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# ENABLING TRENDS IN ELECTRONIC COMPONENTS WITH THEIR IMPACT ON THE ENERGY SECTOR

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# OUTLINE

- The Energy System, Quo Vadis?
- Technical challenges
- (Some) relevant developments in electronics for electrical and multi-energy networks
- EnergyVille: Marrying Energy and ICT on R&D&D-level

# TOWARDS A MORE DISTRIBUTED SYSTEM ?

## DRIVEN BY (DRAMATIC) COST REDUCTION ...


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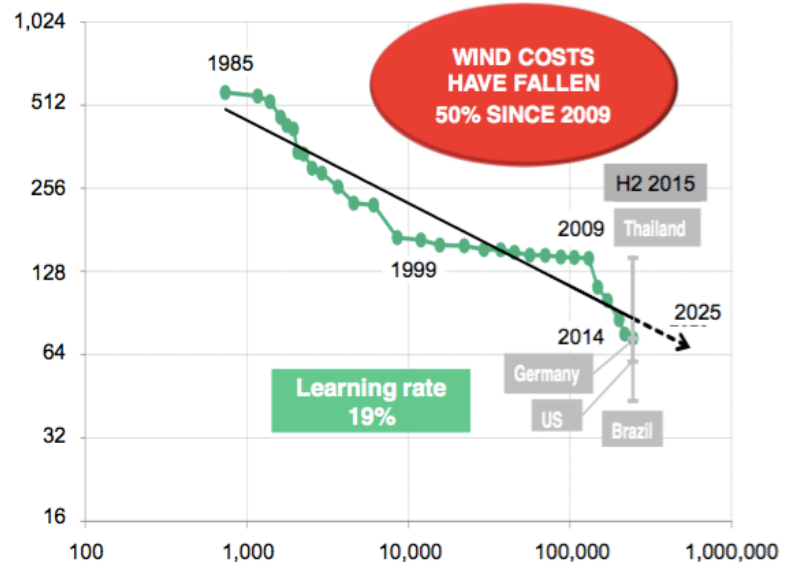
# TOWARDS A MORE DISTRIBUTED SYSTEM

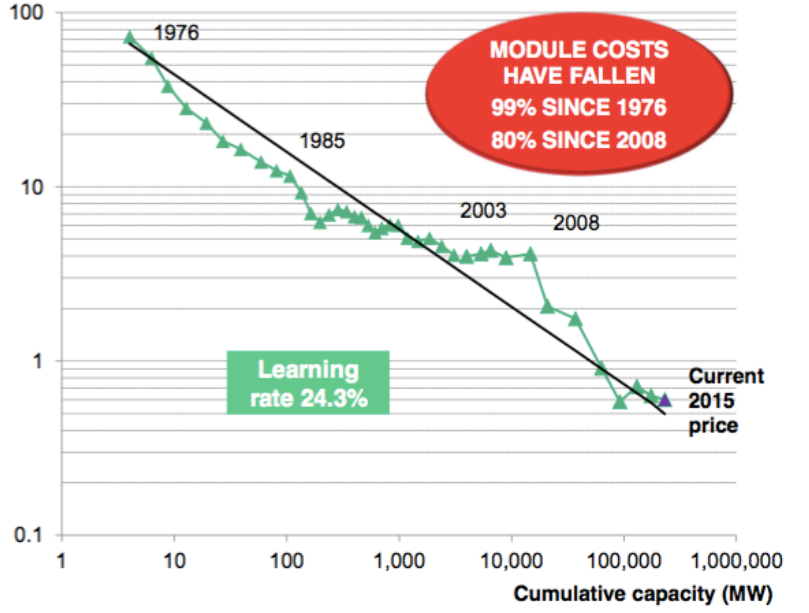
## DRIVEN BY (DRAMATIC) COST REDUCTION ...

### ONSHORE WIND LEVELISED COST ($/MWh)




Note: Pricing data has been inflation corrected to 2014. We assume the debt ratio of 70%, cost of debt (bps to LIBOR) of 175, cost of equity of 8% Source: Bloomberg New Energy Finance

### SOLAR PV MODULE COST ($/W)




Note: Prices are in real (2015) USD. 'Current price' is $0.61/W Source: Bloomberg New Energy Finance, Maycock



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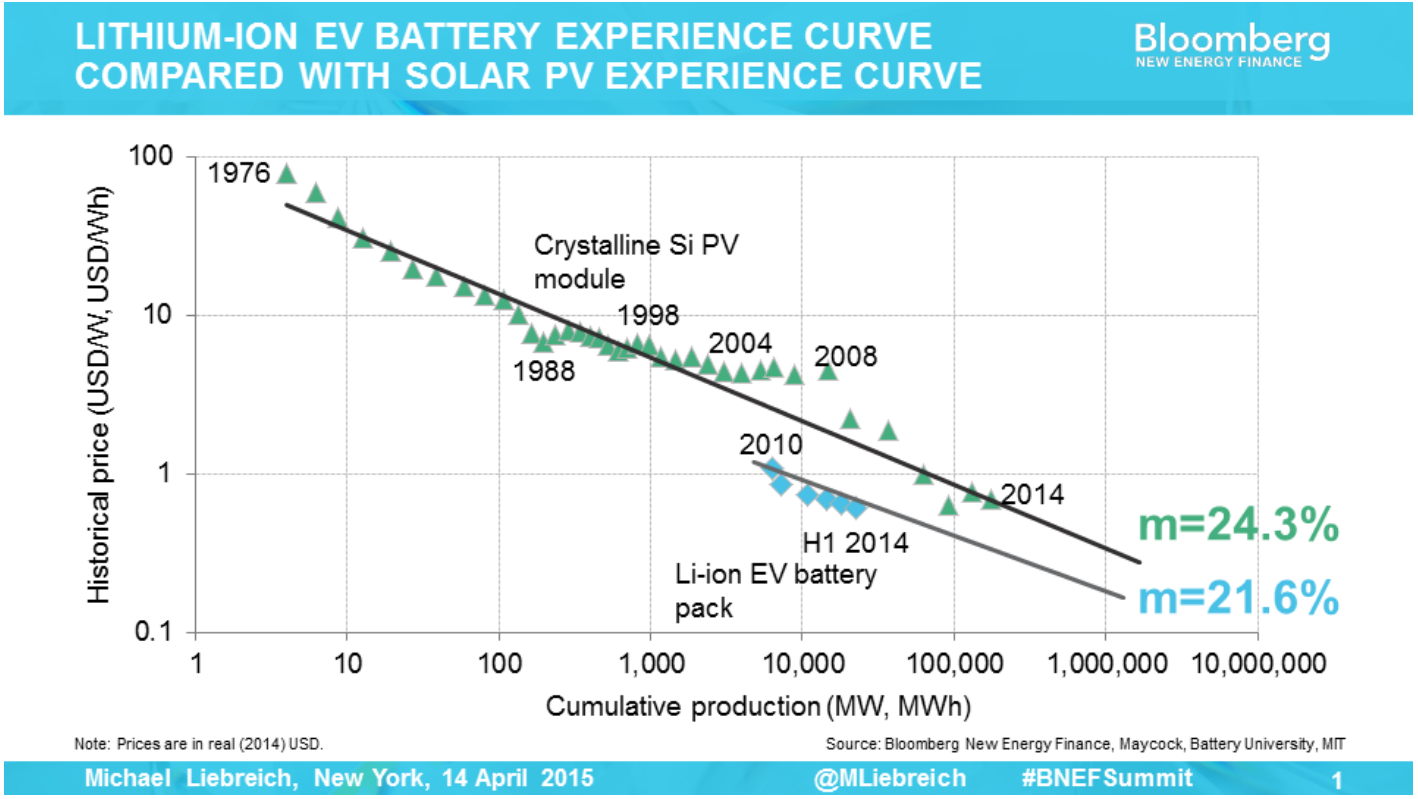
# TOWARDS A MORE DISTRIBUTED SYSTEM

## DRIVEN BY (DRAMATIC) COST REDUCTION ...ALSO FOR STORAGE

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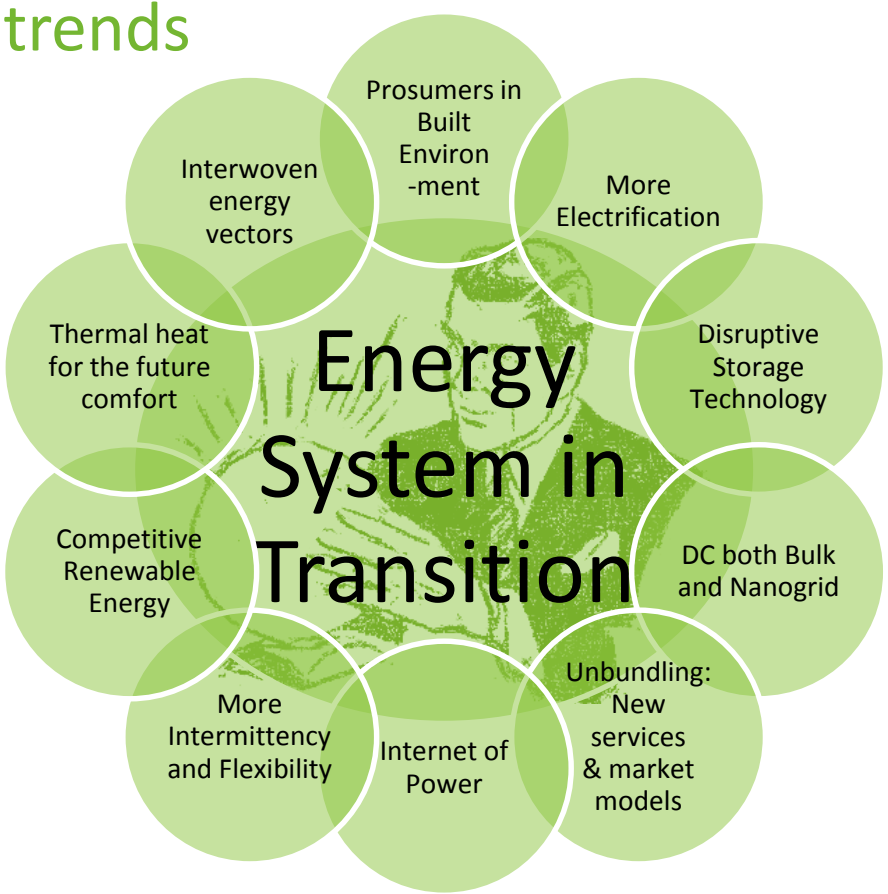
# Megatrends


Energy System in Transition
Prosumers in Built Environ -ment
More Electrification
Disruptive Storage Technology
DC both Bulk and Nanogrid
Unbundling: New services & market models
Internet of Power
More Intermittency and Flexibility
Competitive Renewable Energy
Thermal heat for the future comfort
Interwoven energy vectors

# TRANSITION FROM CENTRAL → DISTRIBUTED

## (R)EVOLUTIONARY SCHEMES

Degree of Decentralization

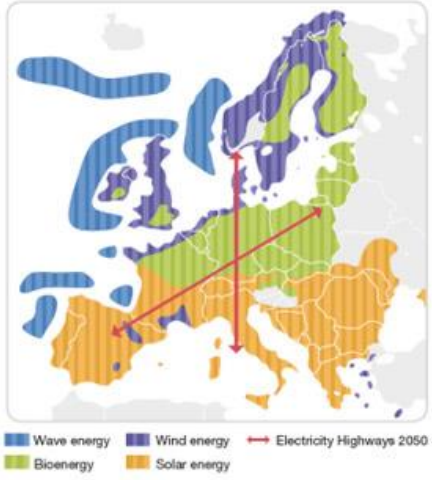
Source: ENTSO-E

41+1 TSOs from 35 countries

532 million citizens served

1020 GW generation

313 Thousand Km of transmission lines




| Emphasis on | Main actors to build and exploit |
|---|---|
| **Large-scale wind** in the North<br>**Large-scale PV** in the the South<br>Interconnection by (HVDC) transmission lines | Traditional energy suppliers<br>Large wind and PV power plant exploitants<br>Transmission companies<br><br>***B2B interactions*** |

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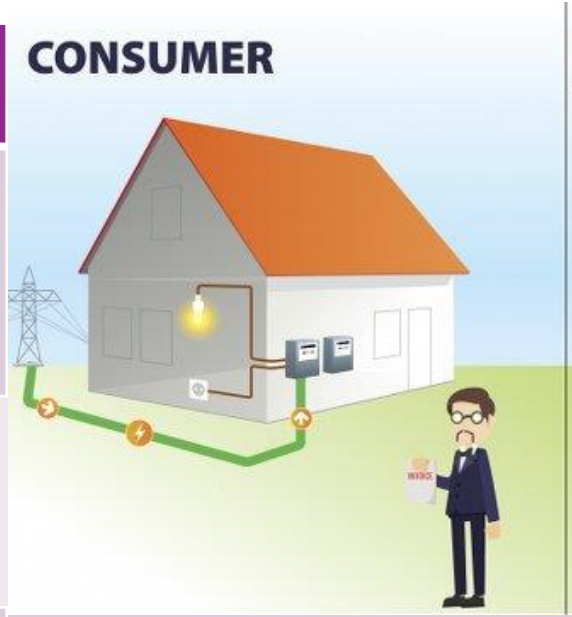
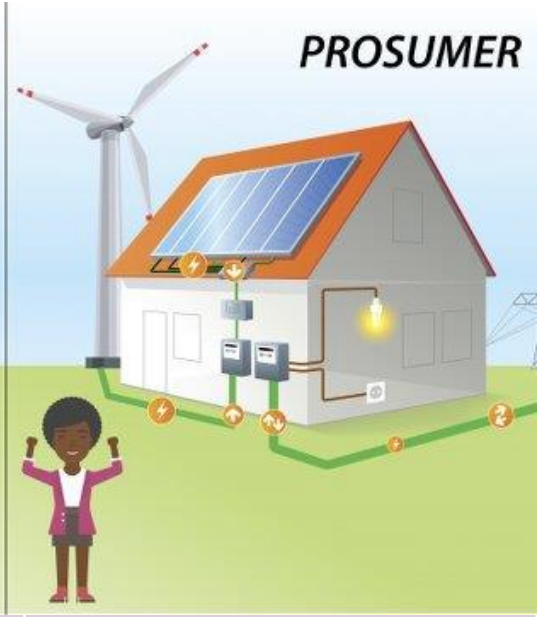
# TRANSITION FROM CENTRAL → DISTRIBUTED

## (R)EVOLUTIONARY SCHEMES

Degree of Decentralization

| Descriptive name | CONSUMER | PROSUMER |
|---|---|---|
| **REPLACEMENT (CONVENTIONAL→RES)**<br><br>**Concentrated RES** interconnected by **transmission lines** |  |  |
| **DEEPLY DISTRIBUTED**<br><br>**Highly localized RES and storage** | **Prosumers**<br>**Self-consumption**<br>DC-nanogrid<br>Context awareness<br>Multi-energy at building level | Aggregators<br>Individual residential and industry building energy management<br><br>***B2C and B2B interactions*** |

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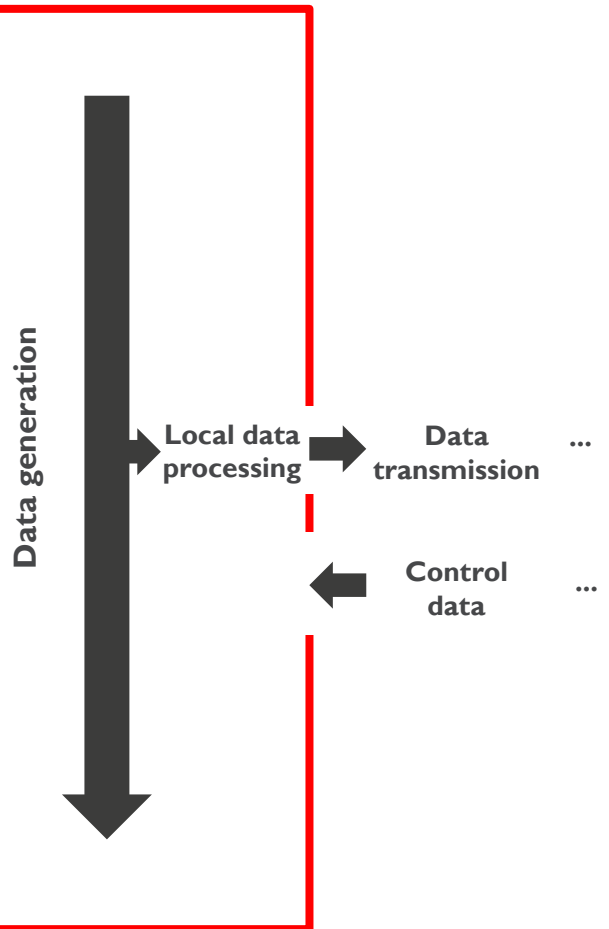
# TRANSITION FROM CENTRAL → DISTRIBUTED

## DATA GENERATION

Degree of Decentralization

| Descriptive name | Emphasis on |
|---|---|
| **REPLACEMENT (CONVENTIONAL→RES)**<br><br>**Concentrated RES** interconnected by **transmission lines** | **Large-scale wind** in the North<br>**Large-scale PV** in the the South<br>Interconnection by (HVDC) transmission lines |
| | **MEET IN THE MIDDLE**<br>**2 Markets?**<br>**Smart Energy in the Cities/Districts**<br>**E-mobility** |
| **DEEPLY DISTRIBUTED**<br><br>**Highly localized RES and storage** | **Prosumers**<br>**Self-consumption**<br>DC-nanogrid<br>Context awareness<br>Multi-energy at building level |

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# OUTLINE

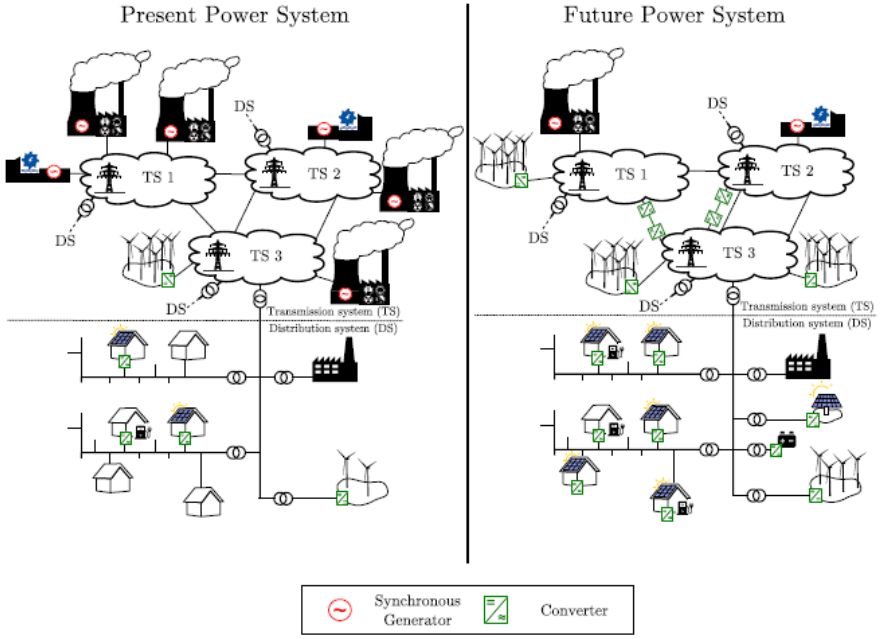
- The Energy System, Quo Vadis?
- Technical challenges
- (Some) relevant developments in electronics for electrical and multi-energy networks
- EnergyVille Case : Marrying Energy and ICT on R&D&D-level

# THE HURDLES

## IT IS NOT ROTATING, SIR ...

Degree of Decentralization

| Descriptive name | Technical challenges |
|---|---|
| REPLACEMENT (CONVENTIONAL→RES) | *Reduction of grid inertia by the reduction of synchronous generators → convertor-based inertia support* |
| MEET IN THE MIDDLE | |
| DEEPLY DISTRIBUTED | |




Courtesy P. Tielens, EnergyVille

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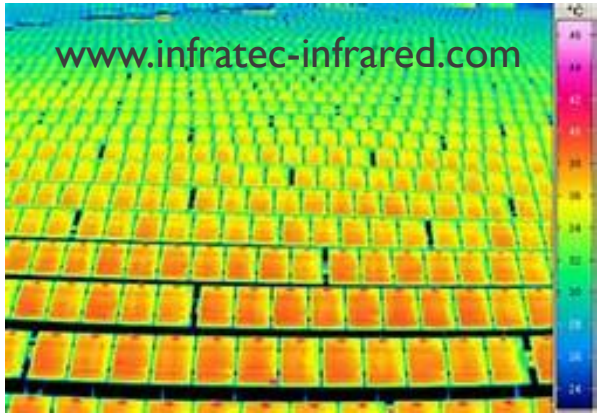
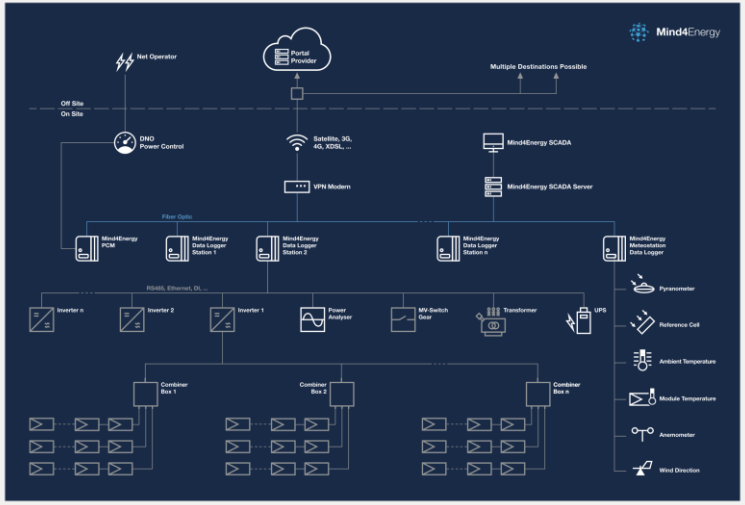
# THE HURDLES

## WE HAVE TO LOOK EVERYWHERE, SIR …

Degree of Decentralization

| Descriptive name | Technical challenges |
|---|---|
| **REPLACEMENT (CONVENTIONAL→RES)**<br><br>**Concentrated RES** interconnected by **transmission lines** | *Reduction of grid inertia by the reduction of synchronous generators → convertor-based inertia support*<br><br>*Plant (wind & PV) energy yield monitoring* |
| **MEET IN THE MIDDLE** | |
| **DEEPLY DISTRIBUTED**<br><br>**Highly localized RES and storage** | |




www.mind4energy.com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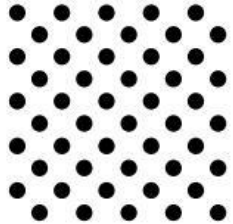
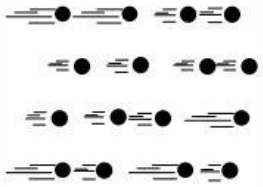
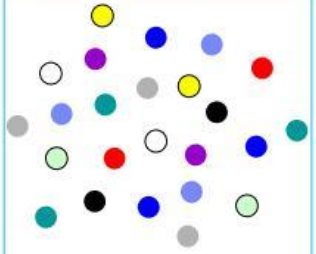
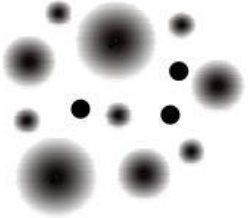
# THE HURDLES

## I AM DRAWNING IN THE DATA, SIR …

Degree of Decentralization

| Descriptive name | Technical challenges |
|---|---|
| REPLACEMENT (CONVENTIONAL→RES) | *Reduction of grid inertia by the reduction of synchronous generators → convertor-based* |
| MEET IN THE MIDDLE | |
| DEEPLY DISTRIBUTED | |

| Volume | Velocity | Variety | Veracity* |
|---|---|---|---|
|  |  |  |  |
| Data at Rest | Data in Motion | Data in Many Forms | Data in Doubt |
| Terabytes to exabytes of existing data to process | Streaming data, milliseconds to seconds to respond | Structured, unstructured, text, multimedia | Uncertainty due to data inconsistency & incompleteness, ambiguities, latency, deception, model approximations |

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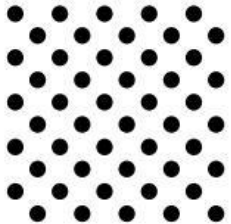
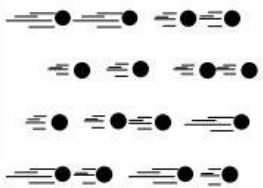
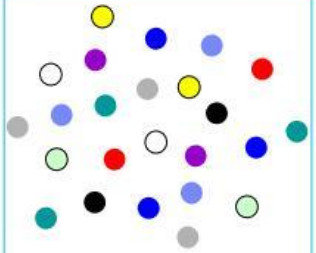
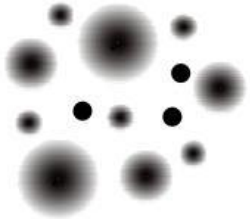
Courtesy D. Van Hertem/H. Ergun, EnergyVille

# THE HURDLES

## TO WHOM DO I HAVE TO SEND THESE DATA, SIR ...

Degree of Decentralization

| Descriptive name | Technical challenges |
|---|---|
| REPLACEMENT (CONVENTIONAL→RES) | *Reduction of grid inertia by the reduction of synchronous generators → convertor-based* |
| MEET IN THE MIDDLE | |
| DEEPLY DISTRIBUTED | |

| Volume | Velocity | Variety | Veracity* |
|---|---|---|---|
|  |  |  |  |
| **Data at Rest** | **Data in Motion** | **Data in Many Forms** | **Data in Doubt** |
| Terabytes to exabytes of existing data to process | Streaming data, milliseconds to seconds to respond | Structured, unstructured, text, multimedia | Uncertainty due to data inconsistency & incompleteness, ambiguities, latency, deception, model approximations |

Courtesy D. Van Hertem/H. Ergun, EnergyVille

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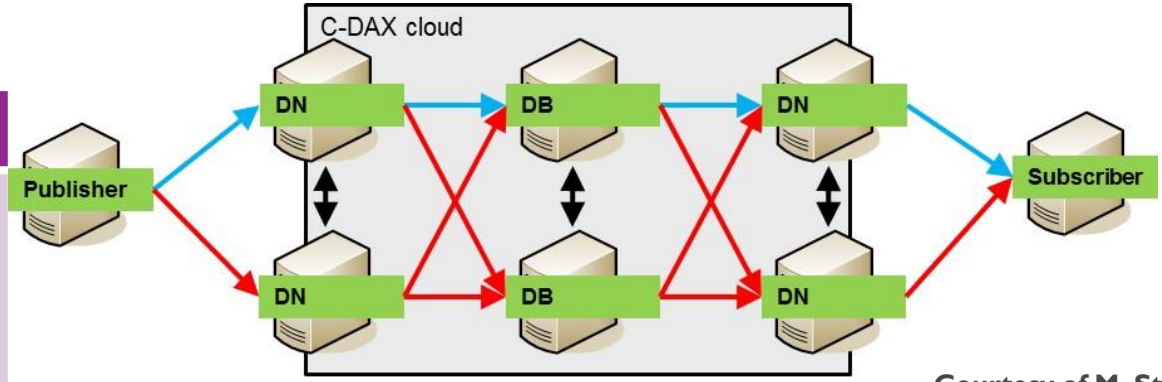
# THE HURDLES

## WHAT IS OUR STATE, SIR ...

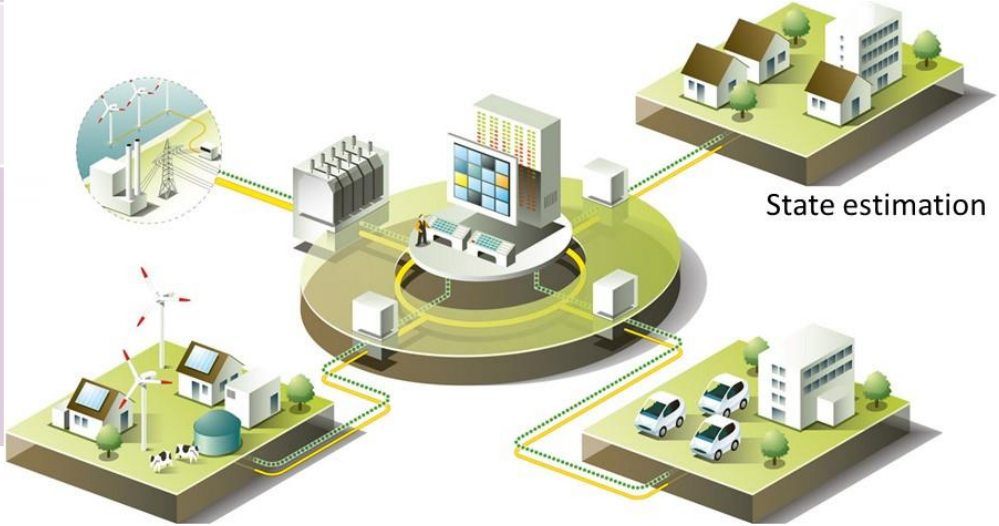
Degree of Decentralization

| Descriptive name |
| --- |
| **REPLACEMENT (CONVENTIONAL→RES)**<br><br>**Concentrated RES** interconnected by **transmission lines** |
| **MEET IN THE MIDDLE** |
| **DEEPLY DISTRIBUTED**<br><br>**Highly localized RES and storage** |




*C-DAX: A Cyber-Secure Data and Control Cloud for Power Grids*

**Courtesy of M. Strobbe, imec/IDLab**

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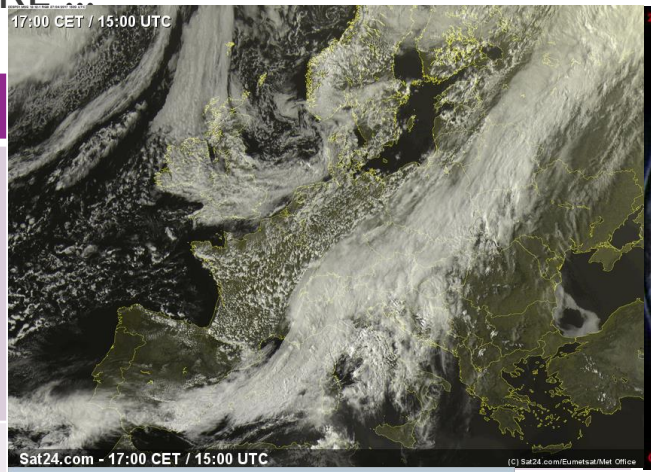
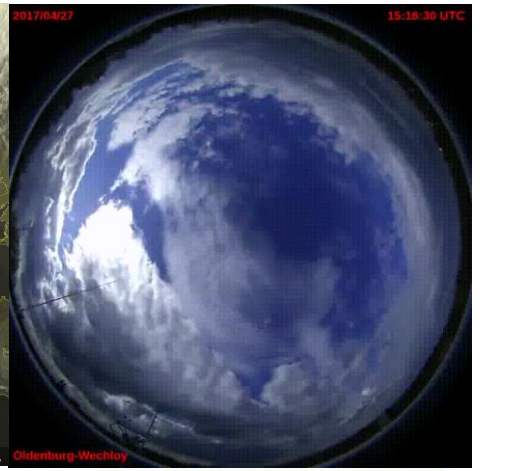
# THE HURDLES

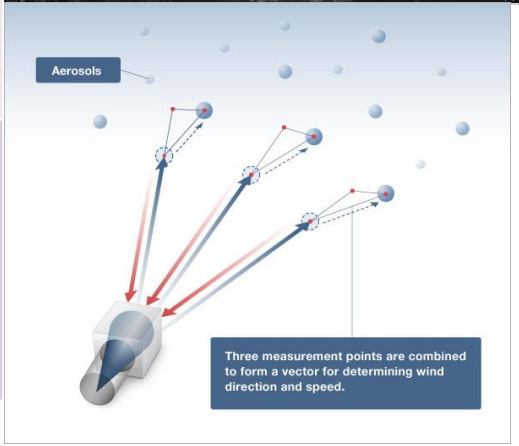
## GAZING INTO THE (NEAR) FUTURE...

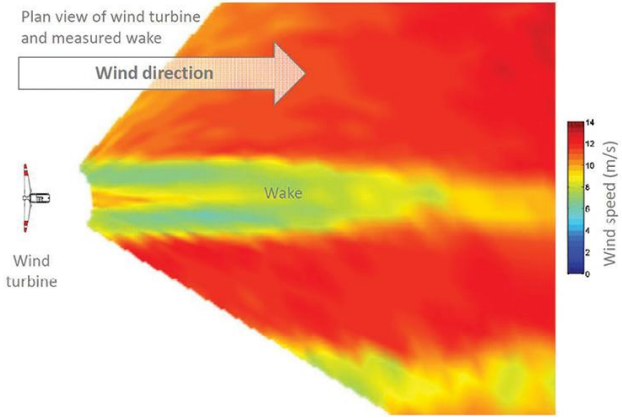
Degree of Decentralization

| Descriptive name |
| --- |
| REPLACEMENT (CONVENTIONAL→RES) |
| MEET IN THE MIDDLE |
| DEEPLY DISTRIBUTED |

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# THE HURDLES

## WE NEED HELP!

Degree of Decentralization

**Descriptive name**

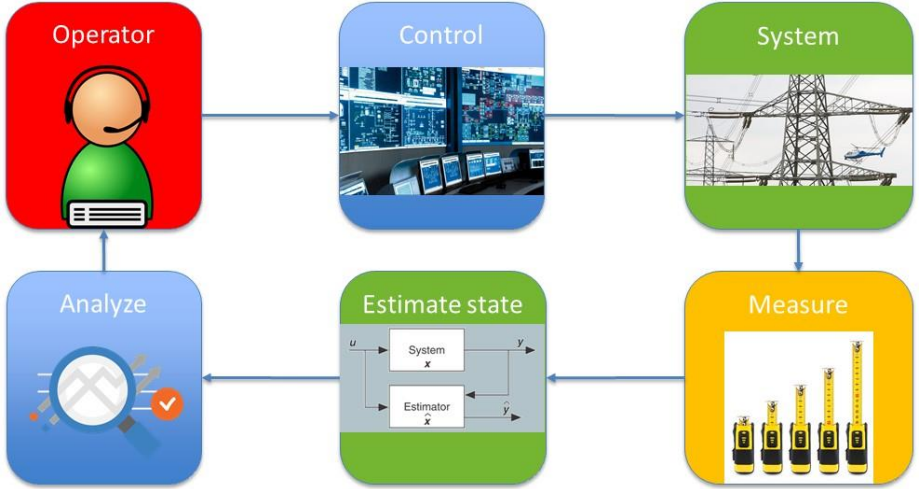
**REPLACEMENT (CONVENTIONAL→RES)**

**Concentrated RES** interconnected by **transmission lines**

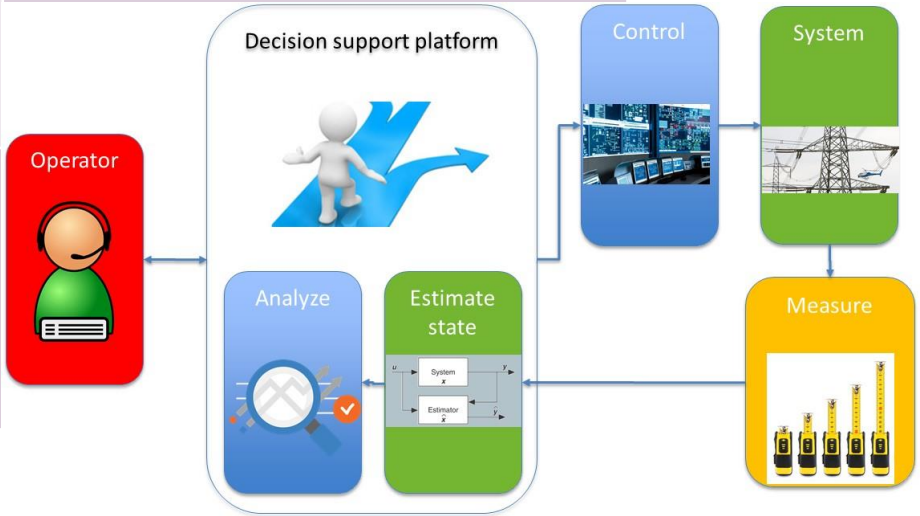
**MEET IN THE MIDDLE**

**DEEPLY DISTRIBUTED**

**Highly localized RES and storage**




***Data explosion because of distributed character (in space and time)***




**Courtesy D. Van Hertem/H. Ergun, EnergyVille**

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# THE HURDLES

## LOOKING FOR A NEEDLE IN A HAY STACK (BIG DATA) ...

Degree of Decentralization

| Descriptive name | Technical challenges |
|---|---|
| **REPLACEMENT (CONVENTIONAL→RES)**<br><br>**Concentrated RES** interconnected by **transmission lines** | ***Reduction of grid inertia by the reduction of synchronous generators → convertor-based inertia support***<br><br>***RES-Plant energy yield monitoring***<br><br>***Data explosion because of distributed character (in space and time)*** |
| **MEET IN THE MIDDLE** | ***Data exchange & interoperability***<br><br>***Correct state estimation of distributed resources*** |
| **DEEPLY DISTRIBUTED**<br><br>**Highly localized RES and storage** | ***Intra-day and Interday forecasting for distributed resources***<br><br>***Decision support for the grid operators***<br><br>***Creation of context awareness/self-learning*** |

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## Big Data and Energy: A Clear Synergy 4

Utilities and energy companies are finding that there are big savings in Big Data. The flood of new information is occurring just as reducing demand and increasing fuel efficiency (with attendant climate benefits) has become a top priority for both government and industry. Fortunately, harnessing information has already yielded big energy gains, and considerably more are promised.

For instance, companies like Virginia-based OPower are using Big Data to allow homeownersto measure their consumption against their neighbors. Cities are optimizing the timing of traffic signals to reduce congestion, airports are communicating with planes to increase the efficiency of waiting ground crews, and building managers are using data analysis to cut energy use by 10% to 20%. And tomorrow's smart thermostats will connect to the web and give consumers remote access to managing their electricity use...

Special Report: Sustainability in the Age of Big Data

# THE HURDLES

## AND ITS LINKS TO MATERIAL/COMPONENT/SYSTEM REQUIREMENTS

Degree of Decentralization

| Descriptive name | Technical challenges | Link material&components |
|---|---|---|
| **REPLACEMENT (CONVENTIONAL→RES)**<br><br>**Concentrated RES** interconnected by **transmission lines** | *Reduction of grid inertia by the reduction of synchronous generators → convertor-based inertia support* | *Power electronics, sensorics, storage with high power density* |
| | *RES-Plant energy yield monitoring* | *Sensorics, power electronics and low-power data processing* |
| | *Data explosion because of distributed character (in space and time)* | *Low-power data processing and communication* |
| **MEET IN THE MIDDLE** | *Data exchange & interoperability* | *High-speed data communication* |
| | *Correct state estimation of distributed resources* | *High-speed data processing & data storage* |
| **DEEPLY DISTRIBUTED**<br><br>**Highly localized RES and storage** | *Intra-day and Interday forecasting for distributed resources* | *Sensorics and data communication* |
| | *Decision support for the grid operators* | *High-speed data processing* |
| | *Creation of context awareness/self-learning* | *High-speed computation & large data storage* |

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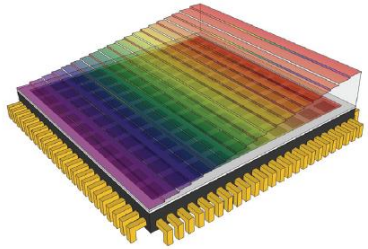
# OUTLINE

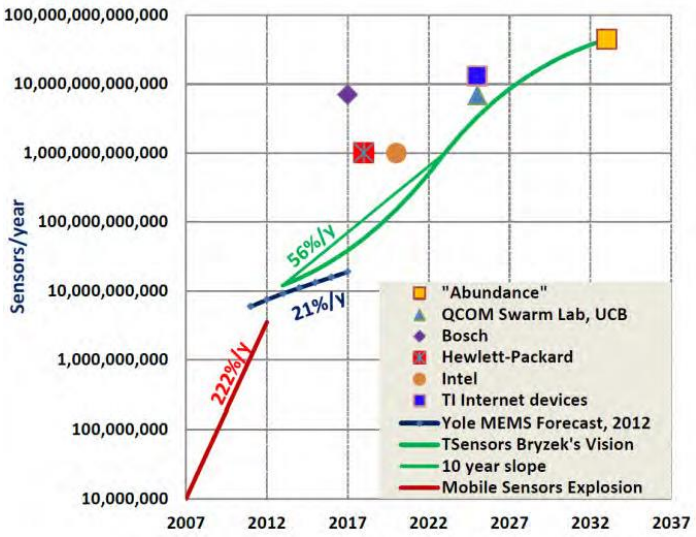
- The Energy System, Quo Vadis?
- Technical hurdles
- Relevance of developments in electronics for electrical and multi-energy networks
- EnergyVille Case : Marrying Energy and ICT on R&D&D-level

# RELEVANT TRENDS IN ELECTRONICS
## AT DEVICE/CIRCUIT LEVEL

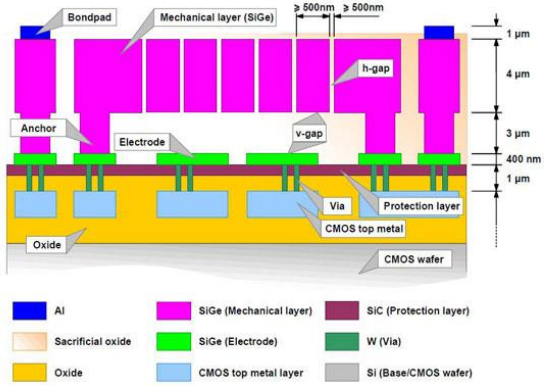
| Type of action | Device level |
|---|---|
| Measure the data? | Post CMOS-processing<br>MEMS<br>Thin-film electronics<br>SOC<br>... |
| Locally storing and processing the data | |
| Transmit the data | |
| Analyze and store the data at higher aggregation level | |
| Control → Actuation by switching of power transistors | |

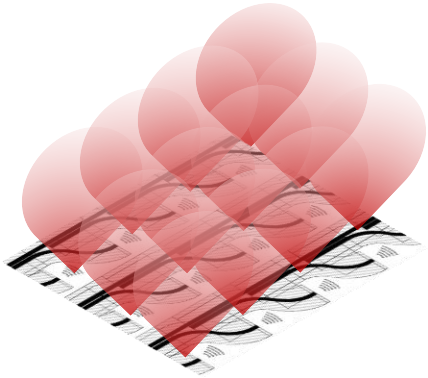


Conceptual drawing of hyperspectral linescan imager with 100 static spectral filter structures




Forecast number of sensors produced each year on a global level until 2037. (Source: Fairchild Semiconductors)



# RELEVANT TRENDS IN ELECTRONICS

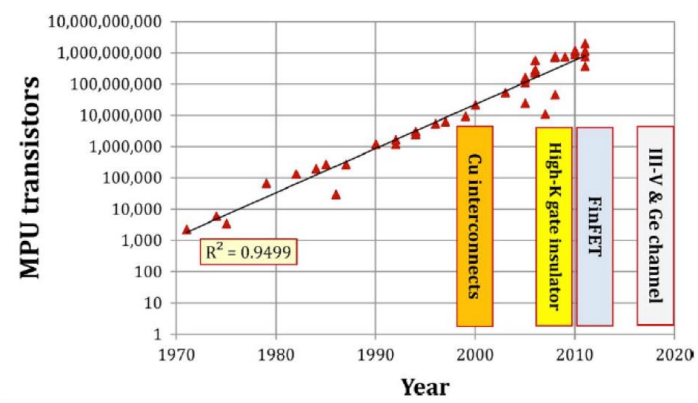
## AT DEVICE/CIRCUIT LEVEL

| Type of action | Device level |
|---|---|
| Measure the data? | Post CMOS-processing<br>MEMS<br>Thin-film electronics<br>SOC<br>... |
| Locally storing and processing the data | Low power data processing<br>Scaling → Low cost/transistor |
| Transmit the data | |
| Analyze and store the data at higher aggregation level (data centers) | |
| Control → Actuation by switching of power transistors | |

$$E = \tfrac{1}{2} C V^2 f$$

**Ultra-low Power processing**

- **Reduction of capacitance**
- **Reduction of voltage**
- **Subthreshold slope**
- **Power gating**

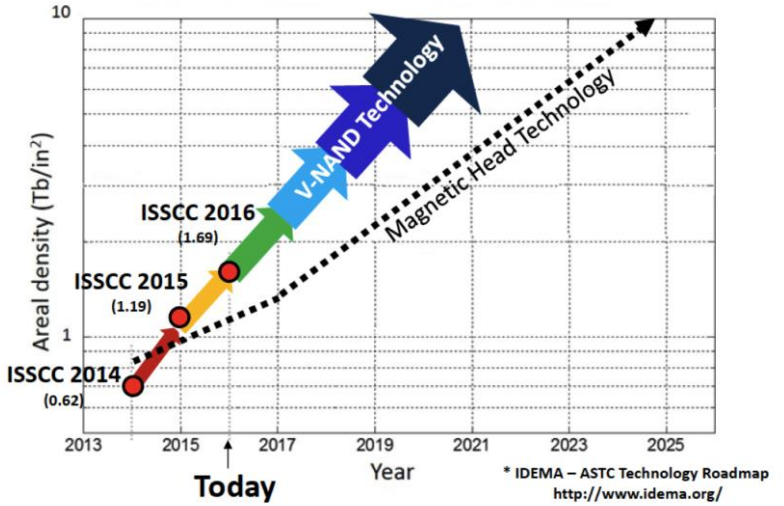


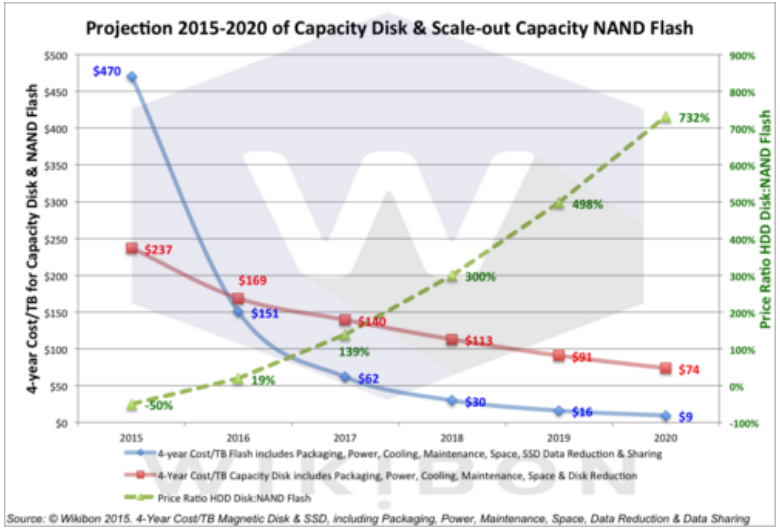

| Energy Source | Characteristics | Efficiency | Harvested Power |
|---|---|---|---|
| Light | Outdoor<br>Indoor | 10-24% | 100 mW/cm²<br>100 μW/cm/cm³ |
| Thermal | Human<br>Industrial | ~0.1 %<br>~3 % | 60 μW/cm³<br>~1-10 mW/cm³ |
| Vibration | Human ~Hz<br>Machines ~khz | 25-50% | ~4 μW/cm³<br>~800 μW/cm³ |
| RF | GSM 900 MHz<br>WiFI | ~50 % | 0.1 μW/cm²<br>0.001 μW/cm² |

# RELEVANT TRENDS IN ELECTRONIC

## AT DEVICE/CIRCUIT LEVEL

| Type of action | Device level |
|---|---|
| Measure the data? | Post CMOS-processing<br>MEMS<br>Thin-film electronics<br>SOC<br>… |
| Locally storing and processing the data | Scaling → Low cost/transistor<br>Increase storage capacity |
| Transmit the data | |
| Analyze and store the data at higher aggregation level | |
| Control → Actuation by switching of power transistors | |

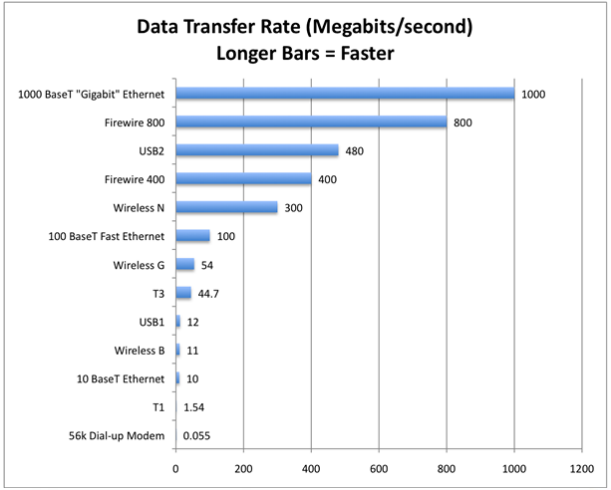


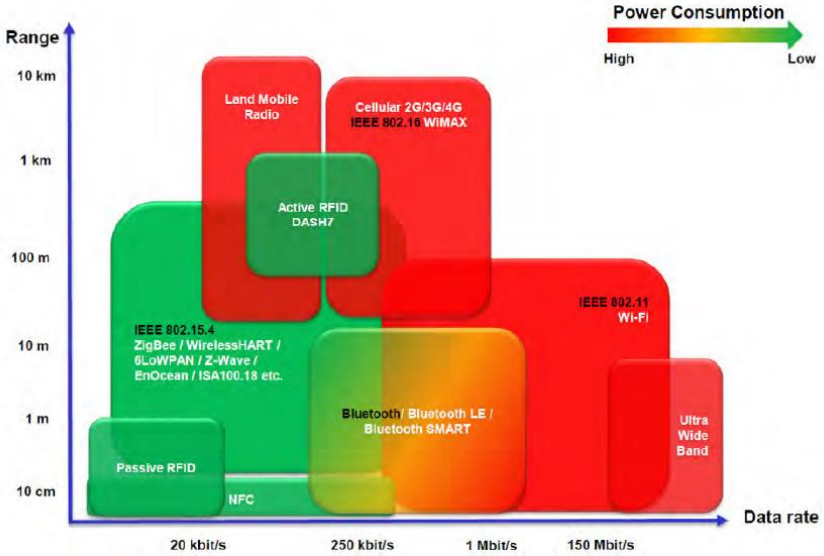



# RELEVANT TRENDS IN ELECTRONICS

## AT DEVICE/CIRCUIT LEVEL

| Type of action | Device level |
|---|---|
| Measure the data? | Post CMOS-processing<br>MEMS<br>Thin-film electronics<br>SOC<br>… |
| Locally storing and processing the data | Low cost/transistor<br>Low-energy data processing |
| Transmit the data | Bit transmission rate<br>Energy /transmitted bit |
| Analyze and store the data at higher aggregation level | |
| Control → Actuation by switching of power transistors | |



# RELEVANT TRENDS IN ELECTRONICS

## AT DEVICE/CIRCUIT LEVEL

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| Measure the data? | Post CMOS-processing<br>MEMS<br>Thin-film electronics<br>SOC<br>... |
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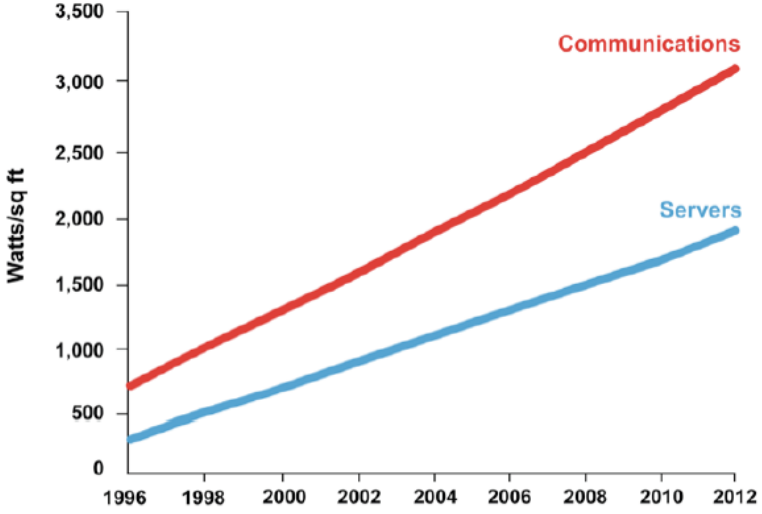
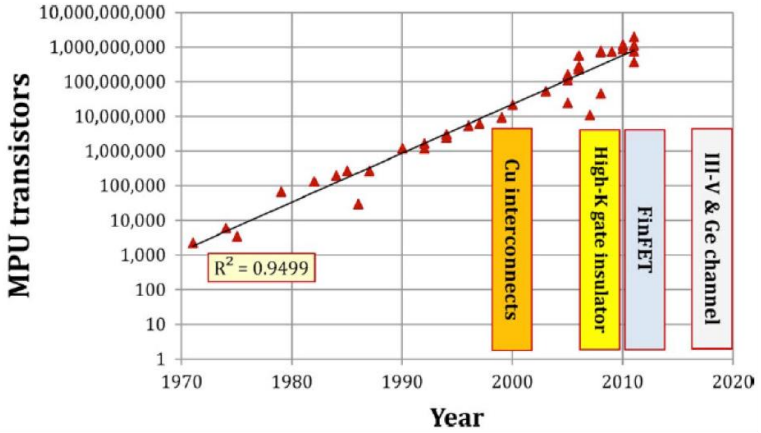
| Control → Actuation by switching of power transistors | |




source: *ASHRAE DatacomEquipment Power Trends*



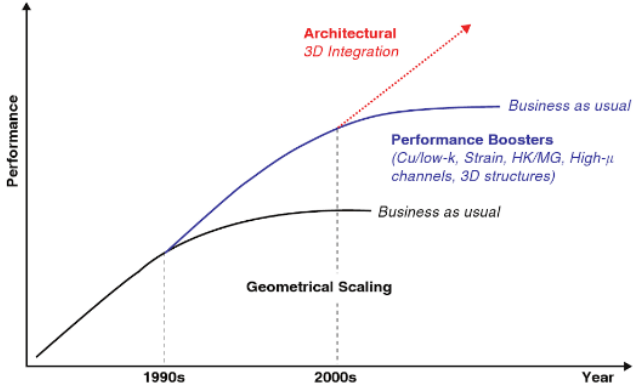




Fig. 1.2 Historical IC performance growth can be sustained with a new paradigm shift to 3-D integration

# RELEVANT TRENDS IN ELECTRONICS
## AT DEVICE/CIRCUIT LEVEL

| Type of action |
| --- |
| Measure the data? |
| Locally storing and processing the data |
| Transmit the data |
| Analyze and store the data at higher aggregation level |
| Control → Actuation by switching of power transistors |

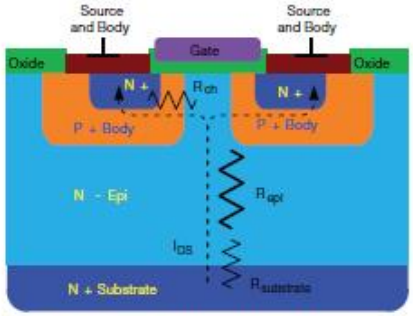



Fig. 1a - Conventional Planar MOSFET Structure

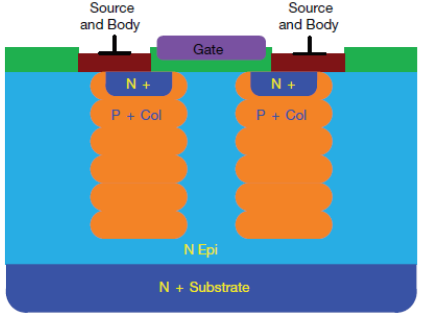
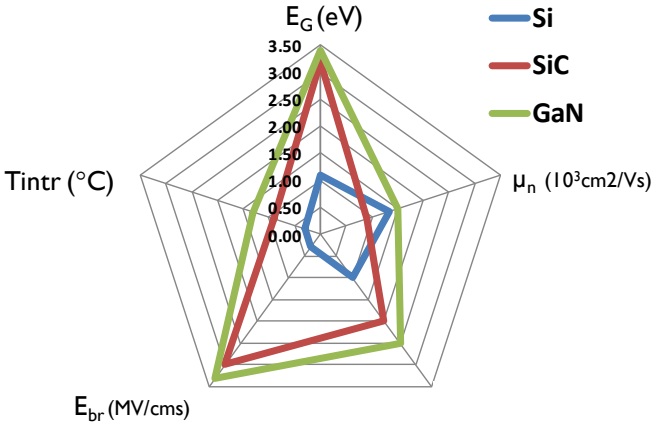
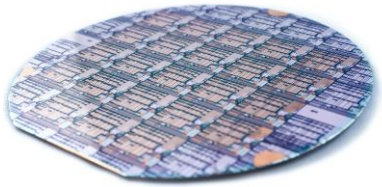
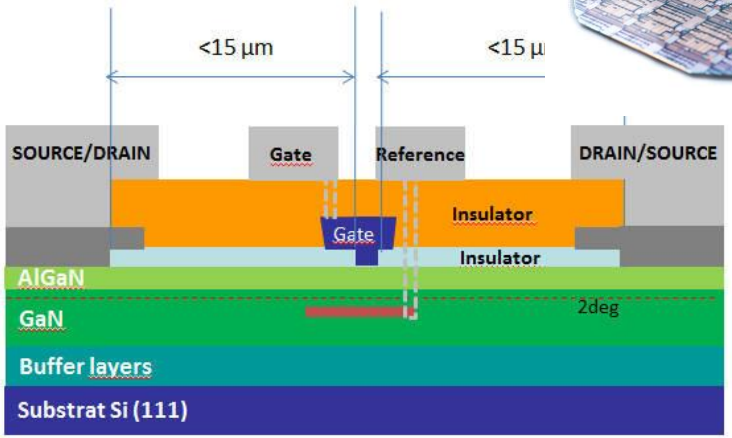




Fig. 2 - Superjunction MOSFET Structure

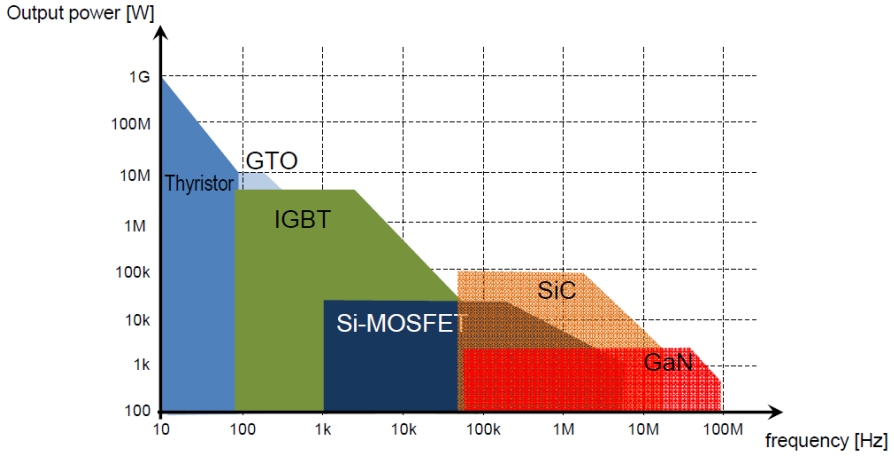


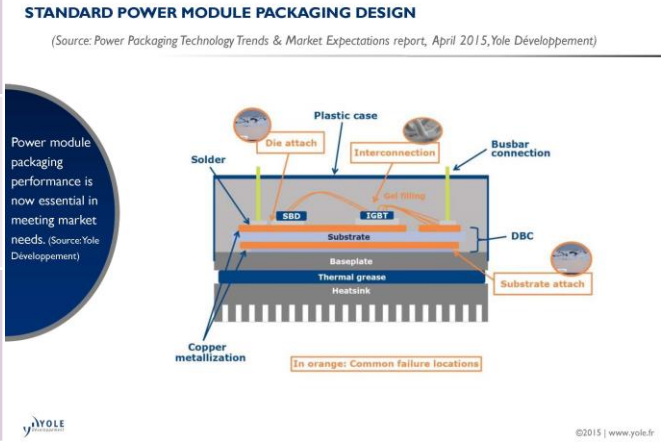



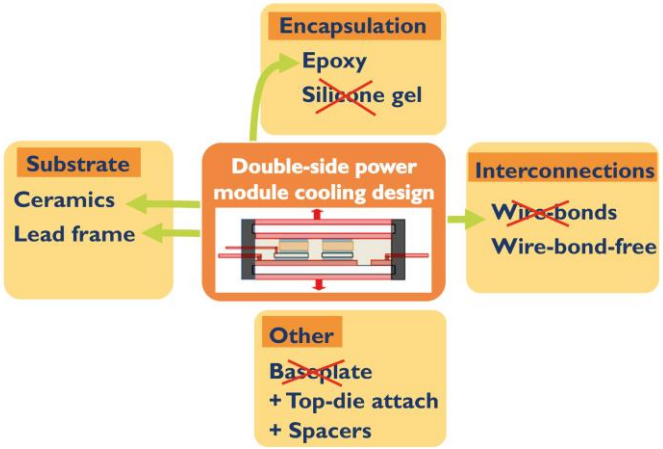


# RELEVANT TRENDS IN ELECTRONICS
## AT DEVICE AND PACKAGE/CIRCUIT LEVEL

| Type of action | Package/circuit level |
|---|---|
| Measure the data? | Post CMOS-processing<br>MEMS<br>Thin-film electronics<br>SOC<br>... |
| Locally storing and processing the data | Low cost/transistor<br>Low-energy data processing |
| Transmit the data | |
| Analyze and store the data at higher aggregation level | |
| Control → Actuation by switching of power transistors | |

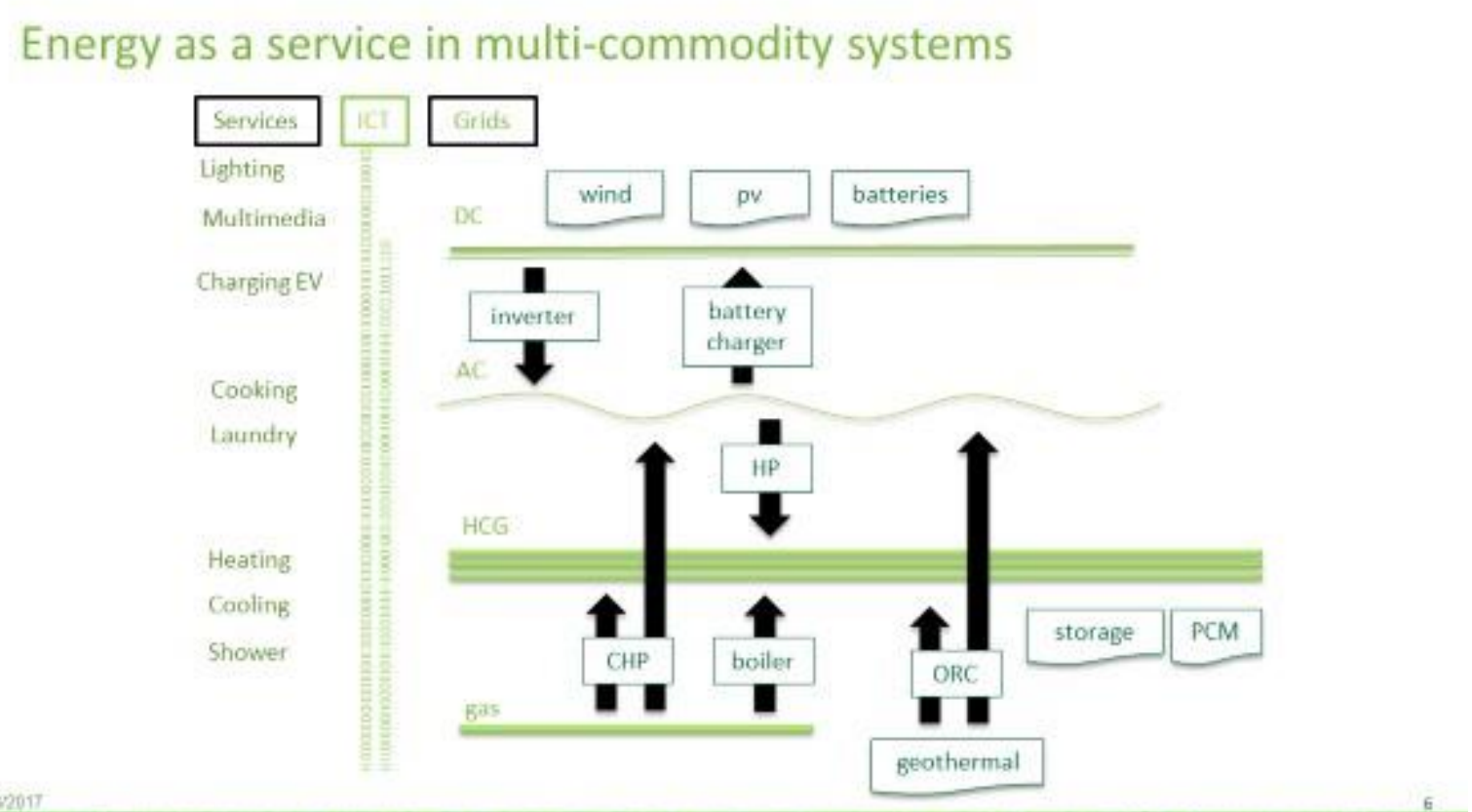


# FROM ELECTRICITY MARKET TO ENERGY MARKET

## MULTI-ENERGY NETWORKS TO PROVIDE MORE MEANS OF FLEXIBILITY …



# OUTLINE

- The Energy System, Quo Vadis?
- Technical hurdles
- Relevance of developments in electronics for electrical and multi-energy networks
- EnergyVille Case : Marrying Energy and ICT on R&D&D-level

imec EnergyVille

# EnergyVille

Research
into sustainable energy
and smart energy systems

# Flemish energy research partnership by

**VITO**
- Energy Technology
- Sustainable Cities

**KU Leuven**
- Electa
- Building Physics
- Mechanics

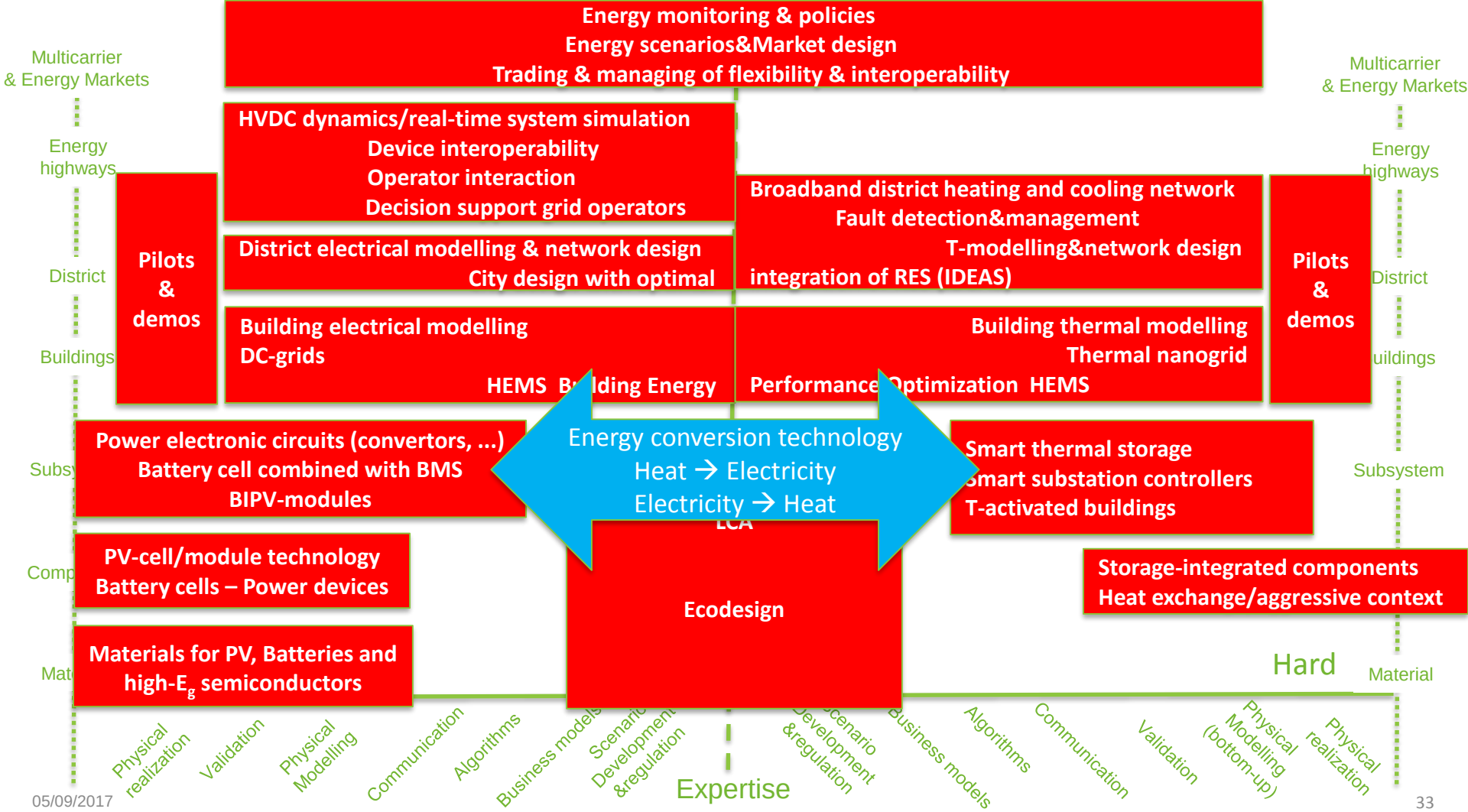
**imec**
- Photovoltaic Research
- Solid-state batteries
- Power devices
- Energy yield forecasting

**UHasselt**
- Materials
- Reliability

# EnergyVille Vision

## Combining energy and ICT

The **concurrent spectacular technology innovation and cost reduction of both ICT and distributed energy resources** creates a unique opportunity for the transition towards a sustainable energy system. This **decentralized multi-energy system will be characterized by a dominance of electricity** as energy vector **strongly coupled with other carriers** as for instance thermal energy. The deployment of this energy system in a **highly complex urban context**, ensuring **security of supply, resilience and sustainability** will be the cornerstone of the Sustainable City.


Energy monitoring & policies
Energy scenarios&Market design
Trading & managing of flexibility & interoperability
Multicarrier & Energy Markets
Energy highways
District
Buildings
Subsystem
Component
Material
HVDC dynamics/real-time system simulation
Device interoperability
Operator interaction
Decision support grid operators
District electrical modelling & network design
City design with optimal
Building electrical modelling
DC-grids
HEMS
Pilots & demos
Broadband district heating and cooling network
Fault detection&management
T-modelling&network design
integration of RES (IDEAS)
Building thermal modelling
Thermal nanogrid
Performance Optimization HEMS
Pilots & demos
Power electronic circuits (convertors, ...)
Battery cell combined with BMS
BIPV-modules
Energy conversion technology
Heat → Electricity
Electricity → Heat
Smart thermal storage
Smart substation controllers
T-activated buildings
PV-cell/module technology
Battery cells – Power devices
Storage-integrated components
Heat exchange/aggressive context
Materials for PV, Batteries and high-$E_g$ semiconductors
LCA
Ecodesign
Hard
Physical realization
Validation
Physical Modelling
Communication
Algorithms
Business models
Scenario Development &regulation
Expertise
Physical Modelling (bottom-up)

# KEY MESSAGES

- Quantitative assessment of impact of electronics trends depends on deployment scenario for a more distributed/sustainable energy system
- In all cases there will be a high impact of evolutions on the level of (power) electronics for these new energy grid architectures
  - To handle large amount of data
  - To be used for correct assessment of grid state
  - To be used for decision support/self-learning
- The cost reduction and performance increase (in terms of speed and energy/bit) of sensorics, data processing & communication key enabler for the distributed energy system of the future.
- EnergyVille brings together Energy and ICT to address these challenges and the partners to cover different aggregation levels to prove materials & devices on system level


embracing a better life