPECT TO Si

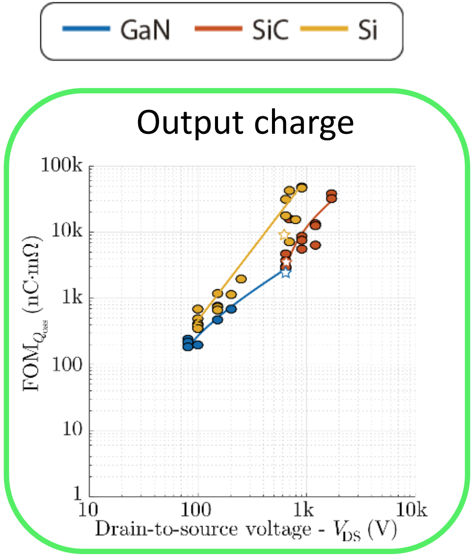
GaN	SiC
Operating voltage < 650 V	Operating voltage > 600 V
Low conduction losses	Similar losses in conduction



New WBG semiconductors

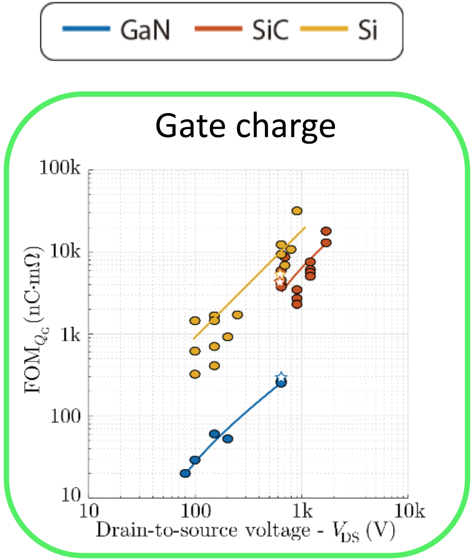
ADVANTAGES WITH RESPECT TO Si

GaN	SiC
Operating voltage < 650 V	Operating voltage > 600 V
Low conduction losses	Similar losses in conduction
Fewer switching losses	Fewer switching losses
It has hardly any reverse coating charges because it is bi-directional	SiC diode has no reverse coating charges



WHERE
TECHNOLOGY
IS AN ATTITUDE

New WBG semiconductors

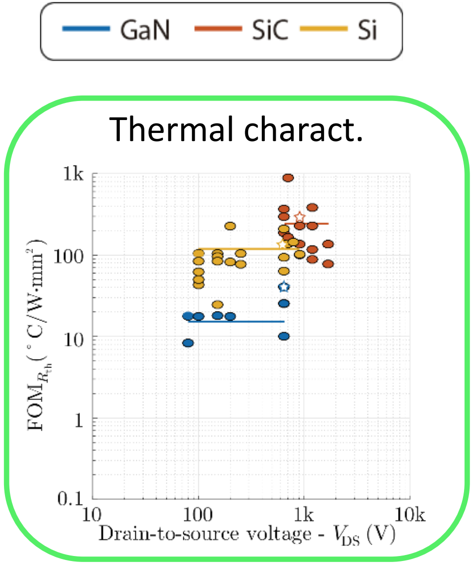


ADVANTAGES WITH RESPECT TO Si

GaN	SiC
Operating voltage < 650 V	Operating voltage > 600 V
Low conduction losses	Similar losses in conduction
Fewer switching losses	Fewer switching losses
It has hardly any reverse recovery charges because it is bi-directional	SiC diode has no reverse recovery charges
Requires very low gate driver charges	Requires lower gate charges

WHERE TECHNOLOGY IS AN ATTITUDE

New WBG semiconductors



ADVANTAGES WITH RESPECT TO Si

GaN	SiC
Operating voltage < 650 V	Operating voltage > 600 V
Low conduction losses	Similar losses in conduction
Fewer switching losses	Fewer switching losses
It has hardly any reverse coating charges because it is bi-directional	SiC diode has no reverse coating charges
Requires very low ignition power	Lower ignition charges
	High thermal cooling capacity

Allows switching at high frequencies with similar losses!

New WBG semiconductors

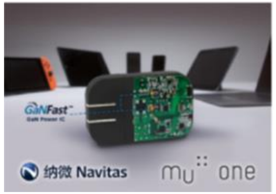
DISADVANTAGES WITH RESPECT TO THE Si

GaN	SiC
Low gate driver voltage- danger of causing false on stages	
Even if it is bidirectional, it has a poor quality diode due to it structure – it is necessary to minimize dead-times to avoid unwanted losses	The SiC-MOSFET has a poor quality intrinsic diode – it is quite common to put an extra antiparallel SiC diode to minimize losses
Less thermal cooling capacity – as the chip is so small, it has very small dissipation area	
Very high switching speed (dv/dt and di/dt) – EMI, degradation insulations, degradation bearings...	
Lack of reliability data - immature technology at application level	In theory better reliability - still to be proven
Cost (x5 relative to a Si-MOSFET 650V-40A). Expectations of a considerable price reduction when dedicated production will be launched for GaN.	Cost (x3 discrete – x10 modules > 1200 V). Downward trend, but will not reach Si prices in the future.

WHERE TECHNOLOGY IS AN ATTITUDE

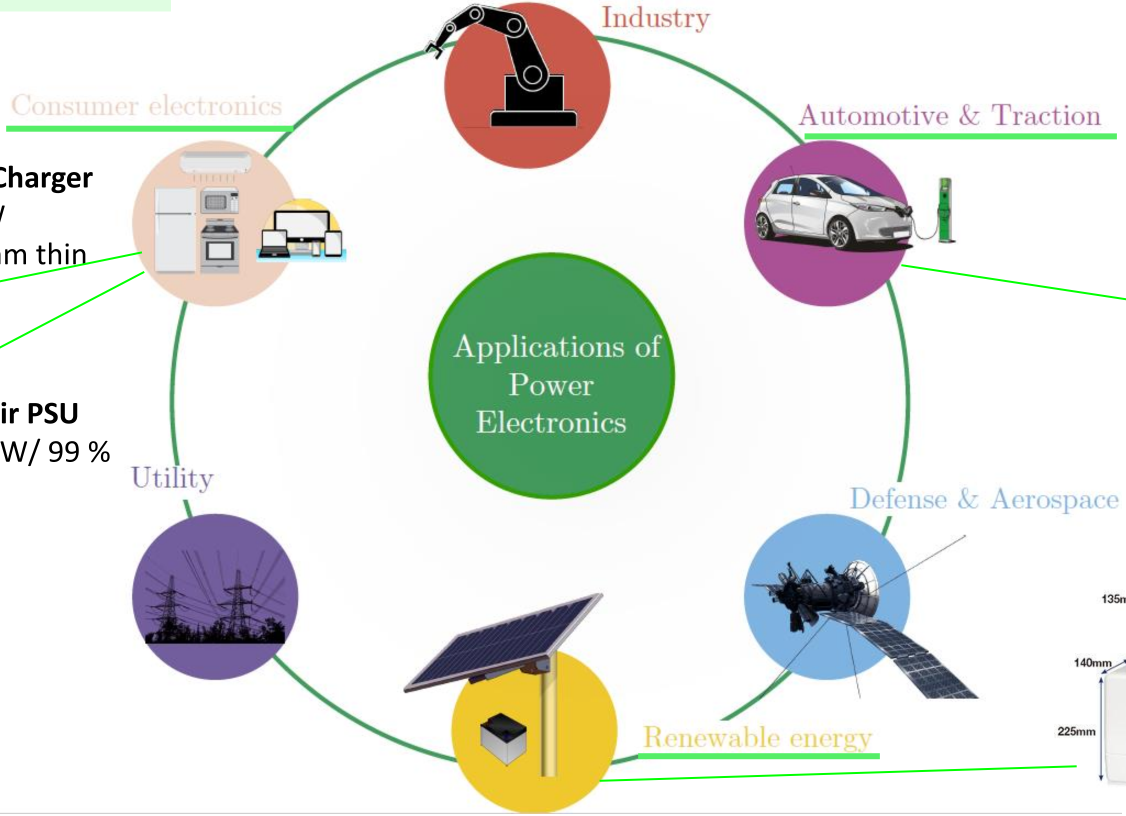
New WBG semiconductors

POTENTIAL GaN APPLICATIONS

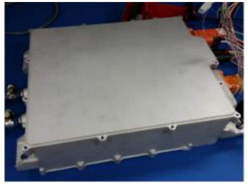


Mu Charger
45 W
14 mm thin

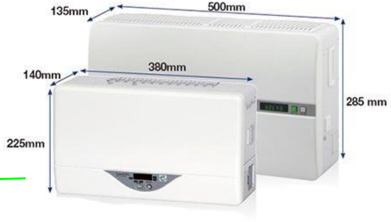
Cosair PSU
1,6 kW/ 99 %



Delta
On-board charger
6,6 kW/ >95 %



Yaskawa
PV Inverter
3 kW/ >95 %



WHERE
TECHNOLOGY
IS AN ATTITUDE

New WBG semiconductors

POTENTIAL SiC APPLICATIONS

Ingeteam
Single-phase inverter
2,5 – 6 kW TLM SERIES

General Electric
2,5 MW
solar inverter

Delta
11k W
solar inverter

Mitsubishi
Automotive inverter

Hitachi
Automotive inverter

Embbeded charger

Mitsubishi
SiC inverter
in e-machine

Toyota
SiC inverter

General Electric
75 kW starter inverter

Kinki Roetgen
Source 500 W for X-Ray generator

Mitsubishi
Traction inverter

ABB
Traction battery charger

Hitachi
Traction inverter

CAF P&A
Traction inverter

IKS Co
100 kV/240 A
Pulse generator

Fuji Electric
Industrial inverter

IKS Co
5 kW/10 kW industrial
induction

General Electric
1 MW substation

03.
Experiences developed at Ikerlan

WHERE
TECHNOLOGY
IS AN ATTITUDE

Experiences developed at IKERLAN

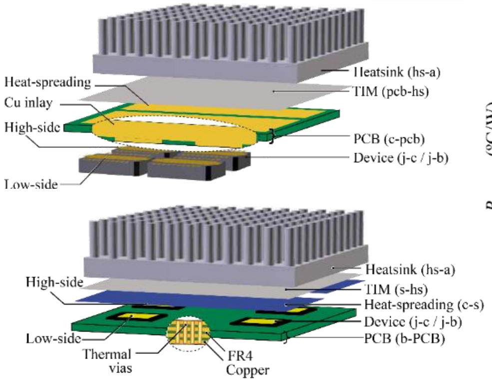
GaN

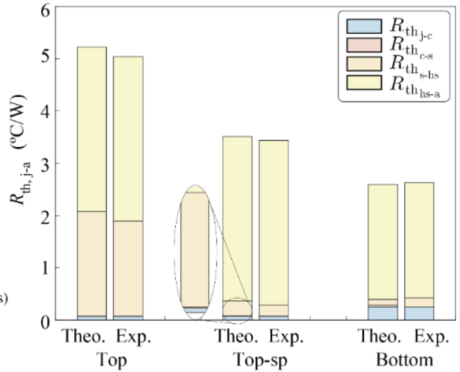
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 662133.

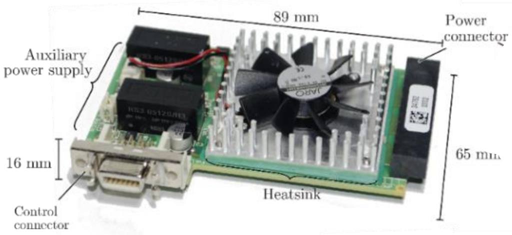
ECSEL/H2020 (2015-2018)

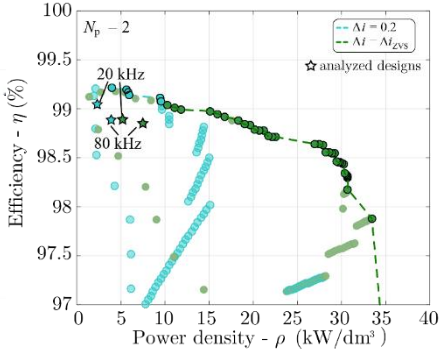
PowerBase

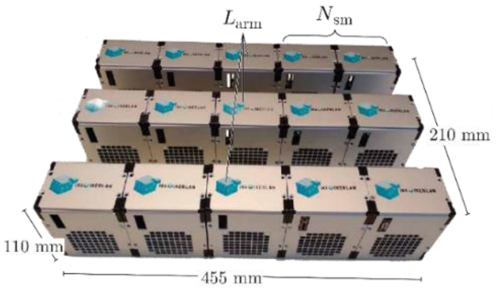
- Evaluating different cooling solutions (Top, Bot)
- 4 kW buck converter and MMC converter
- Soft-switching and hard-switching analysis.
- Single switch and parallel study.
- Efficiencies >99 % at 80 kHz CCM (<10 kW/l).
- Efficiencies >98 % at 300 kHz to DCM (<30 kW/l).



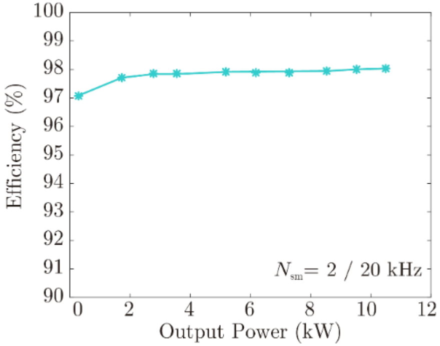








Three-phase MMC



www.powerbase-project.eu

Experiences developed at IKERLAN

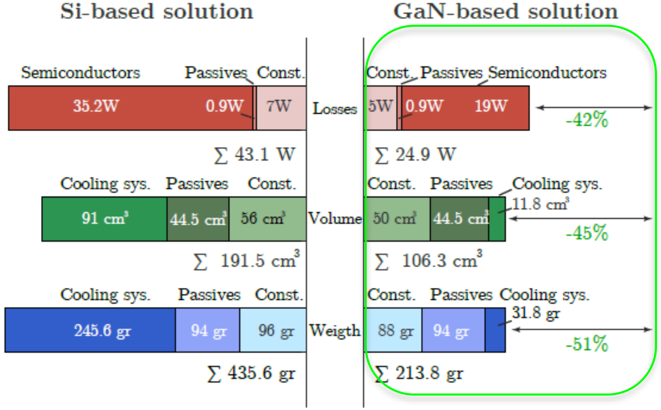
GaN

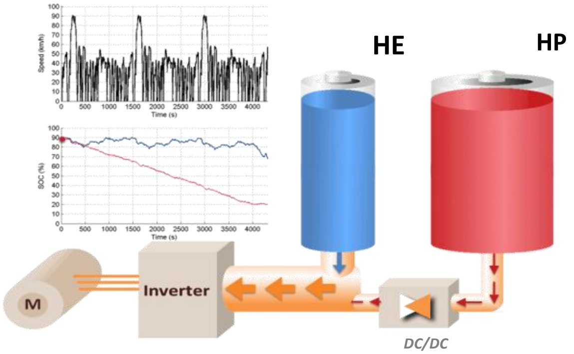
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770019.

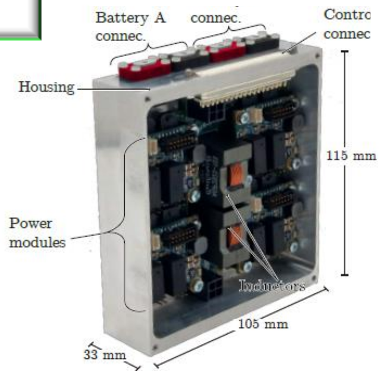
H2020 (2017-2021)

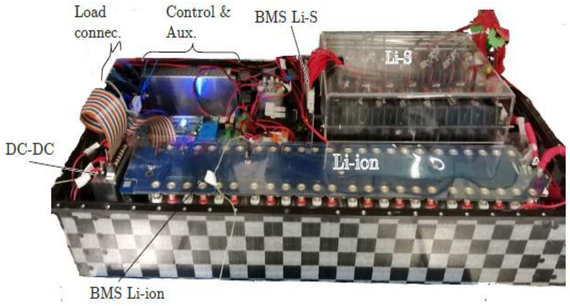
GHOST

- DC-DC converter for hybridization of High Power and High Energy EV batteries.
- 48 V/ 240 W converter.
- Integrated, compact and low weight solution
- Dual Battery system based on Li-ion, Li-S and GaN-based DC-DC:
  - Nominal energy of **1972.9 Wh**
  - **101.90 Wh.kg-1 →** +31.99% with respect to single Li-ion
  - **13.31 Wh.L-1 →** +8.41% with respect to single Li-ion









www.h2020-ghost.eu

WHERE
TECHNOLOGY
IS AN ATTITUDE

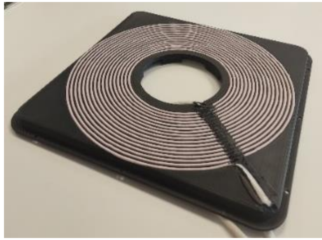
Experiences developed at IKERLAN

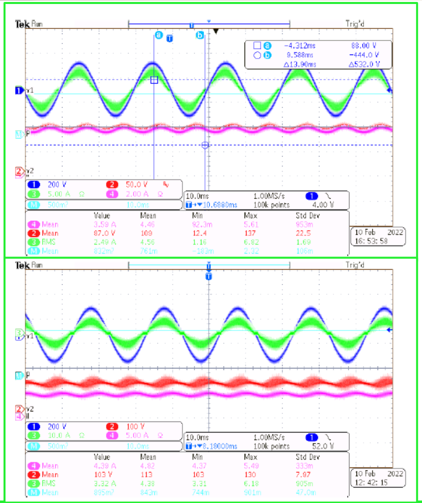
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 826392.

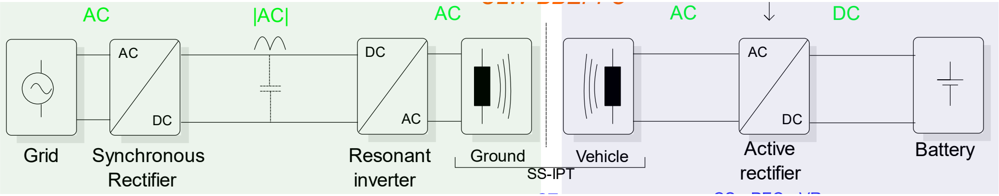
GaN

ECSEL/H2020 (2018-2022)

- Bidirectional domestic 3,6kW Wireless charger
- Low profile design: wallbox and coils in a unique housing.
- Increase the power density using a novel topology).
- 3,6 kW bidirectional charger experimentally validated.
    - Charging distance 100 mm.
    - Switching frequency 85 kHz based on J2954.
    - >96 % efficiency in back-to-back operation.







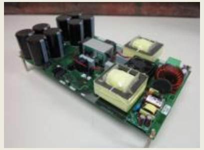
www.ultimategan.eu

Experiences developed at IKERLAN

SiC

2013

Boost PFC 2,5 kW



2014

SiC 1700 V Driver Core

50 kVA Full-SiC inverter

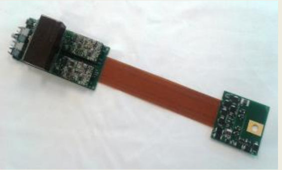
100 kW battery charger

2015

3,2 kW Full-SiC Contactless battery charger

2016

Driver SiC 1700 V



DCDC 225kW traction converter (1,7 kV SiC-hybrid))

2017

225 kW DC/DC traction converter (1,7 kV Full-SiC)

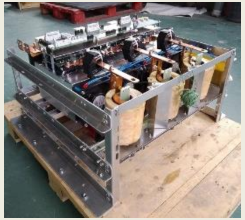
600 kW traction inverter (3,3 kV SiC-hybrid)

Experiences developed at IKERLAN

SiC

2018 SiC-hybrid Installation in Euskotren

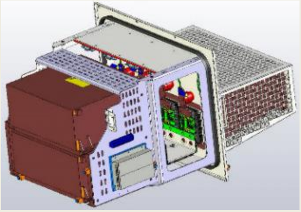
2018 Photovoltaic SiC inverter 167 kVA (1,2 kV full-SiC)



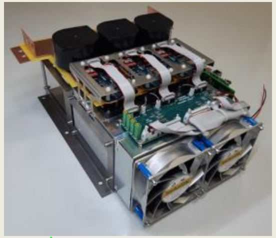
2018 Induction kitchen 7 kW (1,2 kV Full-SiC)

2019 Study of commercial drivers for SiC (PI, Amantys, Isahaya)

2019 Traction inverter core (3,3 kV full-SiC)



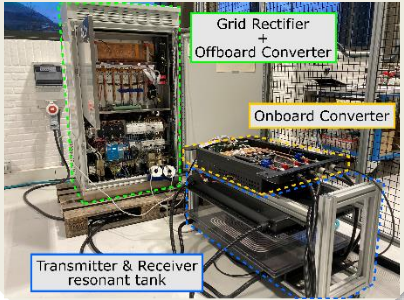
2020 PV SiC 120 kW inverter (1,2k V Full-SiC)



2020 Laboratory tests traction unit 600 kW (3,3kV-Full SiC)

2021 Full-SiC Installation in Euskotren

2021 Bidirectional wireless charger 50 kW (1,2kV-Full SiC)



Experiences developed at IKERLAN

SiC

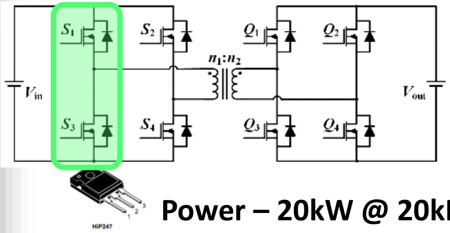
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 783158.

ECSEL/H2020(2018-2023)

- euR*op*EAn siC (Silicon Carbide) eighT Inches pilOt liNe
- 1500 Vdc-690Vac 3 phase 2-leveSiC Inverter.
  - Up to 100kW.
  - Switching frequency 20 kHz.
  - 98% target efficiency.
  - Experimentally validated
- 20 kW isolated DC/DC charger in design phase.

DC

1200-1500V



Power – 20kW @ 20kHz

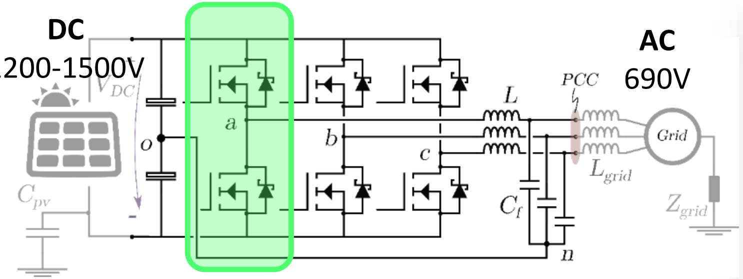
Ad-hoc Module :
2xSCT20N170 in parallel

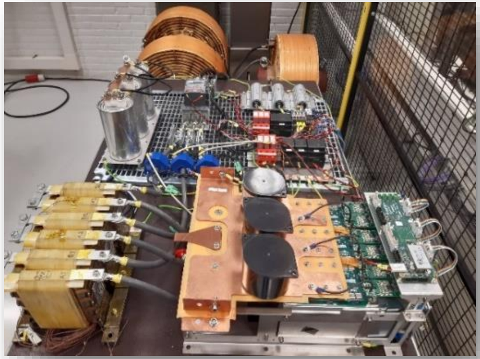
DC

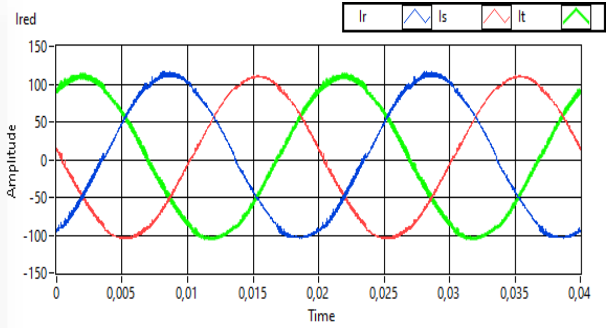
1200-1500V

AC

690V

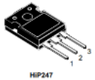






Power – 100kW @ 20kHz

Ad-hoc Module :
4xSCT20N170 in parallel



www.reaction-ecsel.eu

Experiences developed at IKERLAN

SiC

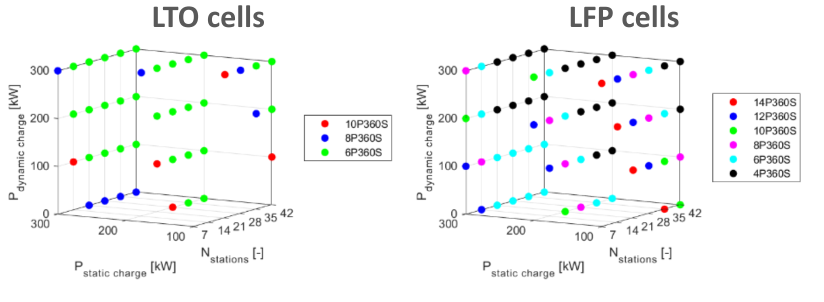
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101015423.

Shift2Rail (2021-2024)

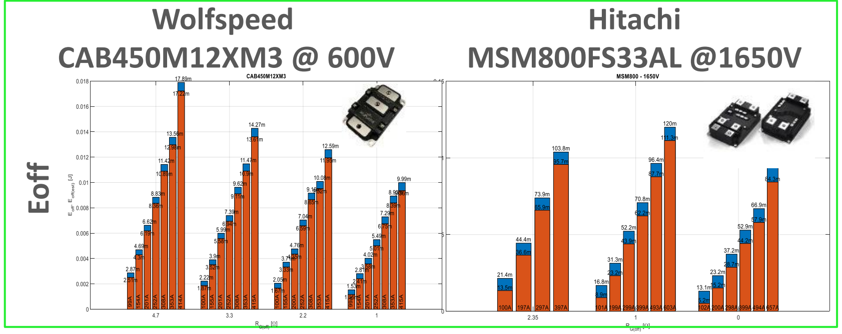
RECET4Rail

- Dynamic Inductive Power Transfer in railway based on SiC power semiconductors.
- Trade-off study of D-IPT and onboard ESU:
  - Comparison of battery technologies.
  - Comparison of charging systems.
- Impact of SiC devices in D-IPT:
  - Characterization of 1200, 1700 and 3300 V SiC power modules in Zero Voltage Switching (ZVS).
- Ongoing: sizing of SiC-based D-IPT system.
  - Higher efficiency
  - Lower size

ESU and charging system sizing results



Estimation of Real-Eoff



www. recet4rail.eu

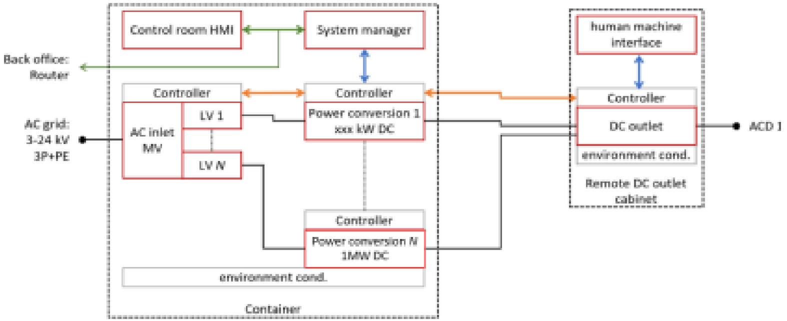
Experiences developed at IKERLAN

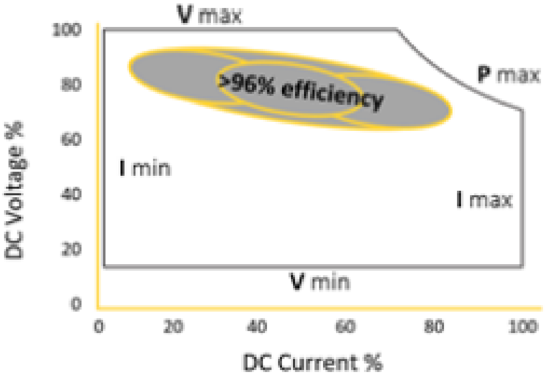
SiC

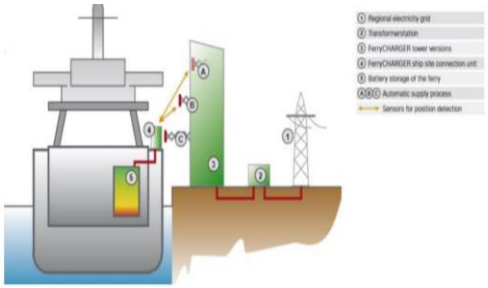
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101056853.

HORIZON EUROPE (2022-2025) **HYPOBATT**

- Fast modular multi-MW charger for maritime application
- Objectives:
  - Improve efficiency by 20%
  - 50% compact charger
  - Reduce charging losses by 50%
  - Reducing operation and maintenance cost by 20%
- Analysis of SiC semiconductors for the charger.
- 2 Prototypes tested for Q2-2025.







Experiences developed at IKERLAN

SiC – EXPERIENCE IN RAILWAY TRACTION

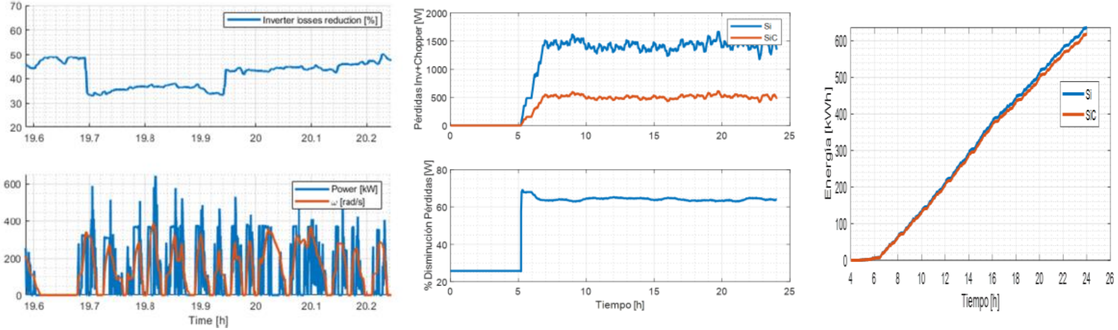
ikerlan | CAF Power & Automation | euskotren

EMU-952 from EUSKOTREN

SiC-hybrid solution

600kW inverter
3,3kV semiconductors
Heat-pipe based cooling

INSTALLATION IN OPERATION	
Installation date	September 2018
Replacement	A single converter per train
Losses reduction	35 % - 50 %
Energy saving	1,4 % - 3 %



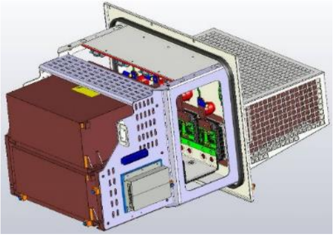
Experiences developed at IKERLAN

SiC – EXPERIENCE IN RAILWAY TRACTION

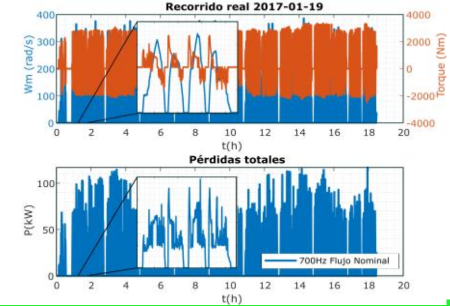
ikerlan | CAF Power & Automation | euskotren

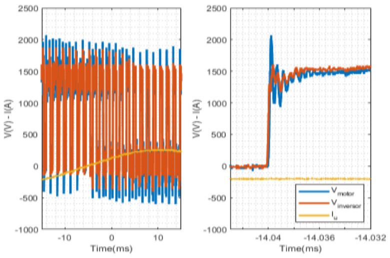
Full-SiC solution

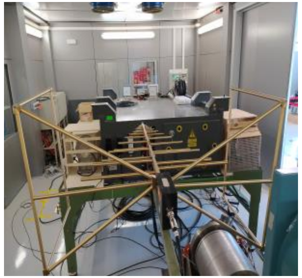
600kW inverter
3,3kV semiconductors
Heat-pipe based cooling



INSTALLATION IN OPERATION	
Installation date	Q2 2021
Volume reduction	-40 %
Weight reduction	-25 %
Losses reduction	65 %
Cost	+220 % (@2020)







04. Conclusions

WHERE
TECHNOLOGY
IS AN ATTITUDE

Conclusions

- **Every WBG semiconductor has its optimal scope of work**
  - GaN -> for low voltages and power, smooth switching and high frequency (>100 kHz)
  - SiC -> for high voltages and hard switching (<200 kHz)
- **WBG technology allows to raise switching frequencies well above what silicon allows**
  - Minimizes the volume and weight of passive components considerably.
  - Minimizes losses significantly in converters (smaller cooling systems).
  - Minimizes acoustic noise to non-audible ranges.
  - Improvements need to be evaluated at System level, not only at converter level.

WHERE
TECHNOLOGY
IS AN ATTITUDE

Conclusions

- **High current SiC product range available <1200V (discrete and modules)**
  - Starting to produce serial devices, but still the price is high.
  - SiC is a promising technology in terms of reliability.
  - GaN can still be considered immature for mass production products.
  - GaN's manufacturing method promises significant price drop.
- **Research should focus on the impact of rapid switching**
  - In the degradation of magnetic components insulation due to high dv/dt.
  - On EMI effects and filters to comply with EMC regulations.

THANK YOU VERY MUCH

IKERLAN
P.º José María Arizmendiarrieta, 2 - 20500 Arrasate-Mondragón
T. +34 943712400 F. +34 943796944

WHERE
TECHNOLOGY
IS AN ATTITUDE

ikerlan
MEMBER OF BASQUE RESEARCH
& TECHNOLOGY ALLIANCE