

Dr. Johan Driesen ◀

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# Power Electronics as the Enabling Technology for Sustainable Energy

TECHNICAL SESSION 5

SREDS19 · DOHA, QATAR · DEC. 2, 2019



# About the Speaker

- Professor KU Leuven, Belgium
- MSc & PhD KU Leuven
- Postdoc at Imperial College (London) & UC Berkeley (US)
- Research topics: power electronics, renewable energy, electrical storage, smart grids, electric vehicles, energy policy
- Programme director international MSc in Energy @ KU Leuven
- Active in EnergyVille research center



# Overview

- From microgrids to smart grids
- Power electronics: a breakthrough technology
- Power electronics for renewables
- The role of batteries
- Rethinking the power system



# Introduction

From microgrids to smart grids

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# Edison vs. Tesla: how "modern" electricity started

## THE CURRENT WAR

THE TALE OF AN EARLY TECH RIVALRY

### DC

**DIRECT CURRENT**

The flow of electricity is in one direction only. The system operates at the same voltage level throughout and is not as efficient for high-voltage, long distance transmission.

Direct current runs through:

- Battery-Powered Devices
- Fuel and Solar Cells
- Light Emitting Diodes

**"(TESLA'S) IDEAS ARE SPLENDID, BUT THEY ARE UTTERLY IMPRACTICAL."**

- THOMAS EDISON

**THOMAS EDISON**

VS.

**NIKOLA TESLA**

You would have never found two geniuses so spiteful of each other beyond turn-of-the-century inventors Nikola Tesla and Thomas Edison. They worked together—and hated each other. Let's compare their life, achievements, and embittered battles.

### AC

**ALTERNATING CURRENT**

Electric charge periodically reverses direction and is transmitted to customers by a transformer that could handle much higher voltages.

Alternating current runs through:

- Car Motors
- Radio Signals
- Appliances

**"IF EDISON HAD A NEEDLE TO FIND IN A HAYSTACK, HE WOULD PROCEED AT ONCE... UNTIL HE FOUND THE OBJECT OF HIS SEARCH. I WAS A SORRY WITNESS OF SUCH DOINGS, KNOWING THAT A LITTLE THEORY AND CALCULATION WOULD HAVE SAVED HIM 90 PERCENT OF HIS LABOR."**

- NIKOLA TESLA

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### FALLING OUT

Edison promised Tesla a generous reward if he could smooth out his direct current system. The young engineer took on the assignment and ended up saving Edison more than \$100,000 (millions of dollars by today's standards). When Tesla asked for his rightful compensation, Edison declined to pay him. Tesla resigned shortly after, and the rival inventor spent the rest of his life campaigning to discredit his counterpart.

**EDISON FRIES AN ELEPHANT**

In order to prove the dangers of Tesla's alternating current, Thomas Edison staged a highly publicized electrocution of the three-ton elephant known as "Topsy." She died instantly after being shocked with a 6,600-volt AC charge.

1847 BORN 1858

Milan, Ohio BIRTHPLACE Smiljan, Croatia

Wizard of Menlo Park NICKNAME Wizard of the West

Home-schooled and self-taught EDUCATION Studied math, physics, and mechanics at The Polytechnic Institute at Graz

Mass communication and business FORTE Electromagnetism and electromechanical engineering

Trial and error METHOD Getting inspired and seeing the invention in his mind in detail before fully constructing it

DC (Direct Current) WAR OF CURRENTS: ELECTRICAL TRANSMISSION IDEA AC (Alternating Current)

Incandescent light bulb; phonograph; cement making technology; motion picture camera; DC motors and electric power NOTABLE INVENTIONS Tesla coil; resonant transformer circuit; radio transmitter; fluorescent light; AC motors and electric power generation system

1,093 NUMBER OF US PATENTS 112

0 NUMBER OF NOBEL PRIZES WON 0

1 NUMBER OF ELEPHANTS ELECTROCUTED 0

1931—Passed away peacefully in his New Jersey home, surrounded by friends and family DEATH 1943—Died lonely and in debt in Room 5327 at the New Yorker Hotel

### WAR OF CURRENTS OFFICIALLY SETTLED

In 2007, Con Edison ended 125 years of direct current electricity service that began when Thomas Edison opened his power station in 1882. It changed to only provide alternating current.

### NOBEL PRIZE CONTROVERSY

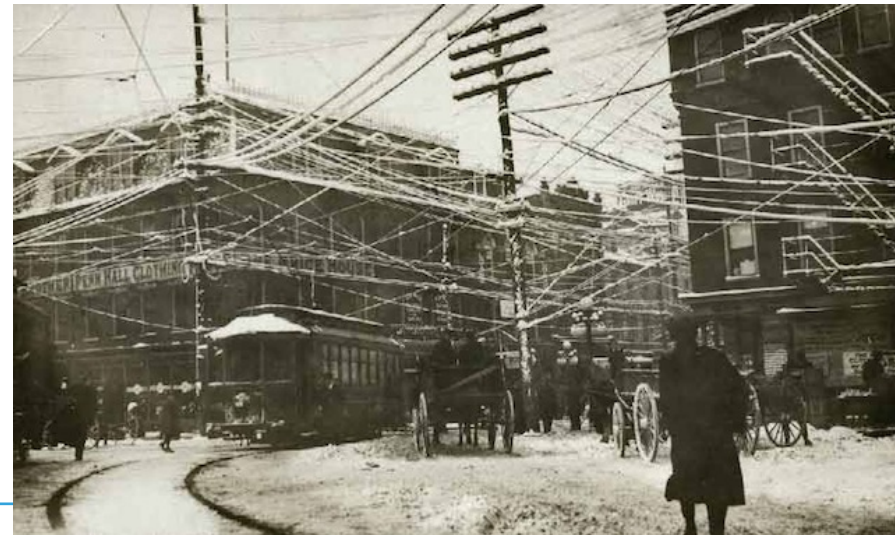
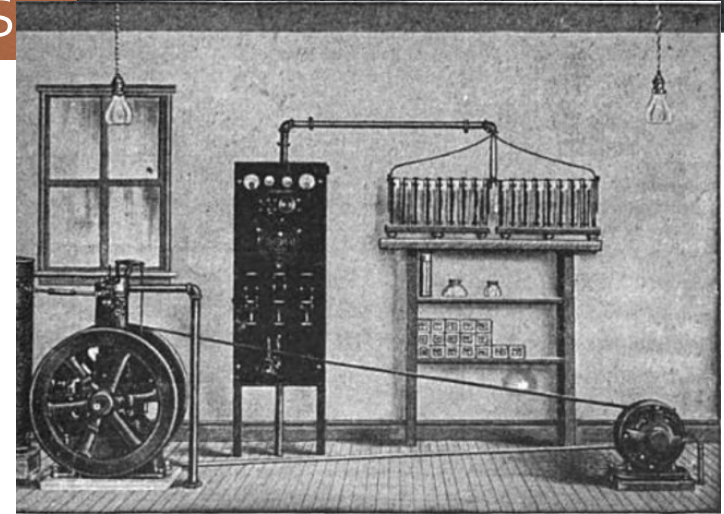
In 1915, both Edison and Tesla were to receive Nobel Prizes for their strides in physics, but ultimately, neither won. It is rumored to have been caused by their animosity towards each other and refusal to share the coveted award.

SOURCES: CHENEY, MARGARET. "TESLA, MAN OUT OF TIME." UPI, ROBERT. "TESLA, MASTER OF LIGHTNING." THOMAS.EDISON.COM | PBS.ORG | HARVARD.EDU | WIKI.ORG

A COLLABORATION BETWEEN GOOD AND COLUMN FIVE

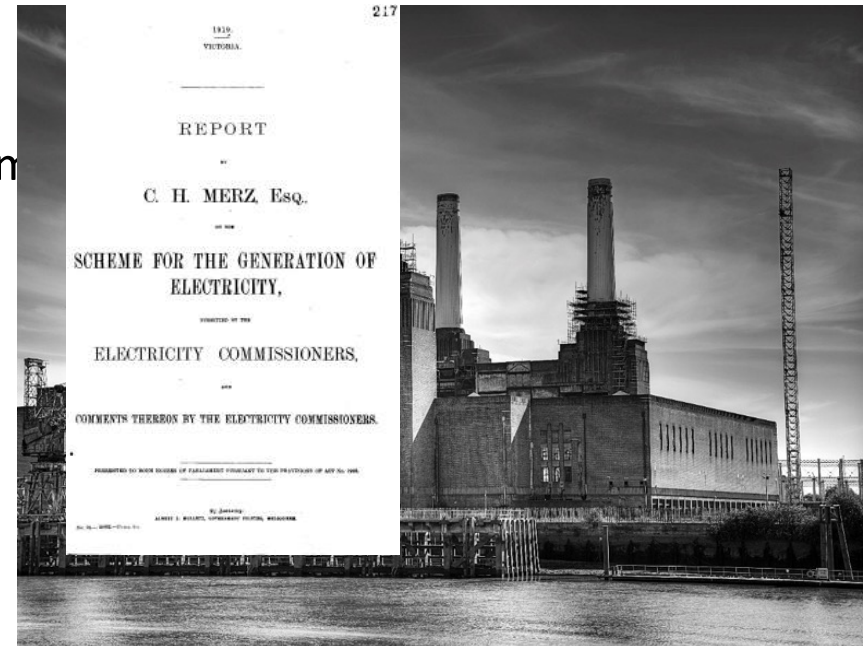
## The first networks = “(DC) microgrids”

- Small isolated autonomous grids
  - Mainly DC technology
  - Local generator + lead-acid batteries
  - Serving lights & drives
  
- Around 1900: more electric cars than combustion vehicles



## Switching to AC power, dominating 20<sup>th</sup> century

- AC power allowed longer distances
- 50/60 Hz became standard
- Electricity:
  - Made the work place safer & healthier (drives)
  - Caused less fires (no candles, gas light)
  - Initiated emancipation of women (electrification of home)
- Central power plants
  - Large hydro
  - Large thermal (coal)
  - Large (industrial) loads
- Large-scale grid interconnection
  - Balancing over larger system
  - Spread reserves



# 21<sup>st</sup> century: Energy Transition

• In



 **20%**  
Reduction in  
GHG emissions<sup>1</sup>

 **20%**  
EU energy from  
renewables

 **20%**  
Improvement in  
energy efficiency


By the year  
**2020**

 **>40%**  
Reduction in  
GHG emissions<sup>1</sup>

 **>27%**  
EU energy from  
renewables

 **27%**  
Improvement in  
energy efficiency

By the year  
**2030**

 **60%**  
Reduction in GHG  
emissions<sup>1</sup> by 2040



 **80-95%**  
Reduction in GHG emissions<sup>1</sup>  
by 2050 (all sectors contribute)

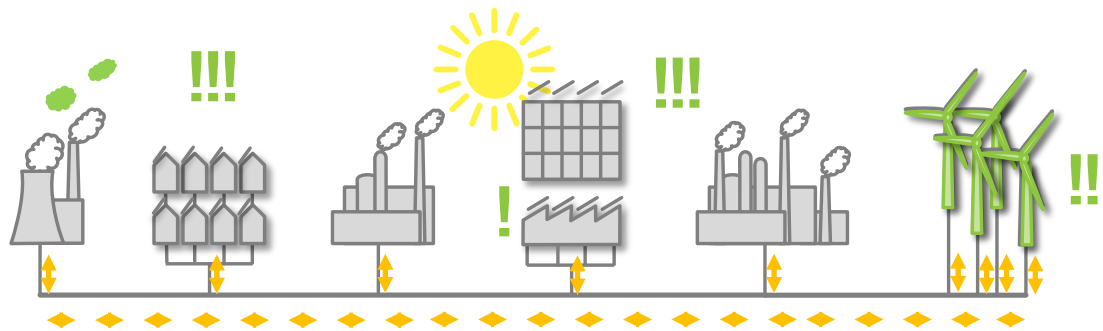
**2050**  
Low-carbon  
economy

<sup>1</sup> Greenhouse gas emission reduction targets from 1990 levels

• The rest of the world...

- Still 840 Million people without power
- China: transition towards less pollution
- US: transition thanks to (fracking) gas and cheap renewables
- Local renewables cheapest source for developing nations

# Challenges for the electricity system

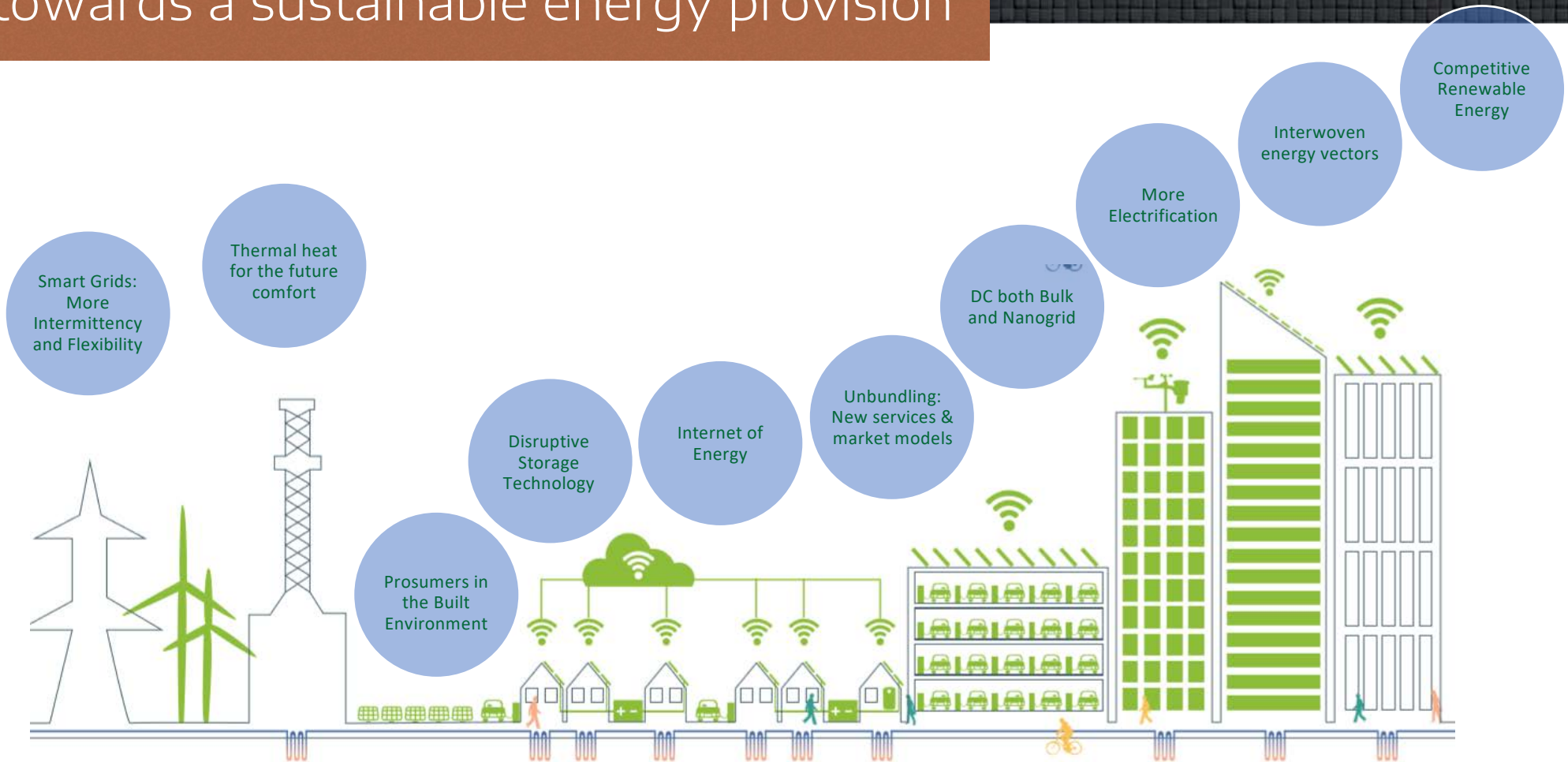


- Demand drives generation ↔ Generation drives demand
- Bidirectional flows
- Techno-economical puzzle:  
coordinated grid actions with all the players involved

From a classic model...



# ...towards a sustainable energy provision



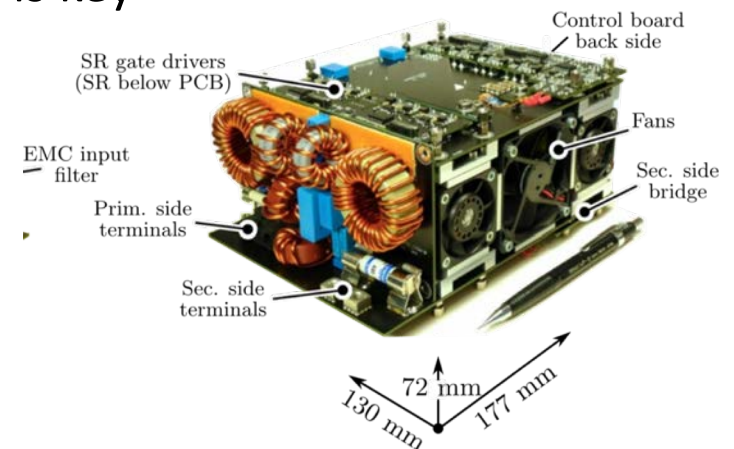
# Power electronics

breakthrough technology

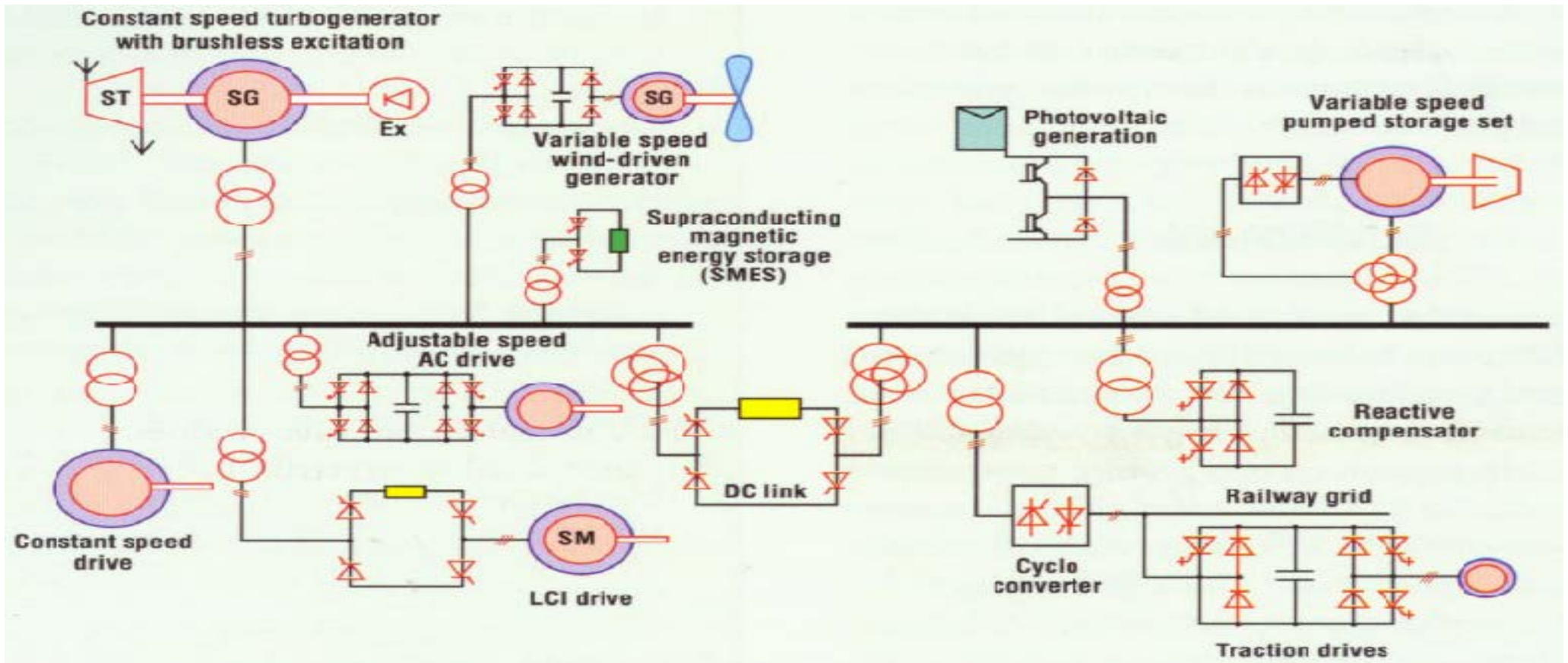
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# Power electronics definition

- Power electronics (PE) is used to convert **electrical energy** to an alternative form
  - Different voltage, current, # phases, frequency
- Comparison with ICT
  - In ICT-electronics voltage, current and frequency is used to transfer information
  - in power electronics energy is converted, so **efficiency** is key
- Circuits
  - analogue in principle
  - the energy often gets 'digitally modulated'
  - EMC problems

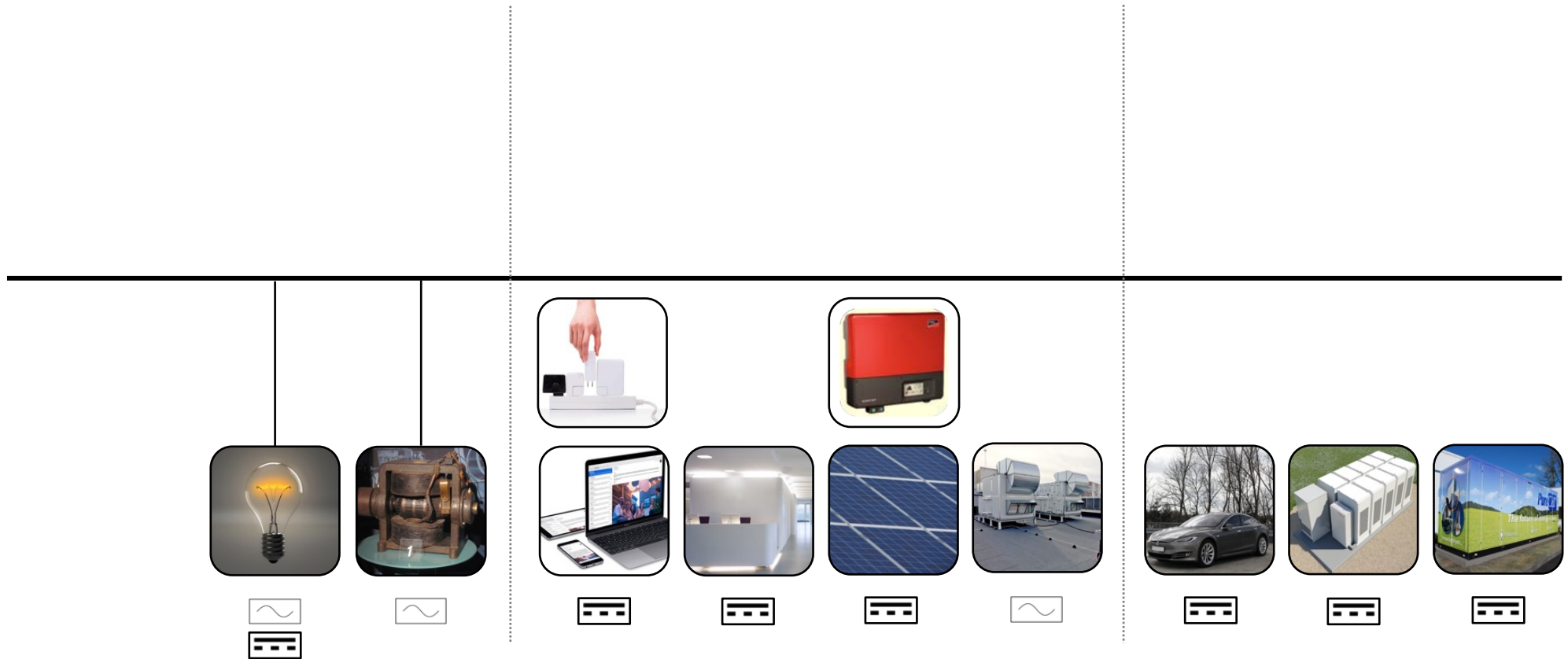


# (current) power electronic dominated grids

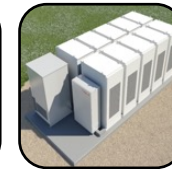
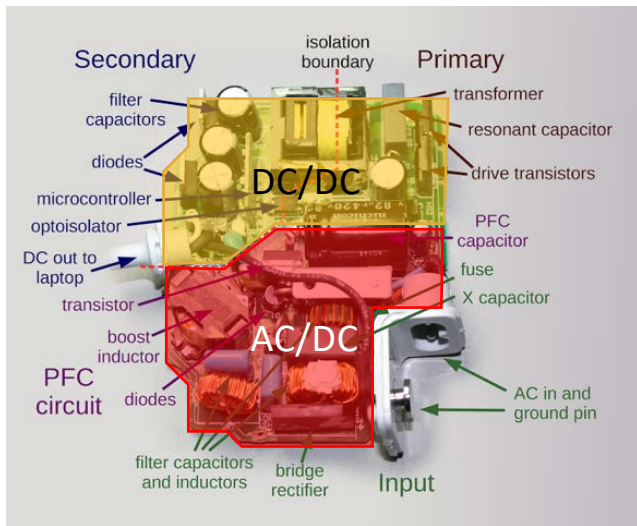


Source: KEMA

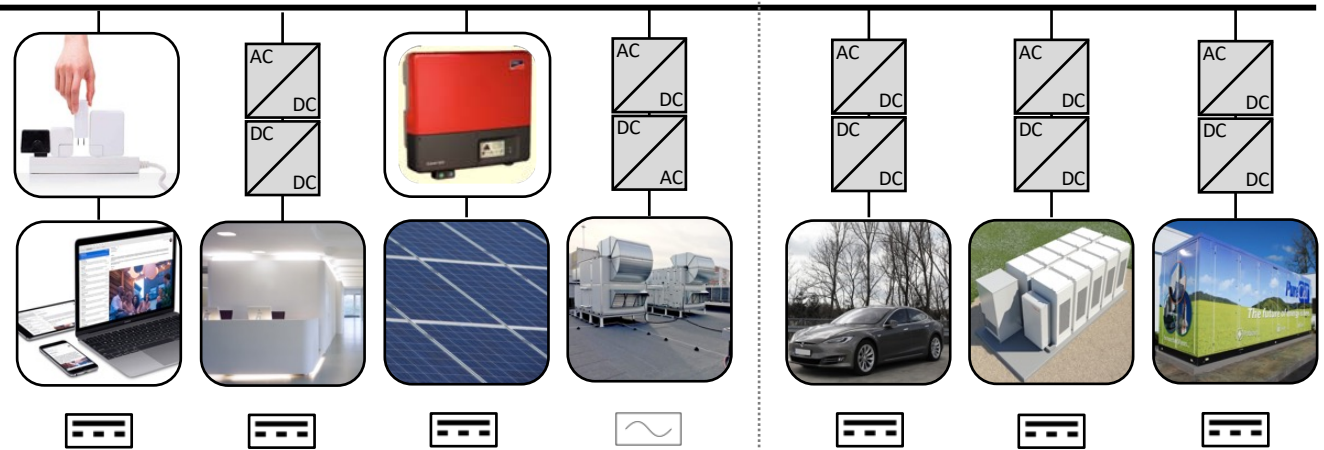
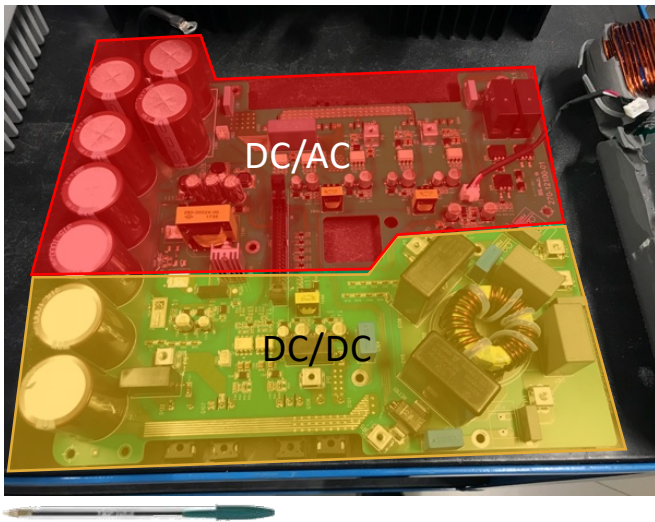
# Omnipresent power converters



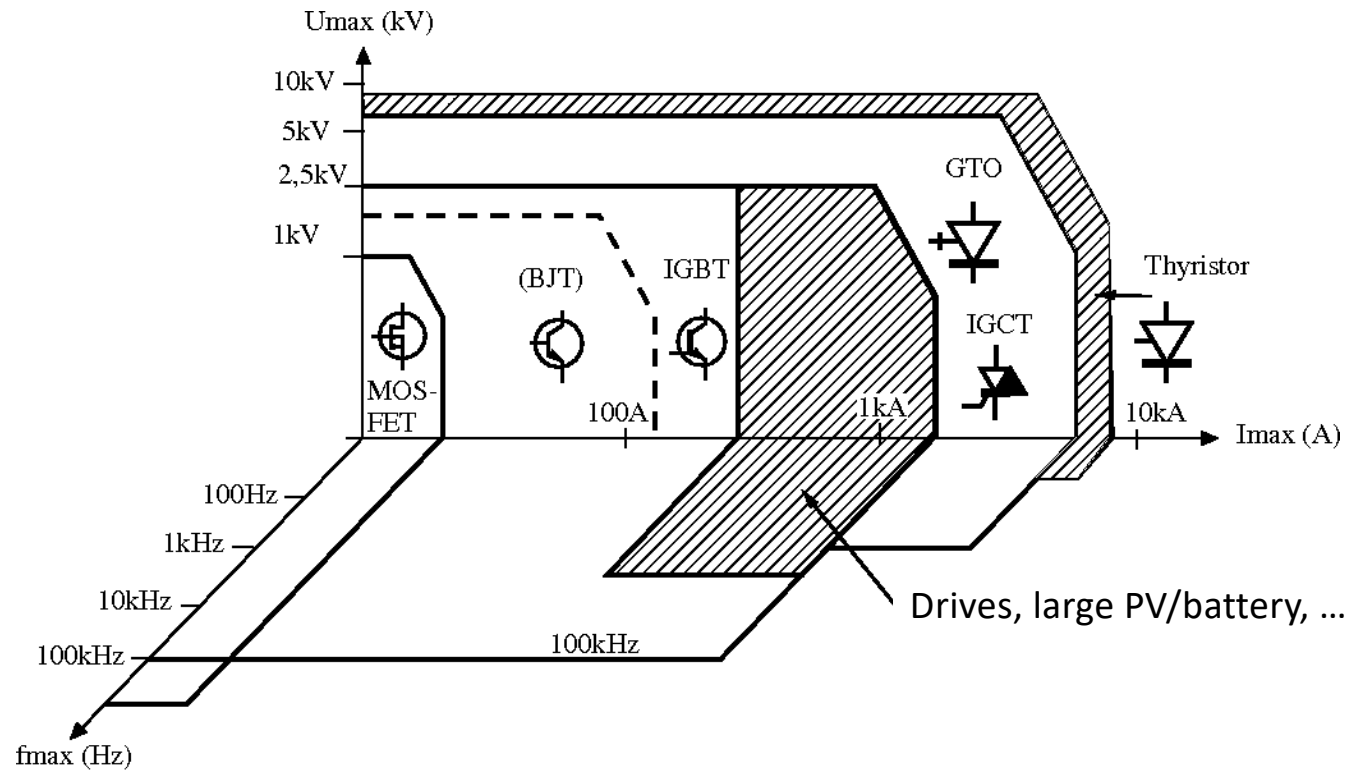
# AC/DC power supplies



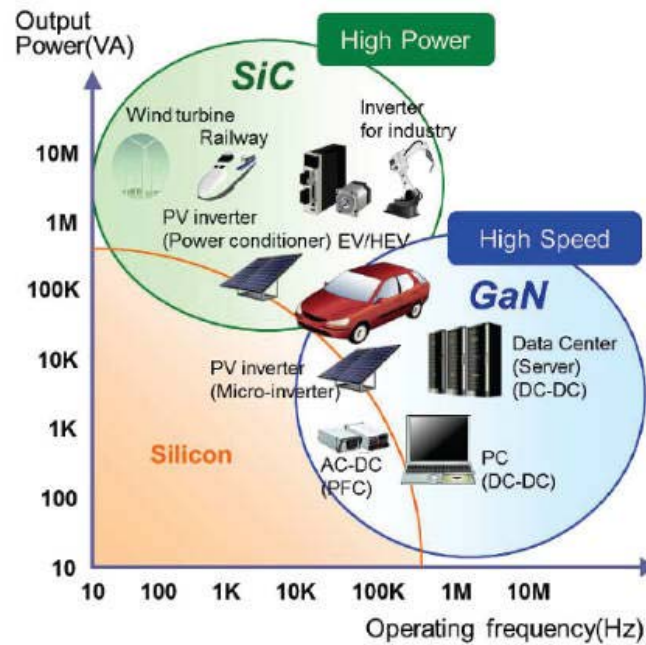
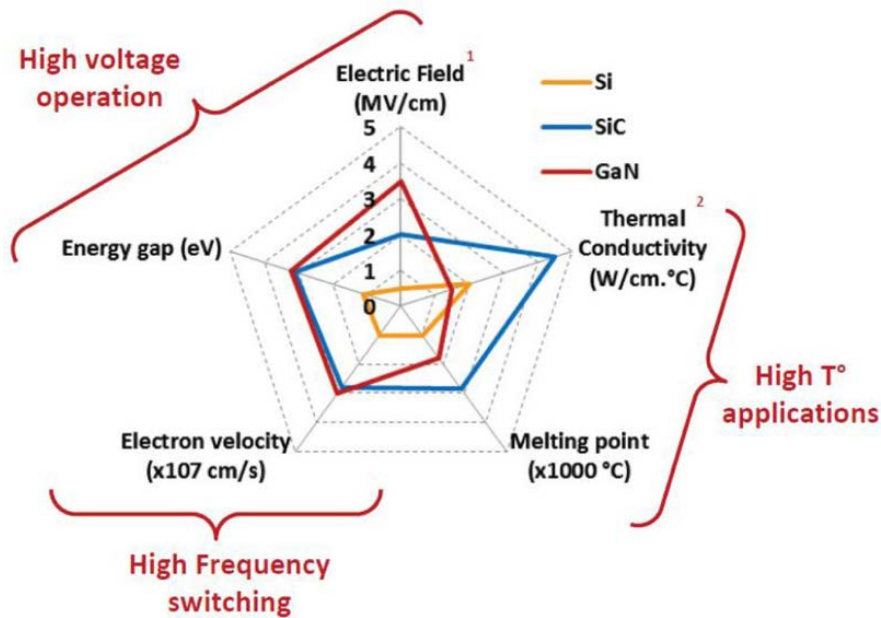
# DC/AC Photovoltaic Converters



# Currently available PE components



# What "new" semiconductor material fits best?

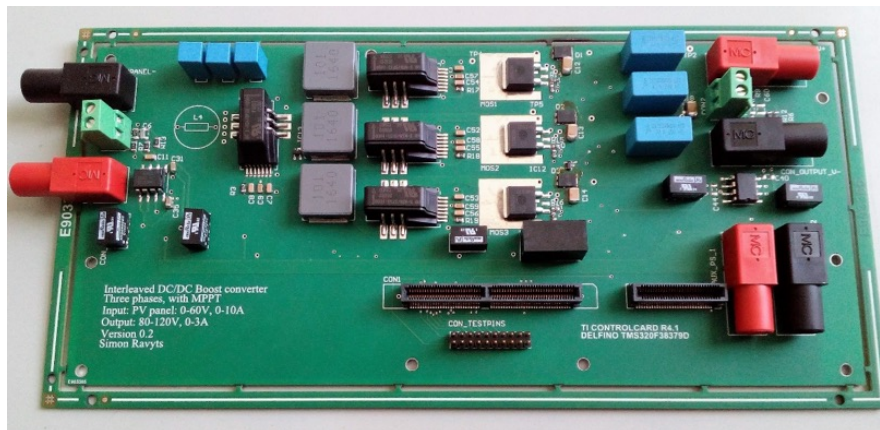


**SiC for high power voltages (>1kV) with high current = niche market**

**GaN on Si for high frequency at midrange voltages (<1kV, up to 100A) = mass market**

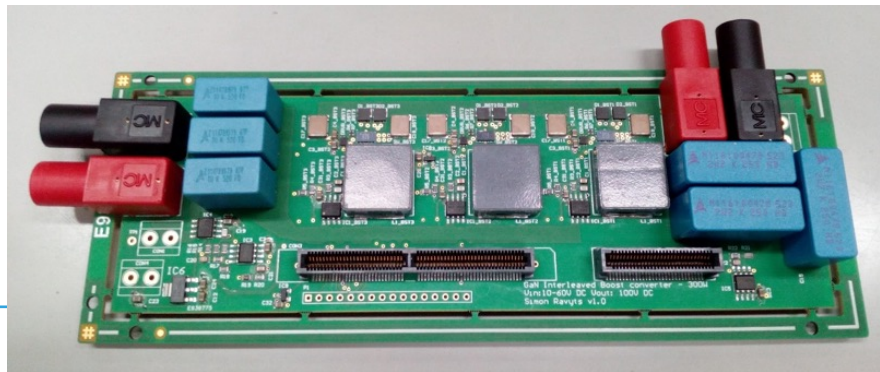
# Comparison of Si vs. GaN

- Two PCB prototypes of PV power optimizer
  - (a) employs Si MOSFETs
  - (b) employs GaN HEMTs and is three times more compact



(a)

115x250x30 mm<sup>3</sup>



(b)

55x175x30 mm<sup>3</sup>

Board	Si MOSFET	GaN HEMT
Switching frequency	100 kHz	200 kHz
Switch	Infineon IPB320N20N3	EPC 2047
$V_{ds,max}$	200 V	200 V
$I_{d,max}$	34 A	32 A
$R_{ds,on,max}$	32 m $\Omega$	10 m $\Omega$
$Q_{g,tot,max}$	29 nC	10,2 nC
$C_{oss}$	180 pF	585 pF
Footprint	10,7x16,05 mm <sup>2</sup>	4,6x1,6 mm <sup>2</sup>
Diode	VS-10CSH02HM3	VS-10CSH02HM3
$V_{R,max}$	200 V	200 V
$V_F$	0,75 V	0,75 V
$Q_{rr}$	53 nC	53 nC
Footprint	6,8x4,8 mm <sup>2</sup>	6,8x4,8 mm <sup>2</sup>
Inductor	BOURNS SRP1770TA	BOURNS SRP1770TA
Inductance	100 $\mu$ H	68 $\mu$ H
$R_{L,DC,max}$	118 m $\Omega$	80 m $\Omega$
Footprint	18,5x12,5 mm <sup>2</sup>	18,5x12,5 mm <sup>2</sup>
Driver	Silicon Labs Si8272	Texas Instruments UCC27611

# Integrated (GaN) components

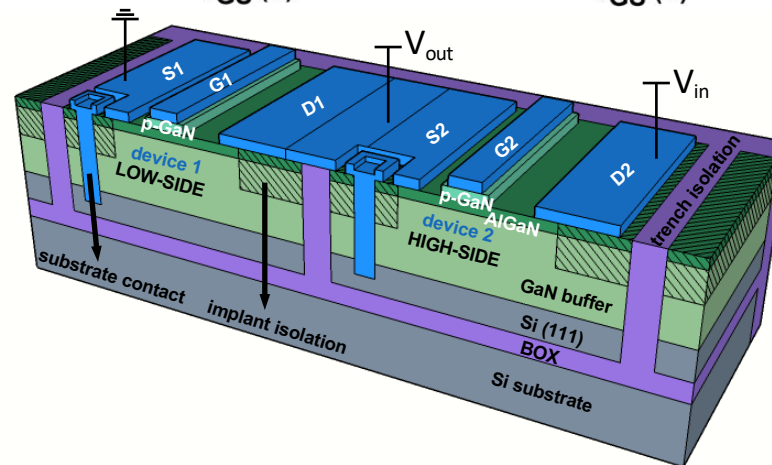
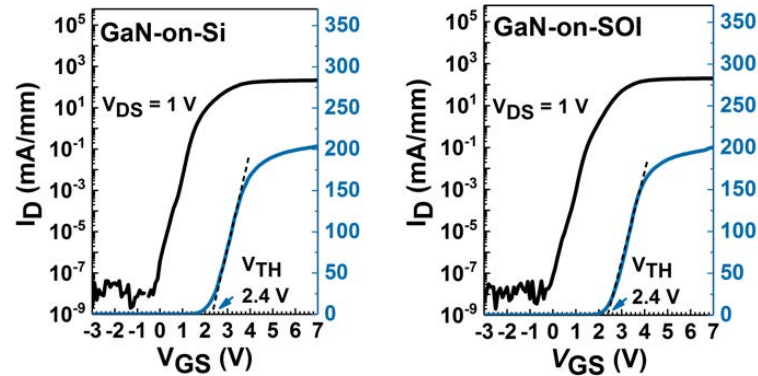
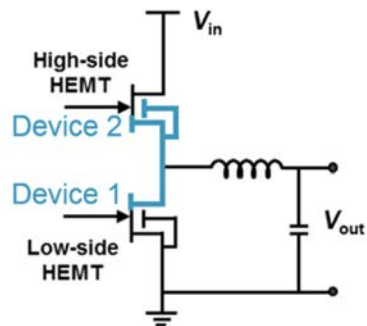
## GaN IC (imec)

### GaN IC : GaN-on-SOI for monolithic integration

- Half-bridge
- GaN driver
- Schottky diodes

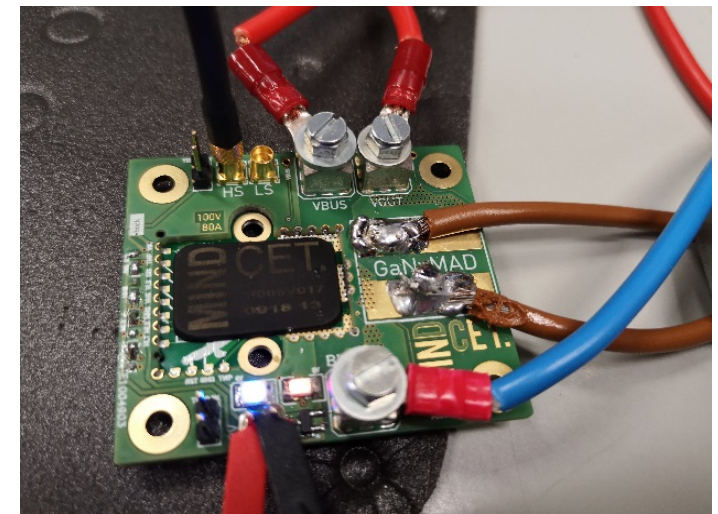
Isolation of common Si substrate by :

- Buried oxide
- Deep trench isolation
- Deep substrate contact



## • GaNyMaD PoL Module

- 300 kHz
- Peak eff = 95,2%
- 48V to 12V

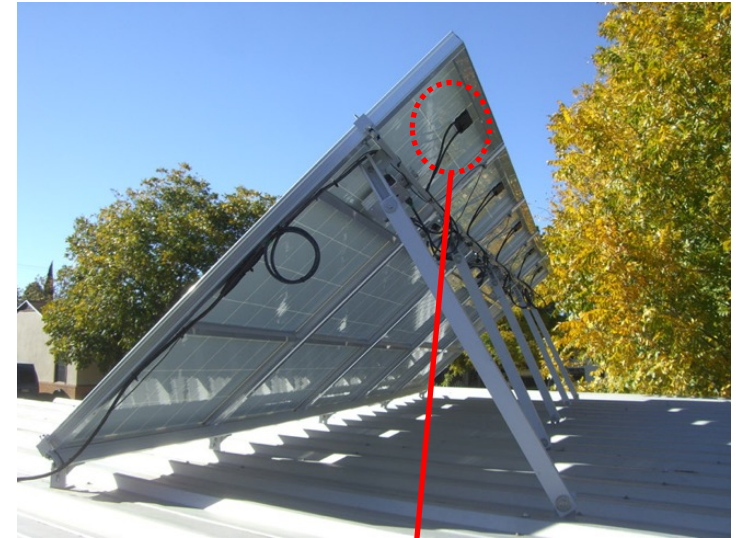


# Power electronics for renewables

New trends in photovoltaics

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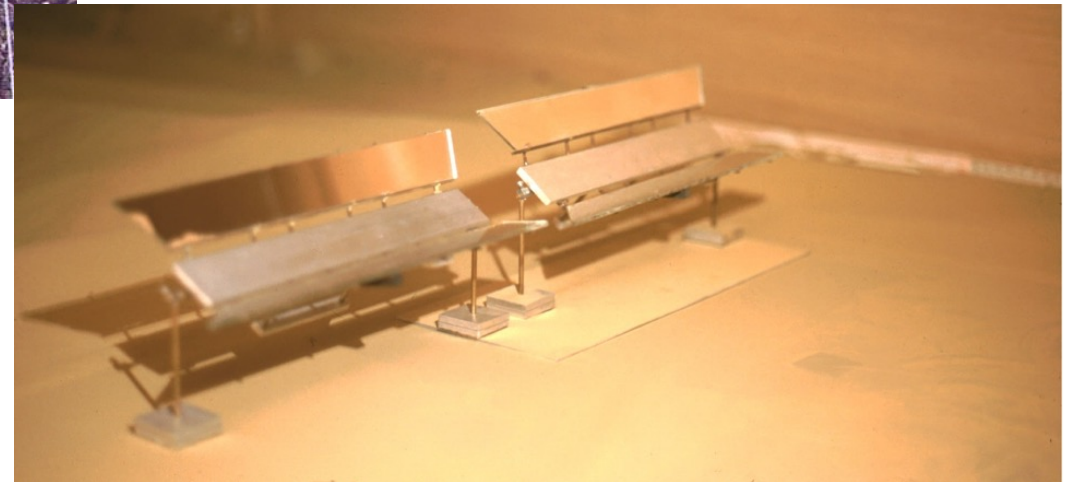
# Solar farms



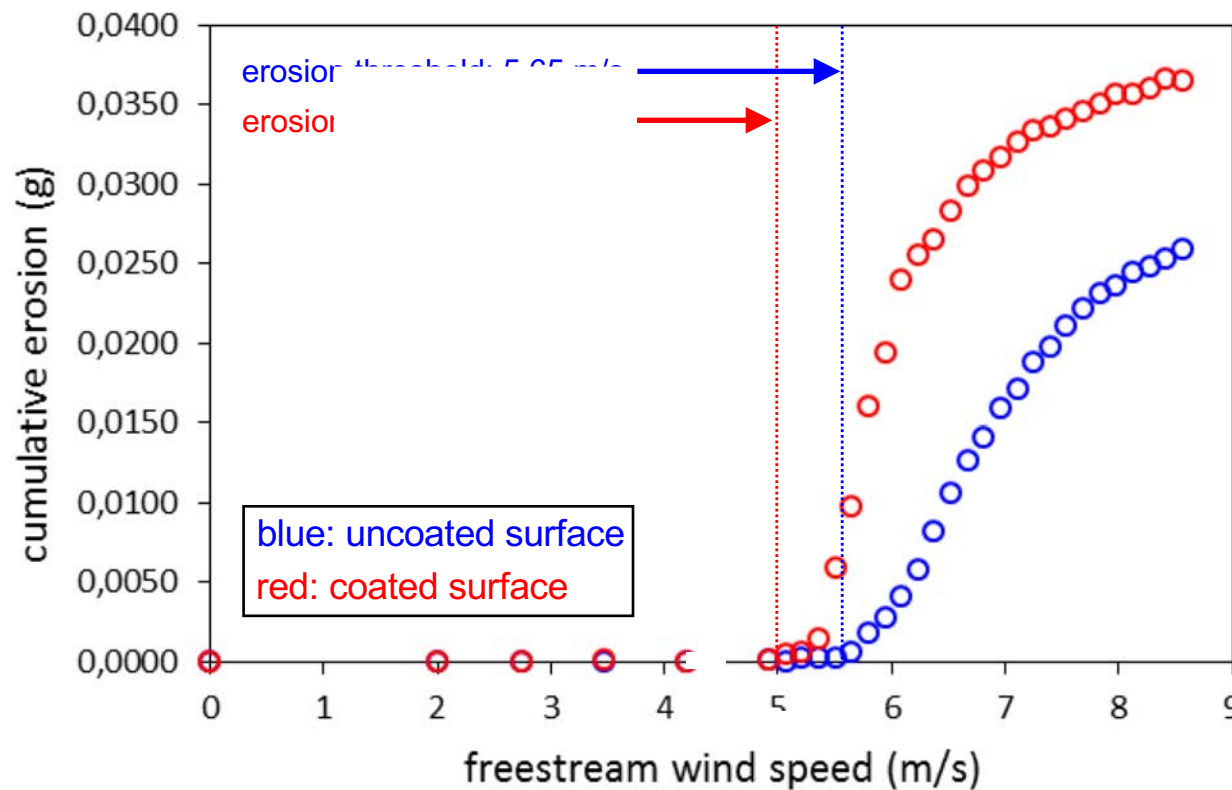
# Dust in PV systems?



Wind tunnel testing at KU Leuven



# Effect of an anti-soiling coating on dust erosion ?

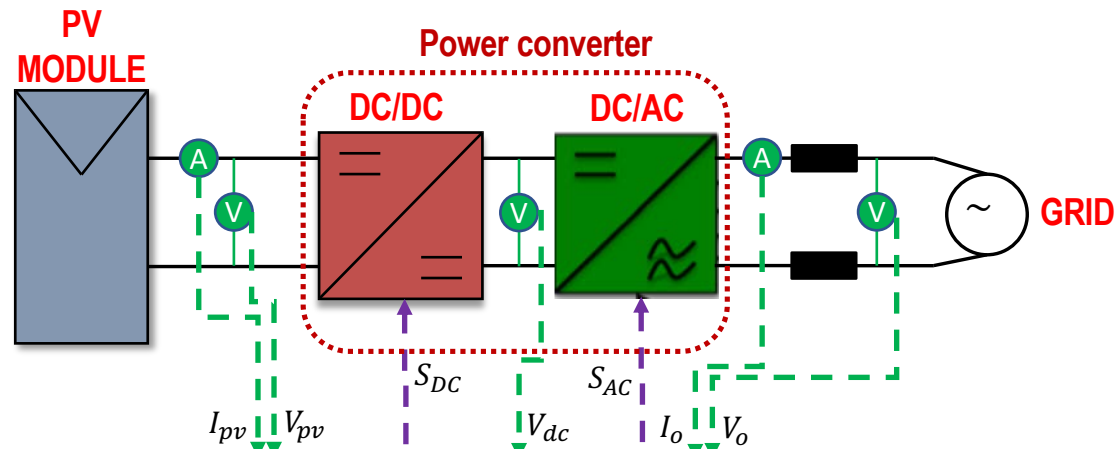


73% of original amount of dust eroded

52% of original amount of dust eroded

(Sometimes) coatings may help to erode off the dust

# From DC module to AC grid



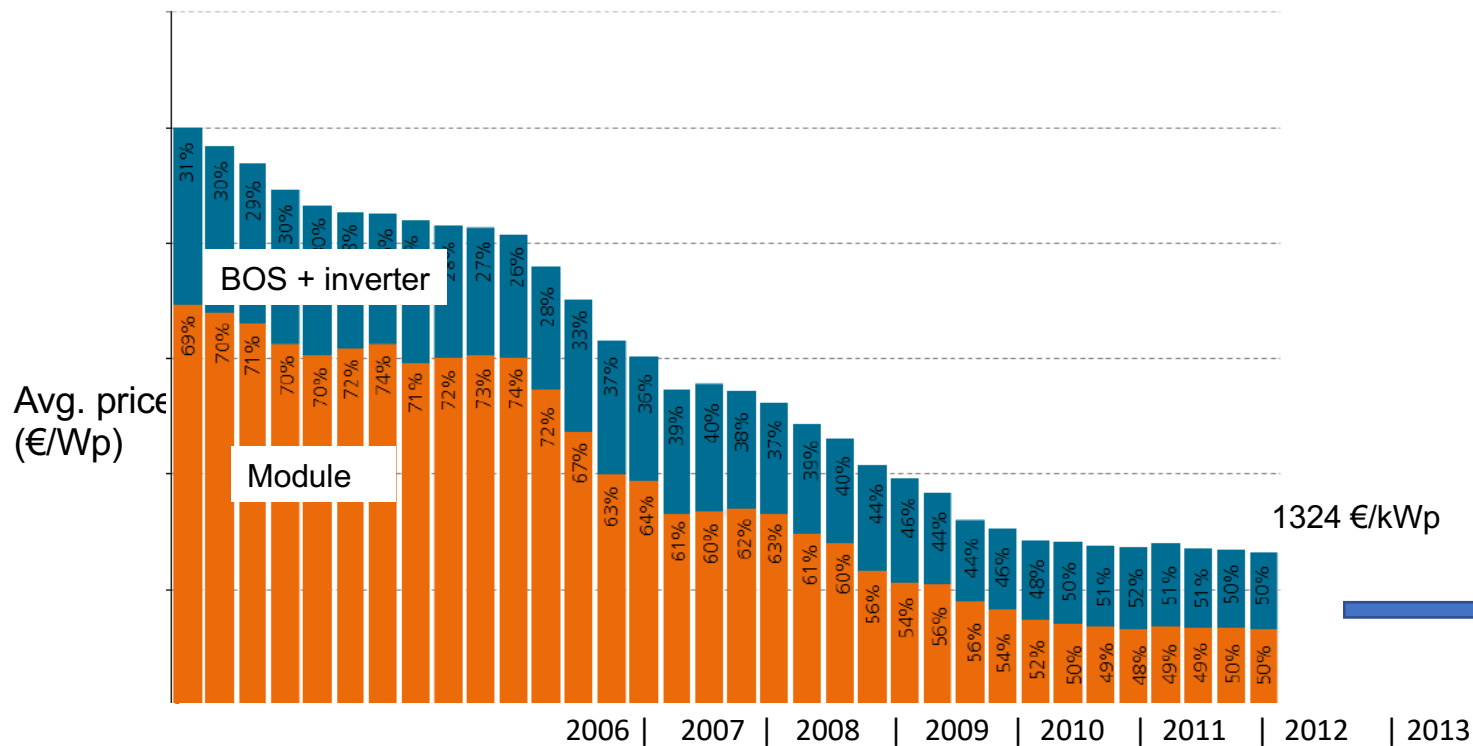
- MPPT algorithm
- Voltage/current controllers
- Synchronization with grid (PLL)
- PWM
- Fault detection

Power controller



# Prices of inverter and balance-of-system (BOS)

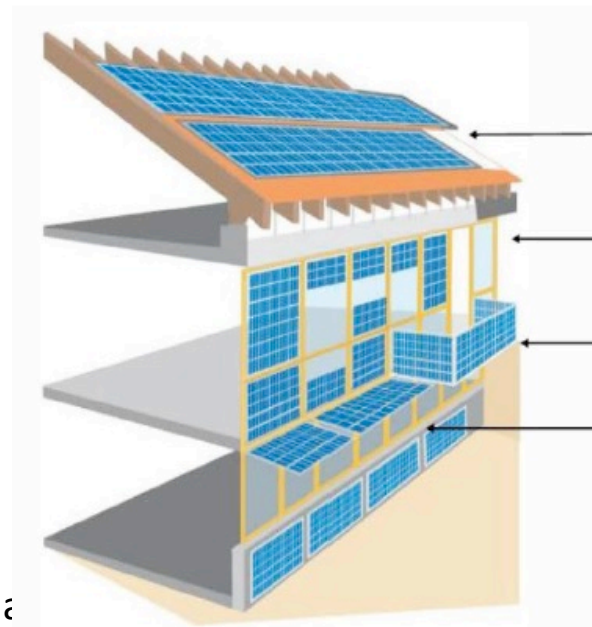
10...100 kWp PV rooftop systems



Challenge:  
Make converters  
cheaper & more  
reliable

# Building-Integrated-PV potential

- Today: PV modules “added” to the building
- BIPV = multi-functional use
  - As building component
  - To generate electricity
- Long lifetime required
  - 30-40 years or >100k hours (more than aerospace!)
  - Problem for converters?
- What will drive BIPV ?
  - Façade-integration of PV for tall NZEB-compliant buildings
    - potential market > 100 GW/yr*
  - PV-roofs with improved esthetics
  - Lower overall cost (building + PV)



Roof integration (opaque or semi-transparent)

Façade integration (warm / cold)

Integration as parapets and balconies

Sun shading elements



# PV in facades of high-rise buildings

- 2020 NZEB directives => enhanced use of PV on buildings

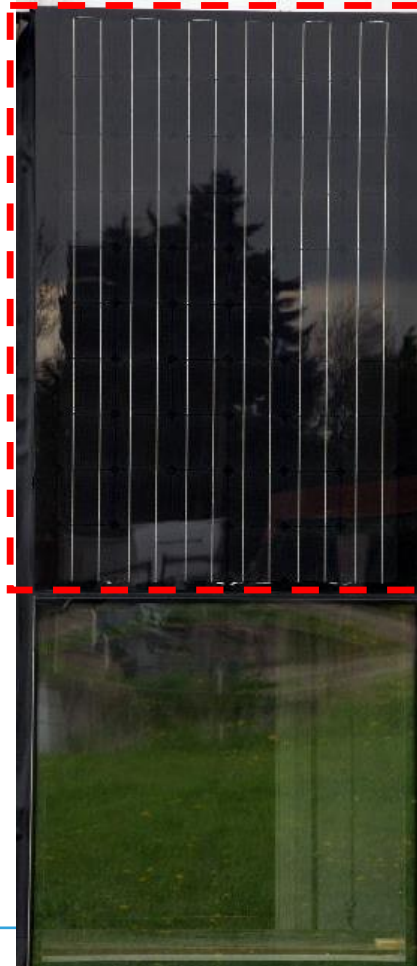
- rooftop area for PV often scarce
- aesthetics suited for office-buildings
- high facade engineering capacity
- benign to the local grid (congestion !)
  - generation close to consumption
  - in sync with airco load
  - East – South – West facades => flatter day profile
  - seasonal profile
- façade cost Euro/m<sup>2</sup> marginally increased and compensated by enhanced “greening”



# Prototype: PV in curtain wall

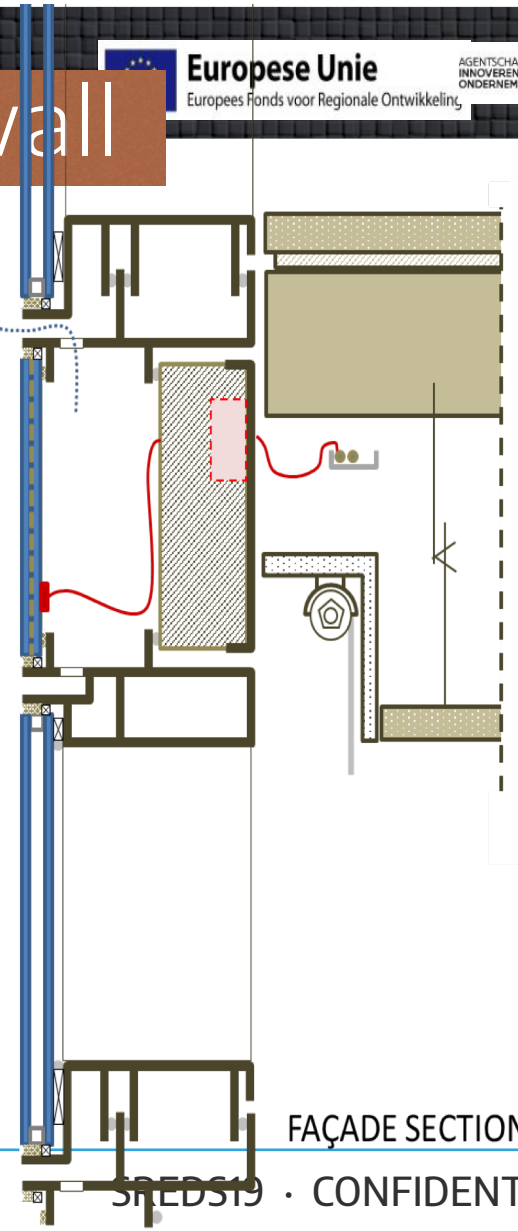


Ventilation  
holes



PV module

Glass

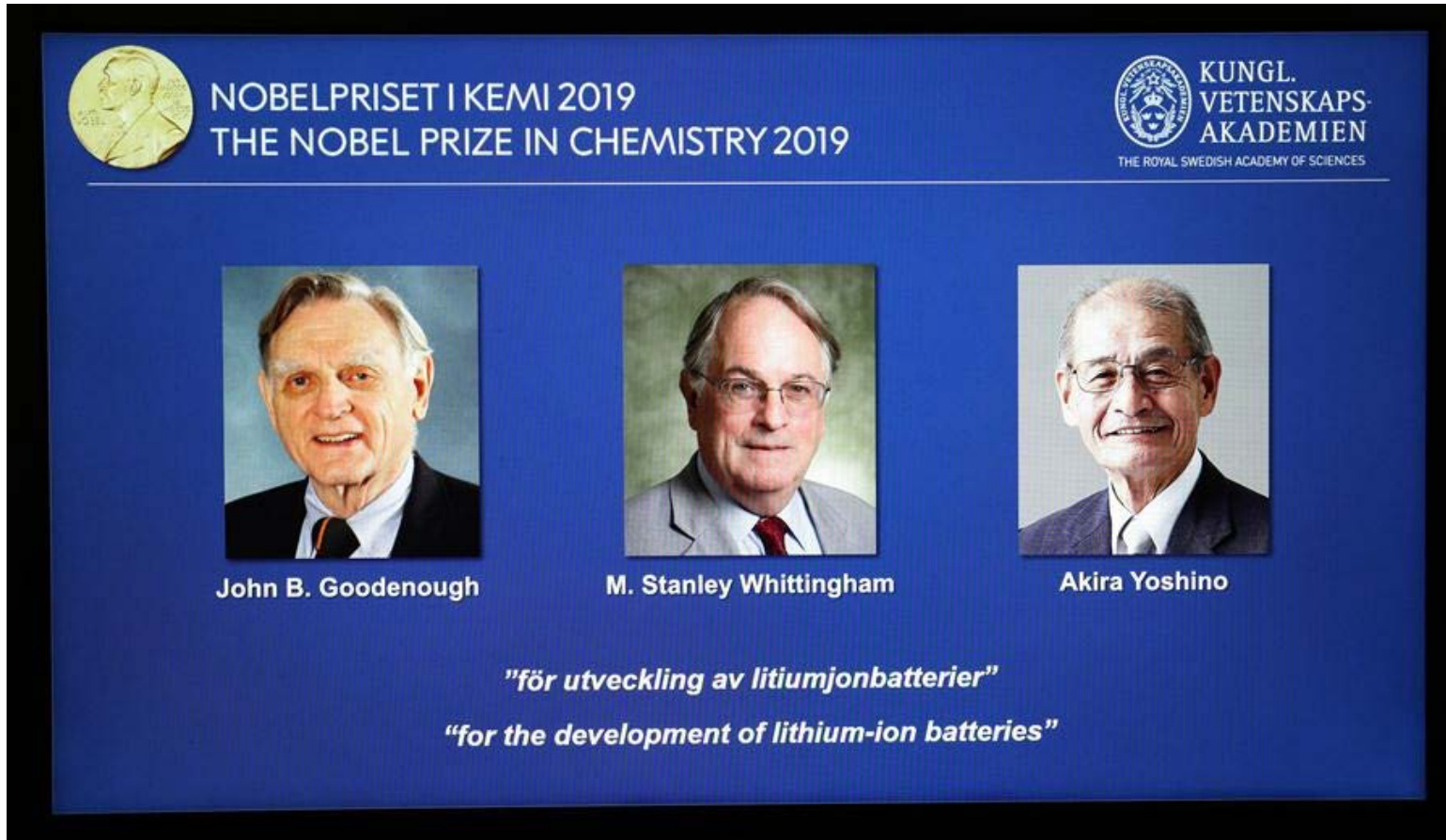


FAÇADE SECTION

# The role of batteries

The missing link for sustainable electrical energy?

# Nobel Prize Chemistry 2019



The graphic is a blue rectangular banner with a black border. At the top left is a gold Nobel medal. To its right, the text reads "NOBELPRISET I KEMI 2019" and "THE NOBEL PRIZE IN CHEMISTRY 2019". At the top right is the logo of the Royal Swedish Academy of Sciences, with the text "KUNGL. VETENSKAPS-AKADEMIEN" and "THE ROYAL SWEDISH ACADEMY OF SCIENCES". Below the text are three portrait photographs of the laureates: John B. Goodenough, M. Stanley Whittingham, and Akira Yoshino. Below the portraits is the award citation in Swedish and English.

NOBELPRISET I KEMI 2019  
THE NOBEL PRIZE IN CHEMISTRY 2019

KUNGL. VETENSKAPS-  
AKADEMIEN  
THE ROYAL SWEDISH ACADEMY OF SCIENCES

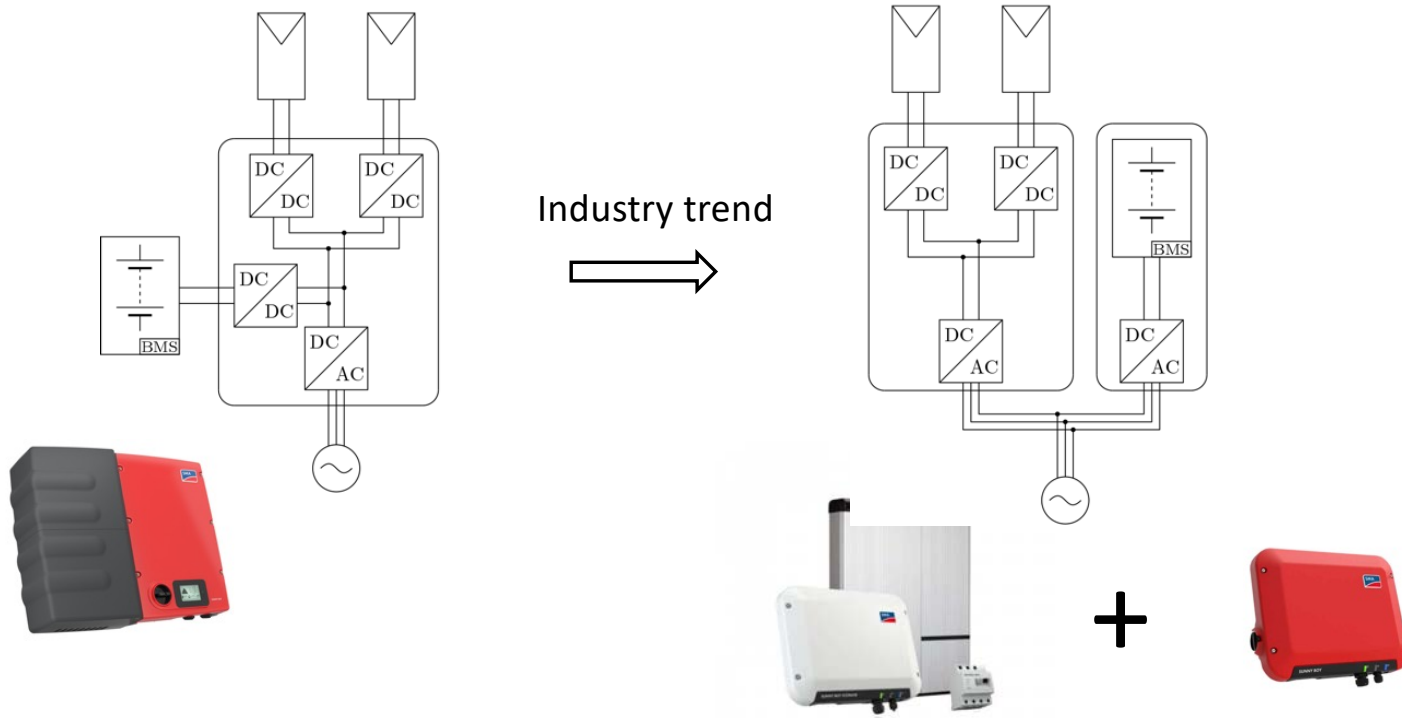
John B. Goodenough

M. Stanley Whittingham

Akira Yoshino

*"för utveckling av litiumjonbatterier"*  
*"for the development of lithium-ion batteries"*

# PV + battery systems



# Large-scale BESS



18 MW battery units by Tesla (Dilsem-Stokkem)



Second-life battery units (coming from Renault-Nissan) – pilot at Umicore

# Ever cheaper batteries thanks to Gigafactories



# Batteries push transition in mobility towards EV



Audi e-tron



350 kW charger

# EnergyVille Smart Charging

- **EnergyVille 1 – Some relevant numbers...**

EnergyVille 1 - Infrastructure	
Installed EV charging power	530kVA
Charging connections:	
OCPP compliant	12(+6)
Non-controllable	7
Fast charger	2 (DC) + 1 (AC)
Vehicle-2-grid	1
Electric cabinet of parking	436kVA
Electric vehicles per day	Avg. 6,4 (max. so far 14)
Photo-voltaic rooftop installation	369kWp



- Capacity of electric cabinet < installed EV charging power
- Regular grid injection due to large PV rooftop installation
- Morning peak in electrical consumption due to coinciding EV charging sessions

→ *Smart Charging at EnergyVille*

# EnergyVille Smart Charging

- **User interaction - web page**

- **Settings:**

- En- or disable smart charging
- Select departure time

- **Monitor: overview of current charging session**

- Current power
- Energy charged
- Charging schedule

EnergyVille Smart Charging

Session 912F0709-F27A-45A0-995E-42C24A0B076D

Settings Monitor

Smart charging  Enabled

Departure time After 17:00

Use as default for future charging sessions

[Detailed view...](#)

Save

© 2019 - EnergyVille - Klaas \*

EnergyVille Smart Charging

Session 912F0709-F27A-45A0-995E-42C24A0B076D

Settings Monitor

Transaction ID	Charging Station	Connector	Start Time	Stop Time	Finished
9500630	ALFEN1	1	2019-10-16 08:30:33	2019-10-16 17:43:21	True

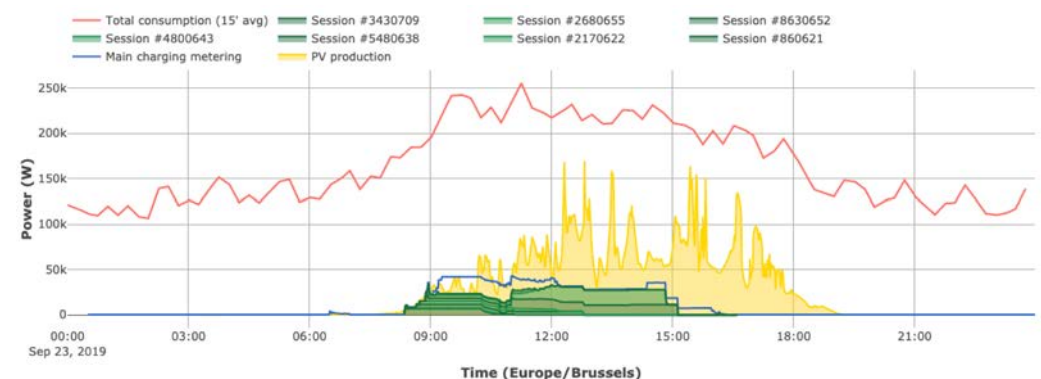
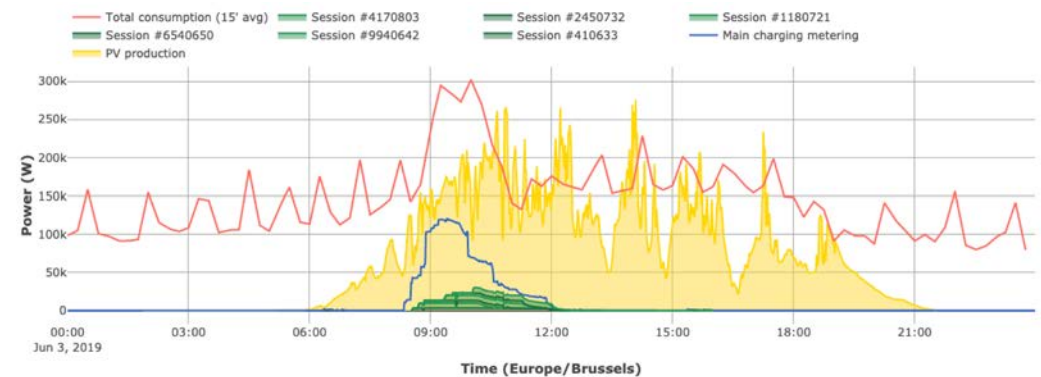
Charging Power (W) Energy (Wh) Charging schedule (W)

Time (Europe/Brussels)

© 2019 - EnergyVille - Klaas \*

# EnergyVille Smart Charging

- A first 'smart' algorithm
  - Without 'smart' algorithm:
    - Clear morning peak in overall electricity consumption at EnergyVille 1
    - Affects capacity costs in energy bill
  - With 'smart' algorithm:
    - Charging sessions of select users are delayed and reduced in power
    - More spread of charging times
    - Mostly flattened peak



# Electric buses: silent & clean cities



Volvo + ABB flash charger



Leuven electric buses



Schiphol airport

# Electric vans & trucks: the next step



Deutsche Post



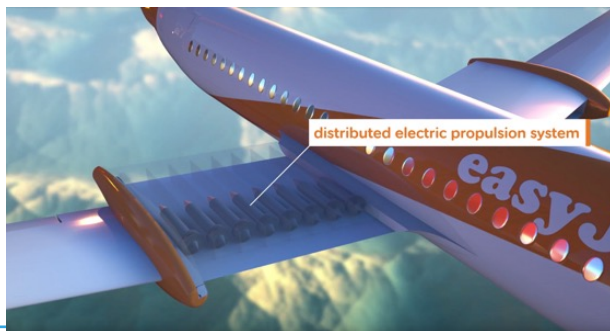
Tesla



Mercedes

# Electric airplanes: the last challenge

- Short distance (<1000 km): full electric
- Personalised transport using electric drone transport



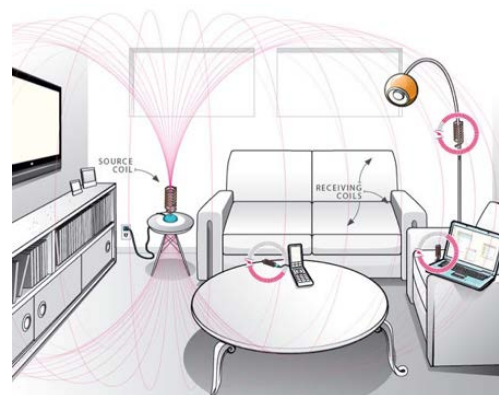
# Back to DC?

Rethinking the power system

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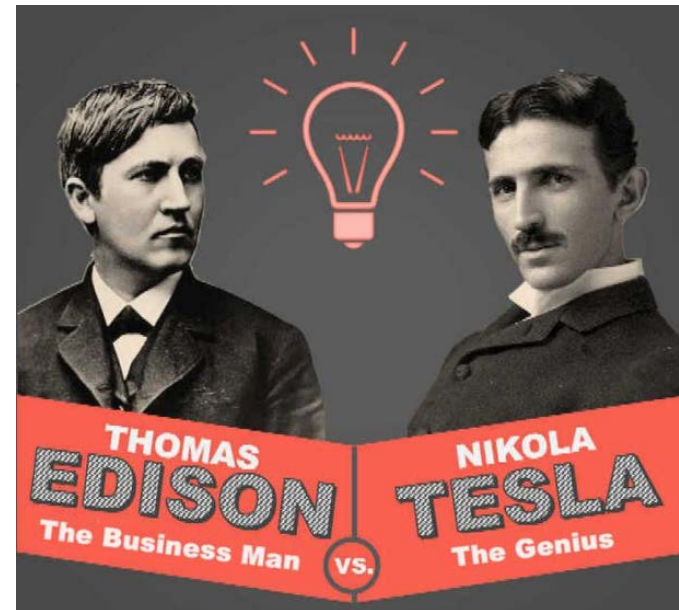
# Wires, sockets & plugs still needed ?

- Many appliances are “cordless”, contain batteries
- Charging through a wireless link: e.g. IT-equipment (Qi), kitchen & garden (KI), electric car (enough power?)
- Can be expanded to full room wireless charging: “witricity”



# Do we still need AC power ?

- PV = DC
- Batteries = DC
- LED-lighting = DC
- IT-equipment = DC
- Electric cars (batteries) = DC
- Etc.
  
- Hence: lots of AC-DC conversion
  - Extra losses
  - Extra (too much?) electronic converters
  - Different types of cabling
  
- Should we go back to DC in buildings?



# Applications of DC nanogrids

## Datacenters



Source: <https://www.quadranet.com>

Running on 380V<sub>DC</sub>

- 10% less energy losses (ABB, Green.ch datacenter, 1 MW)
- 15% less upfront capital cost
- 33% less floor space occupied
- Increased availability

## Public street lighting



Source: Direct Current BV

Running on +/-350V<sub>DC</sub>

- Copper conductor savings
- Feeder length up to 4 km reduces the number of AC connection points
- LED driver becomes more reliable

## Commercial buildings/districts



Source: Arda Power

Running on +/-380V<sub>DC</sub>

- Reduce the number of converters
- Less conversion losses
- Able to operate in islanding mode
- Able to provide ancillary services to the AC grid

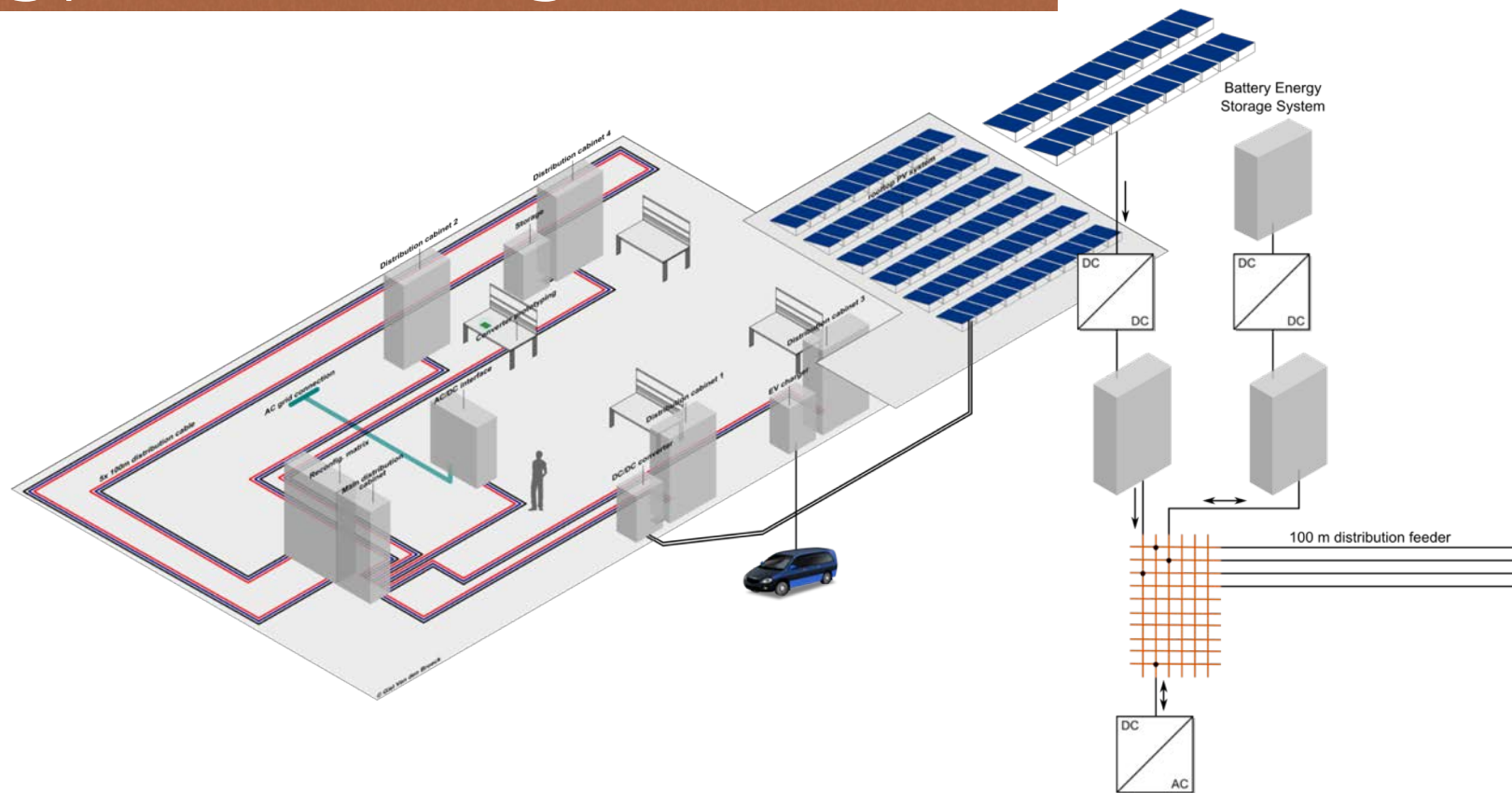
## Industry



Running on 600V<sub>DC</sub>

- DC improves immunity and grid stability
- 40% less copper consumption
- Able to operate in islanding mode

# Living Lab: LVDC living lab in EnergyVille building



# Final thoughts

breakthrough technology

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# The role of power electronics

- Power electronics have become the core conversion technology of modern electricity systems
- Power electronics enable energy controllability & efficiency, renewable resources, energy storage, sustainable mobility
- New components & circuits allow higher performance, lower losses, smaller converters, and eventually high reliability

Thank You ㄥ

Feedback and  
Interest Survey ㄥ



Dr. Johan Driesen

Johan.Driesen@energyville.be

