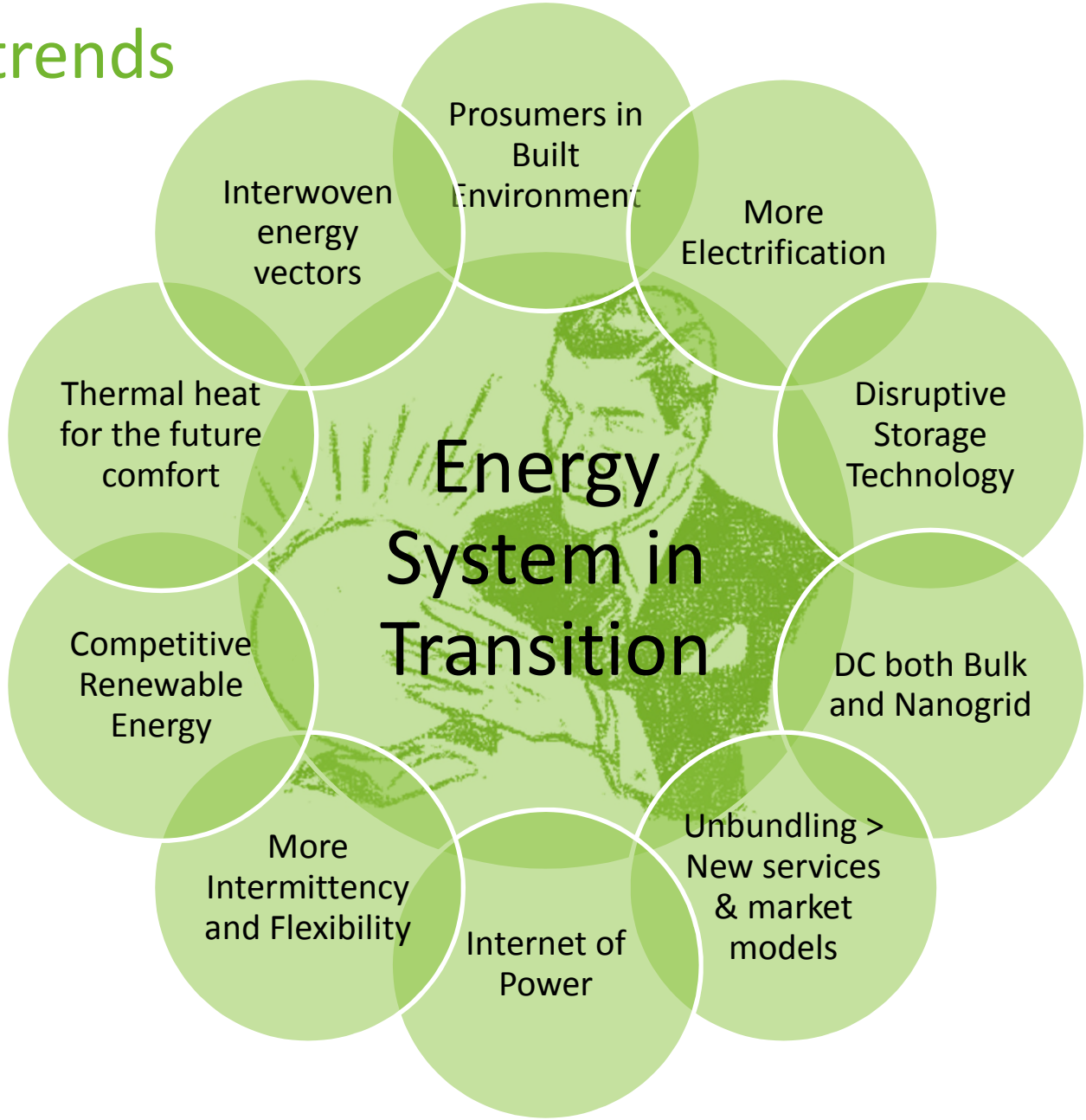
EnergyVille

Research

into sustainable energy

and smart energy systems

Megatrends


Energy System in Transition
Prosumers in Built Environment
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

EnergyVille

- Large Energy Consumers
  - Commodity
  - PRICE, PRICE, PRICE and reliability
  - Electricity and gas are products
  - Europe based
- Service for Small Consumers
  - Energy sources: do not care
  - Comfort, well-being
  - SME: Sit back and relax
  - Local-based (Flanders, ….)

Large Energy Consumers

- Energy: one of the major cost drivers
- Mainly electricity and/or gas
- Conversion internally (CHP)
- Flexibility in some of the manufacturing processes recognised
- Flexibility can become much wider (eg electrical steam generation)
- Sourcing: Europe-wide for electricity; global for gas
- Often international contracts
- Internal competition (different sites globally and European): energy price as element of choice

Small Energy Consumers

- Home: gas, heat, electricity
- SME: manufacturing
- Office Buildings
- Specific buildings (hospitals, education, …)
- Ownership is critical

Is Energy Efficiency THE Issue?

- Comfort or efficiency
- What if marginal cost is zero?
- Capex versus Opex
- Flexibility may cause energy loss (cooling warehouses)
- Quality of energy: low temperature heat versus electricity
- Better efficiency, less flexibility

Consumer at the center

Energy System

Less energy – More electricity – Smart Heat

- Better insulation: electric heating & increased potential for renewables
- Heat pumps: combination of green electricity and green heat
- Advanced heat networks (4th generation)
- Renewables: common carrier is electricity
- Transport
- Gas demand goes down

The end of the kWh as billing unit for energy

- 30 % is commodity (energy) cost
- 40 % grid
- 30 % levies
- Only for commodity kWh is relevant
- Grid: capacity
- Levies: policy
- Commodity is marginal cost, goes to zero
- Capacity for grid service
- Local generation/storage: disconnection feasible?
- Insurance contracts

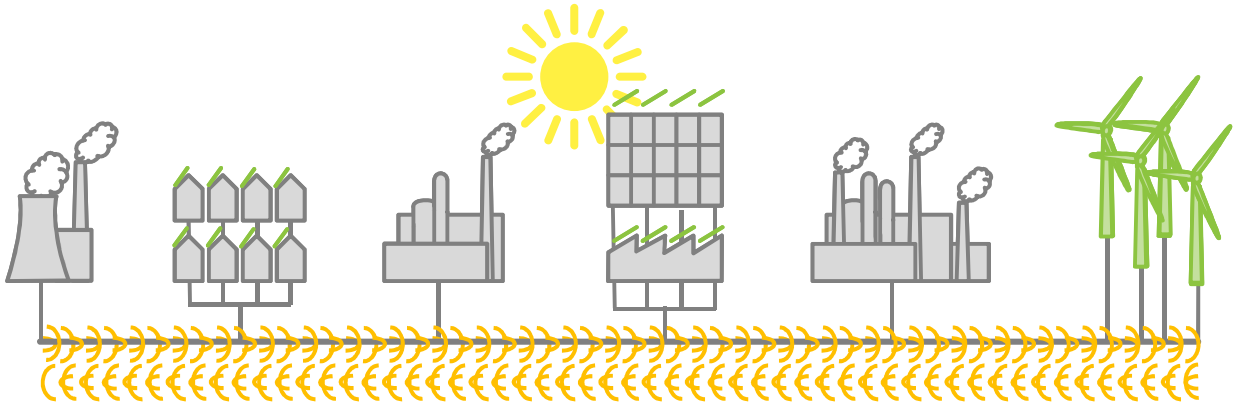
The world is changing

Europe:

40%

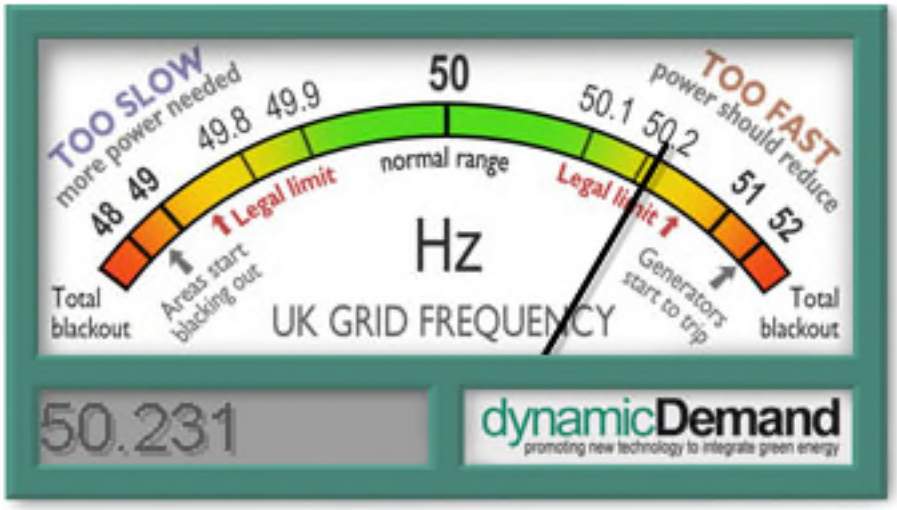
LESS CO_2 EMISSIONS
vs. 1990

Trends

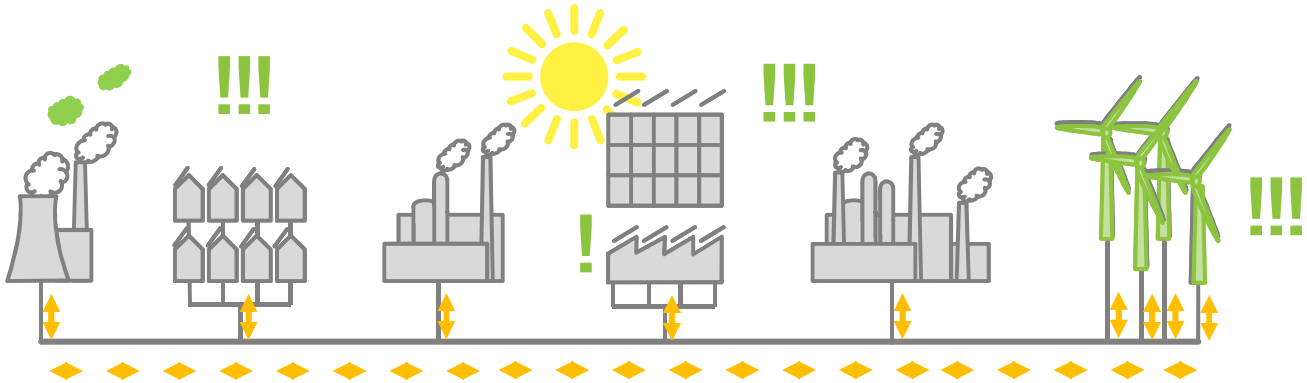


- Large-scale integration of Renewable Energy Sources
- Large-scale integration of Distributed Energy Resources
- Evolution towards smart grids

Balancing the grid



Challenges



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

How to tackle these?

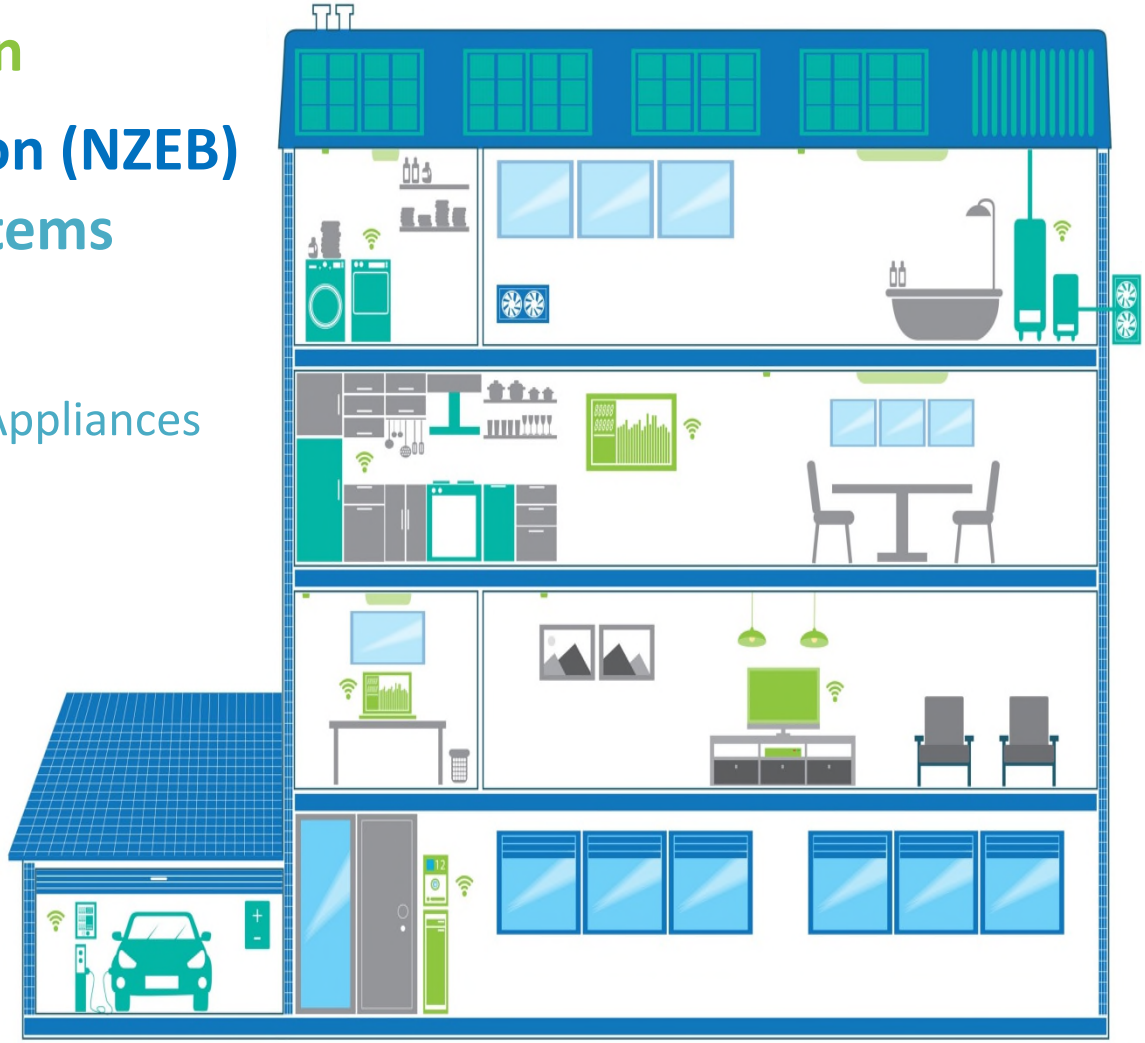
“ To adapt

… or to adapt ”

Hobson’s Choice

Smart Homes … from which perspective?

- **Home Automation**
- **Smart Construction (NZEB)**
- **Smart Energy Systems**
  - Smart heat Pump
  - Solar panels
  - Smart Household Appliances
  - EV Charging



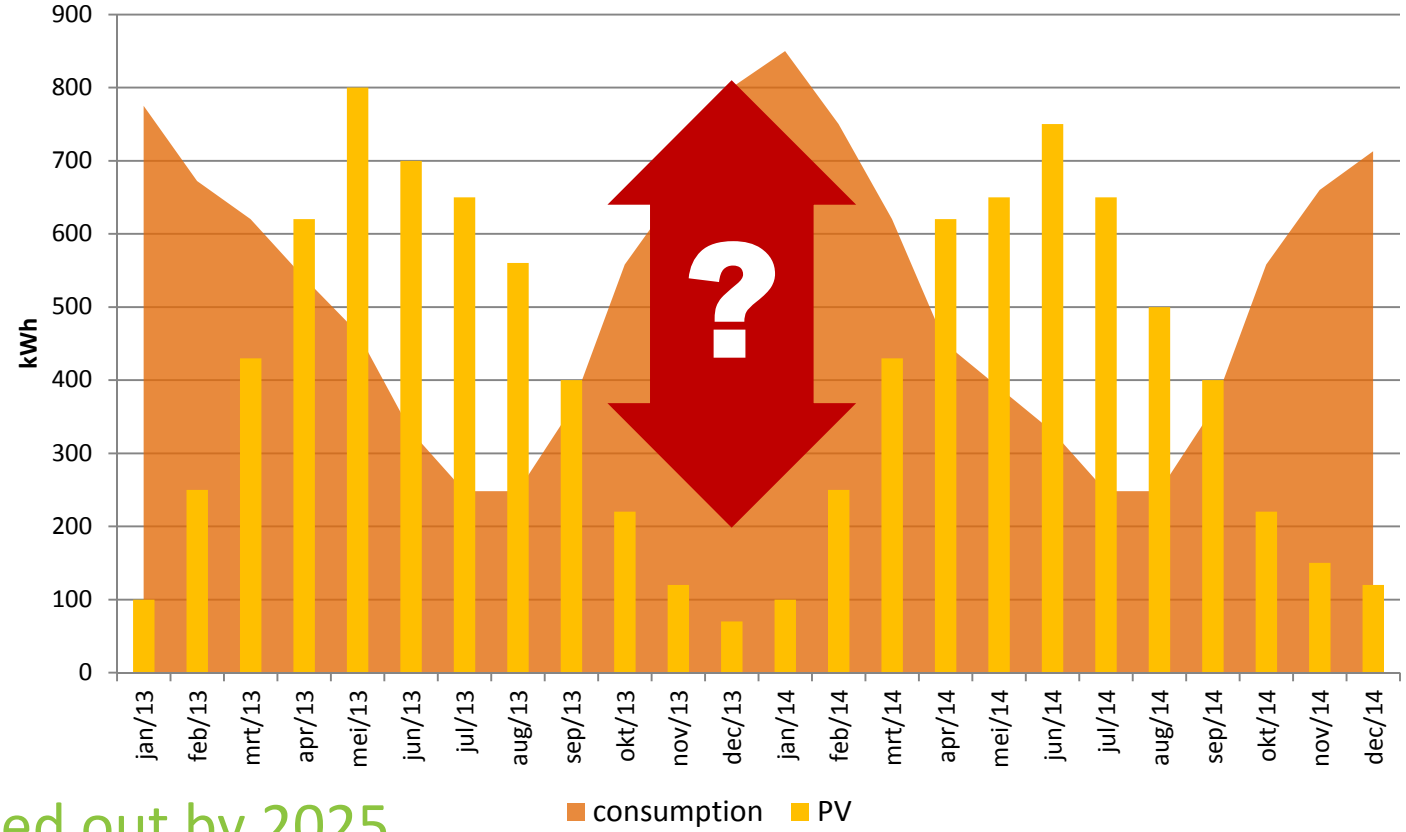
Nearly Zero Energy Buildings and the reality of energy markets

Insulation

Ventilation

Heat pumps

+ PV



Nuclear phased out by 2025

Currently no investments in gas plants

Biomass: 200M€/year subsidies for 400 MW plant

Your Home, an Intelligent Energy Cluster

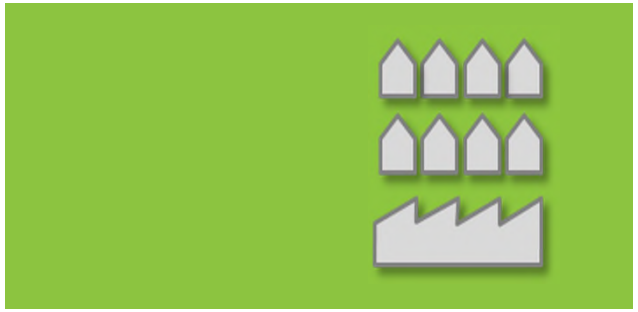
- Investments
  - ROI (financial)
  - Peace of mind (insurance)
  - Time Management (comfort)

? reduce CONNECTION CAPACITY, while increasing total electricity consumption

? Back-up = STORAGE
HEATING + DC (LED, multimedia, mobility, …)

? AUTOMATED SYSTEMS
climate control, cost savings ToU prices

Flexibility is key – an opportunity!

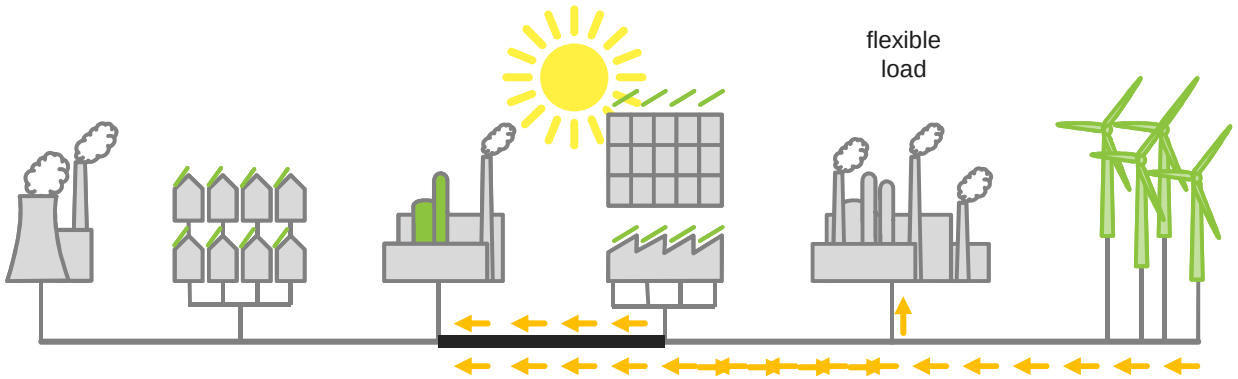


- Consumer-side Flexibility
  - Shiftable Demand

- Generation-side Flexibility
  - Flexible Generation

- Storage
  - Electricy
  - Heat

Consumer Flexibility: demand response

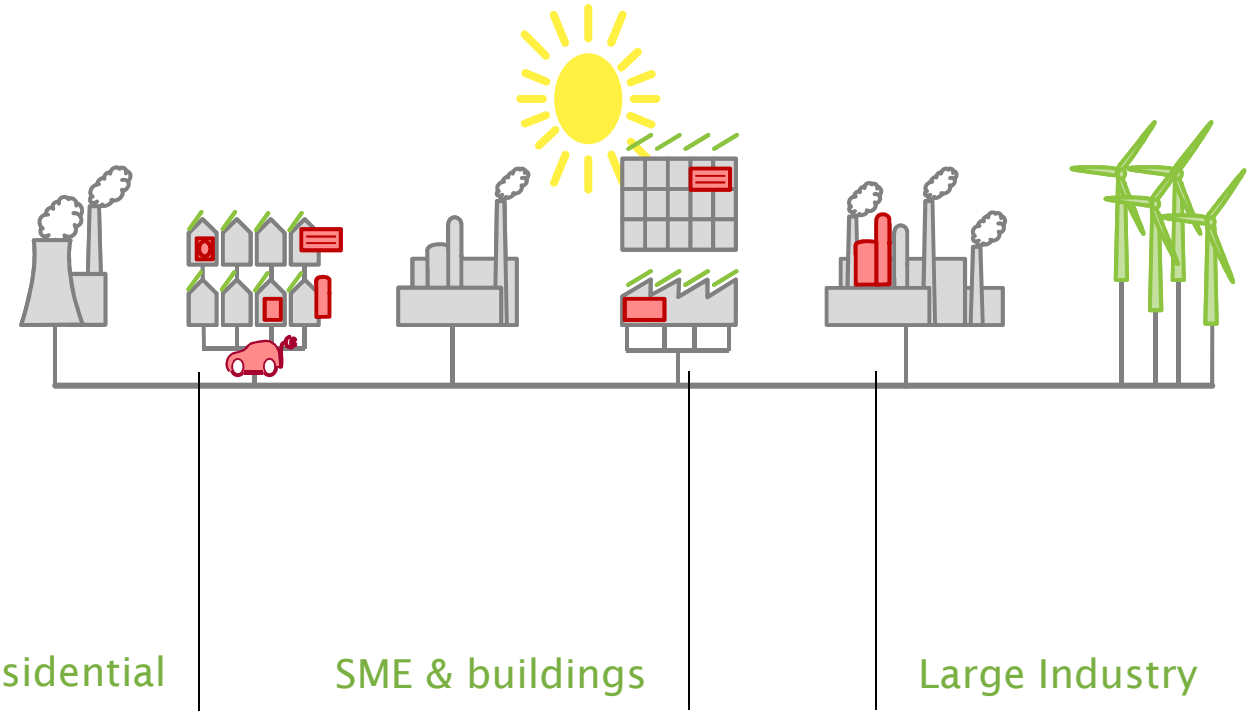


- When nts of renewable energy are injected, grid overlo s are possible
- Activa tional demand can solve this

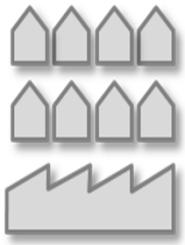
Quote (Art. 15.8) from the European Commission Energy Efficiency Directive (2012/27/EU):

"Member states shall promote access to and participation of Demand Response in balancing, reserves and other system services markets"

Sources of Consumer Flexibility



Flexibility is key – an opportunity!



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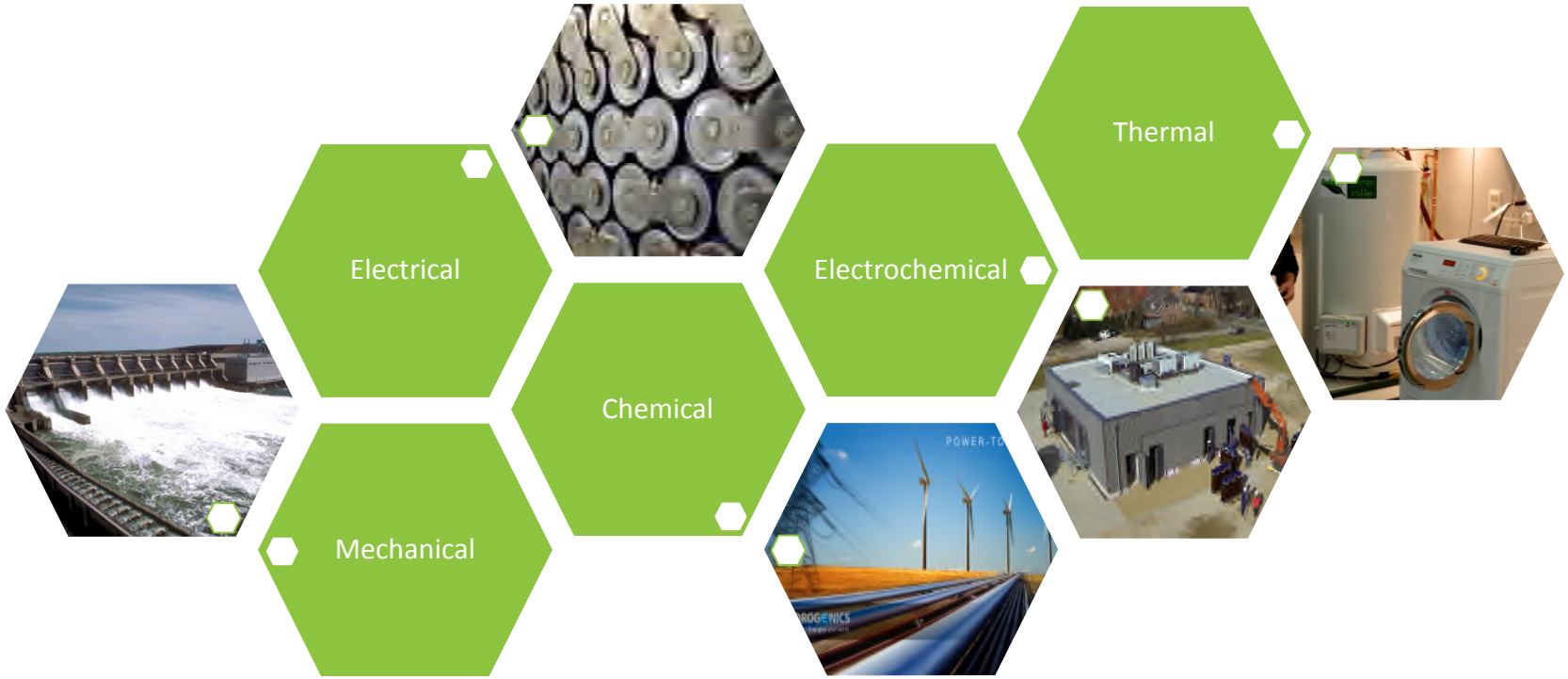
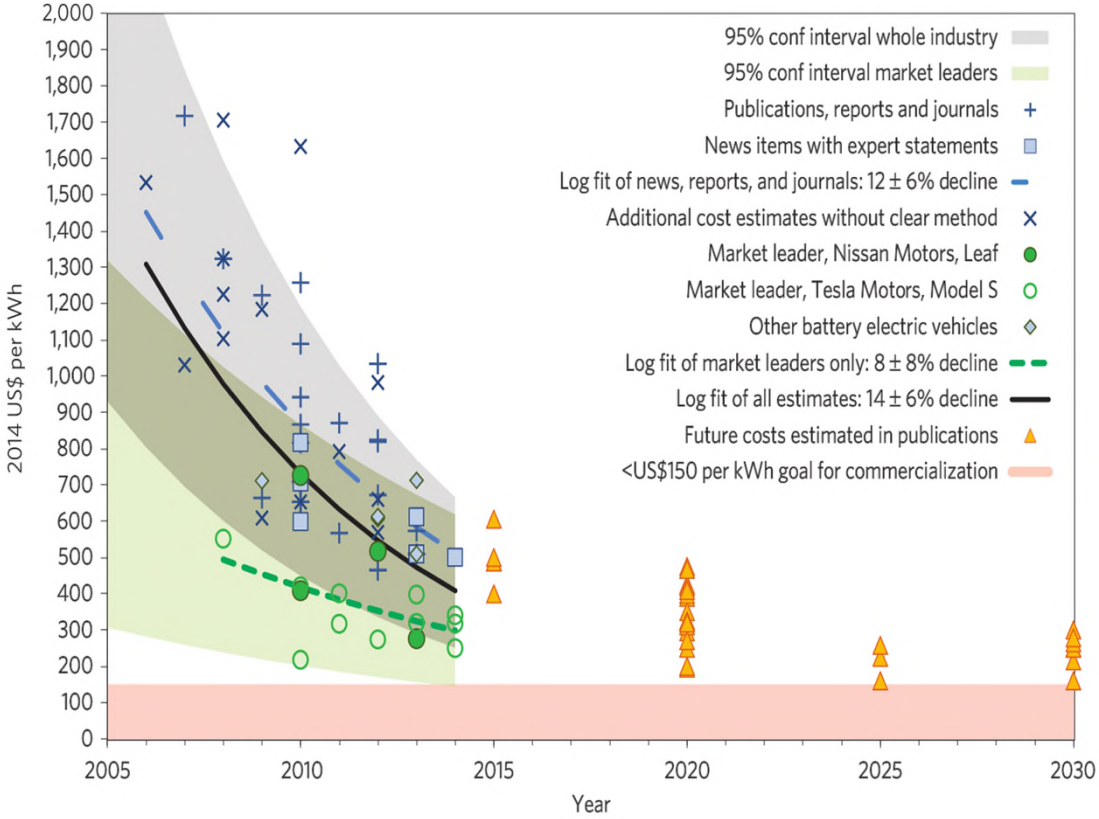
Storage technologies



Batteries

- Pro:
  - Scalability
  - Efficiency
  - Energy Density
  - Mass Production



Rapidly falling costs of battery packs for electric vehicles
Björn Nykvist and Måns Nilsson, Nature Climate Change, 2015

Batteries in Practice

- At your home?

Iron Edison

SolarCity, Tesla Powerwall

Batteries in Practice

- In your car!

Tesla Motors

Flexibility is key

- Consumer-side Flexibility
  - Shiftable Demand

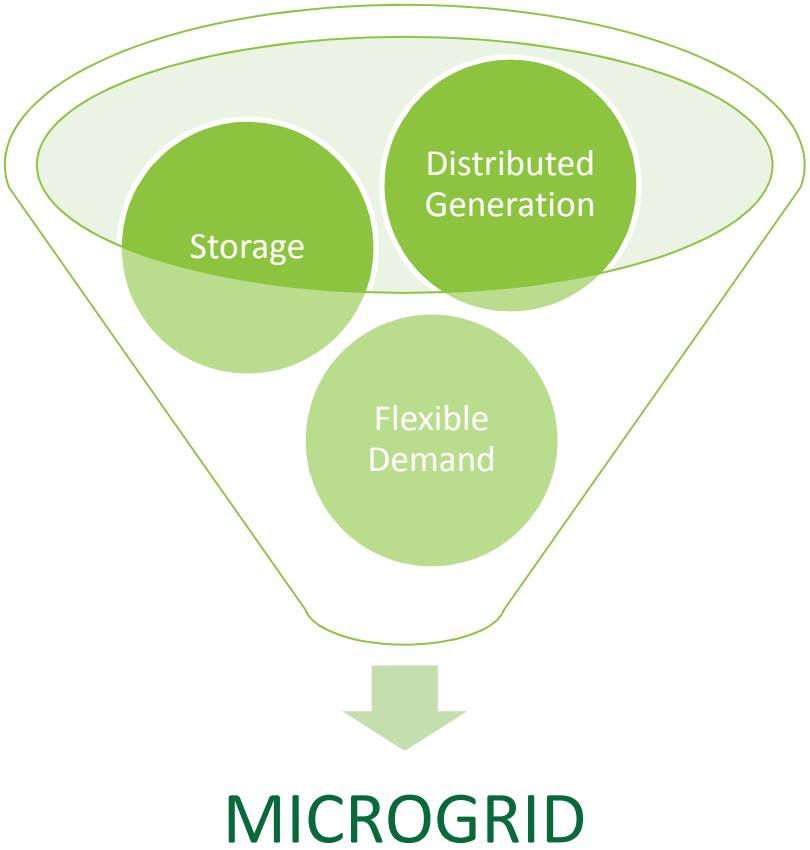
- Generation-side Flexibility
  - Flexible Generation

- Storage
  - Electricy
  - Heat

Dia 26

IB8 zou leuk zijn als we hiervan 3 bolletjes konden maken die dan in de trechter belanden... maar ook wel veel werk :)
Isabelle Borremans; 23/09/2015

Back to the future: Decentralised Supply



Why would flexibility work now?

We’ve already seen:

- Demand-side management
- Decentralised systems
- Electrical vehicles

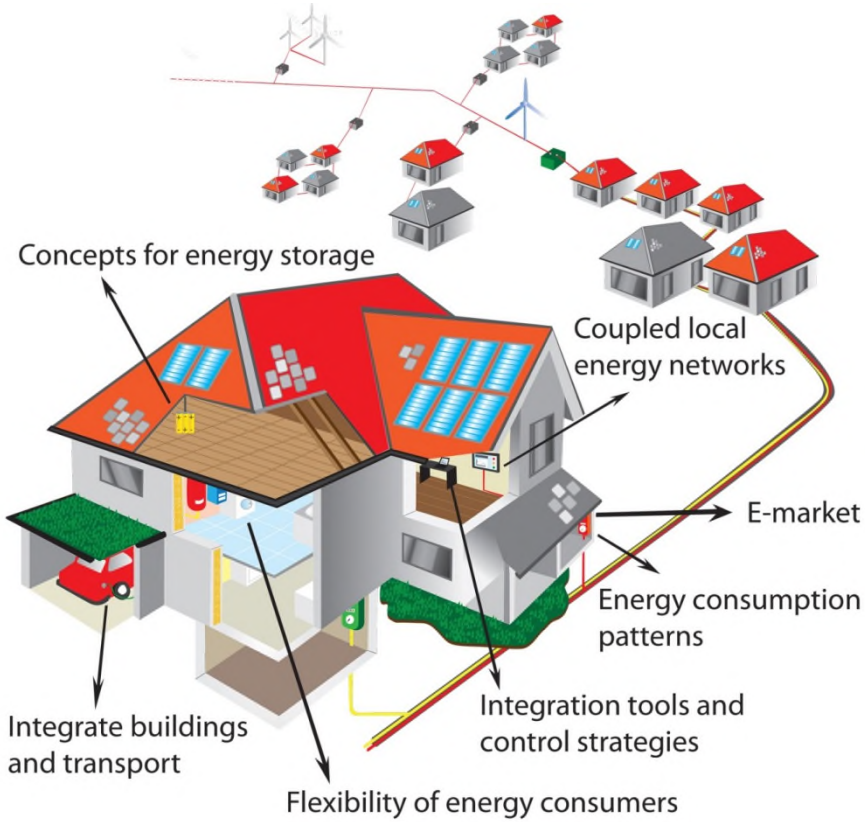
We devices
Communicate
With each other
Share information

- Greater efficiency
- Automation
- Security
- Comfort

NEW

Your home, an intelligent cluster

- End-to-end systems
- Integrate:
  - Security
  - Privacy
  - Stable Performance
  - Big Data
  - Market & Regulation



Dia 29

IB9 Nathalie: uw tekening zal hier beter zijn, best paginagroot zodat de mensen tijdens ronnie's uitleg op hun gemak de details kunnen bestuderen
Isabelle Borremans; 22/09/2015

IB10 voertuig laten oplichten in tweede fase van slide
Isabelle Borremans; 23/09/2015

Flemish energy research partnership by

VITO
- Energy Technology
- Sustainable Cities

KU Leuven
- Electa
- Building Physics
- Mechanics

imec
- Photovoltaic Research

Flemish energy research partnership by

EnergyVille

EnergyVille

Expertise in sustainable energy and intelligent energy systems in the built environment

Research – Development – Training – Industrial Innovation

For:

- Industry
- Public Entities

With:

- Local partners
- Regional partners
- International partners

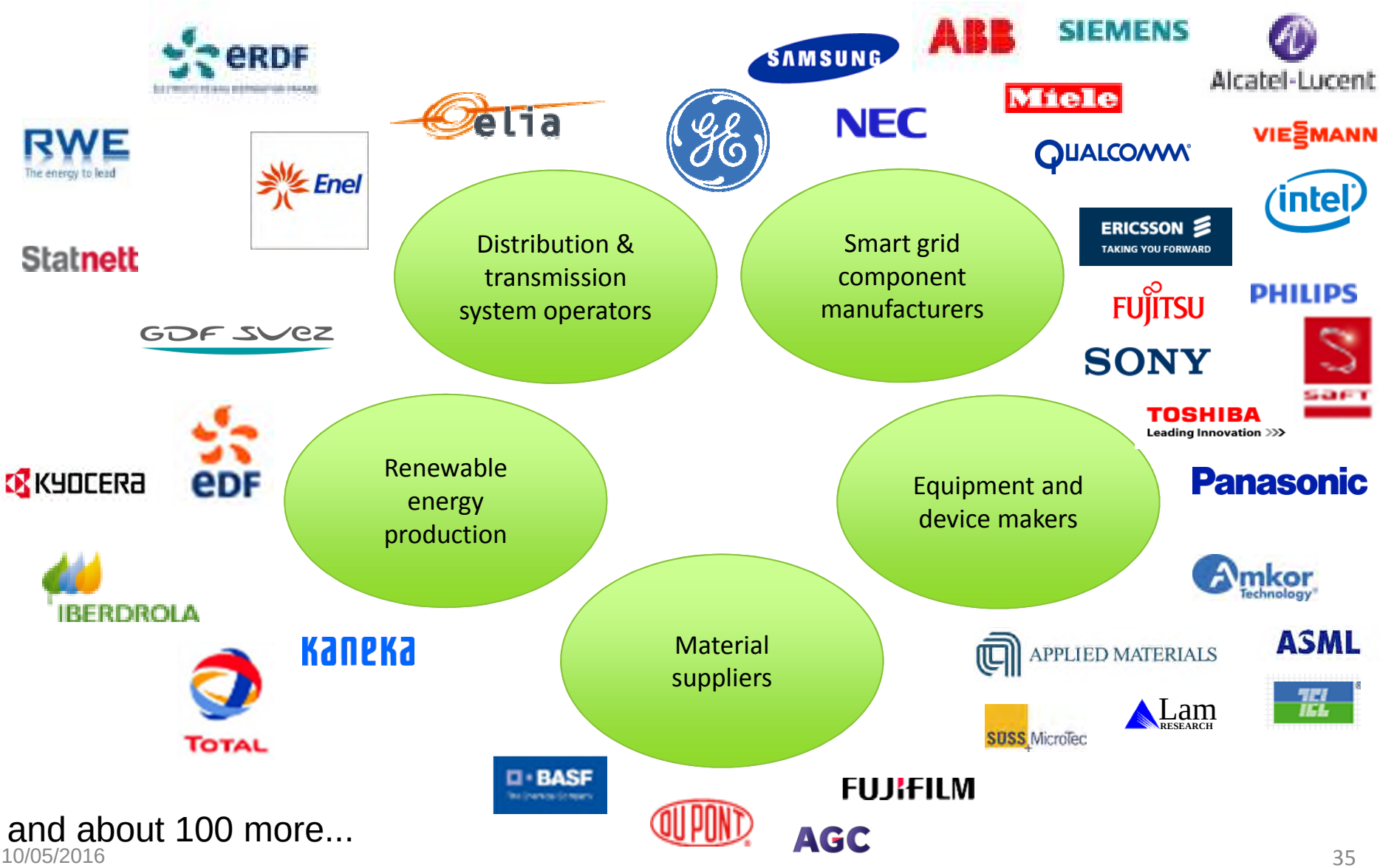
EnergyVille: some figures

Employees	>700	>6000	>3400
Revenues (Meuro)	146	815	363
PhD's	70	>5000	250

"Employees"	200
Revenues (Meuro)	34
PhD's	95

EnergyVille – embedded in a broad context

Some of our global R&D partners across the value chain



and about 100 more...

EnergyVille

- Driving force behind the transition towards sustainable energy supply
- Stimulus for research, business development and jobs in Genk
- Central position in the European knowledge triangle ELAt, Eindhoven, Leuven, Aken

- 15.000m² floor area
- 5.000m² lab infrastructure
- 200 desks
- Parking lot : electrical vehicles
- BREEAM excellence
- **LIVING LAB and by extension ‘regulation free area’**

Labs

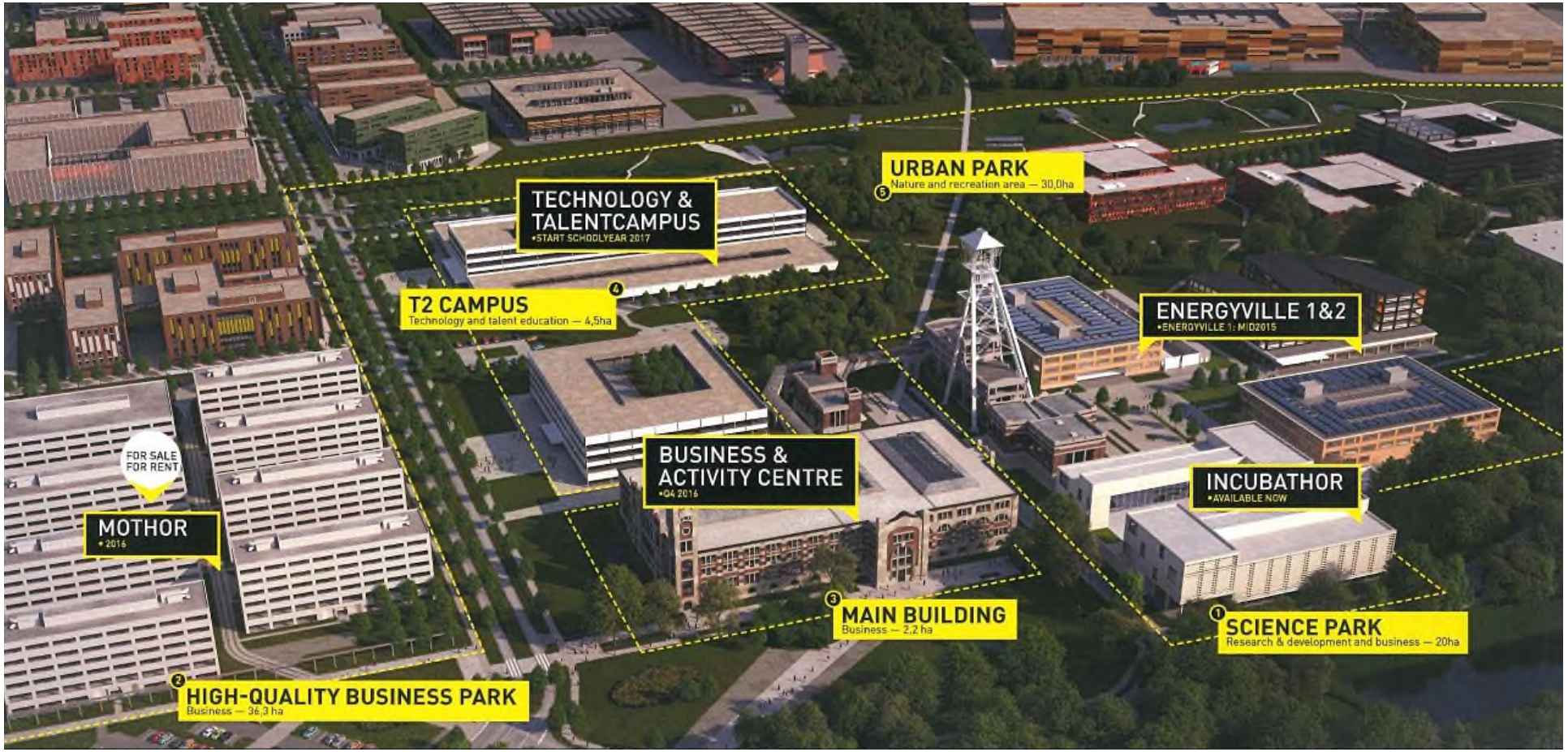
- Battery Testing Lab
- Home Lab
- Smart Grid Infrastructure Lab
- Thermo Technical Lab
- Medium Voltage Lab
- PV Metrology Lab
- Matrix Lab

The story continues: EnergyVille 2

- Facilities
  - 4.900 m^2 floor space:
    - 2.000 m^2 lab space
    - 2.900 m^2 offices
- Planning:
  - Apr 2016:
    building permit
  - Aug 2016:
    start construction
  - Dec 2017: construction ended
  - Apr 2018: installation finished

Embedded in an eco-system

Campus EnergyVille



Thor Park Programme

MenThor

An ecosystem:

Bring stakeholders together

Visions on energy
➔ roadmaps
➔ experiments

Integrate research, education
and entrepreneurship

AcceleraThor

Stimulate start-ups in energy services and technology

1. boost entrepreneurship (FBS)

2. Idea
➔ validated business plan
(KIC InnoEnergy)

3. Upscaling
(LRM/Numha)

IncubaThor

Develop your business @Thor

INCUBATHOR

MoThor

Host teams @Thor

MOTHOR

DemonstraThor

Integrate technology and research

Offer a Living Lab

EnergyVille:
- Home Lab
- Battery Lab
- Matrix Lab
- Thermal Lab
- EV Lab
- Solar Lab

Thor:
- Buildings
- Smart Grid
- 4G Heat Network

Regulation Free Area

R&D thematics & roadmaps

Thematics

Strategy & markets	Energy networks	Buildings & Districts	Storage	Materials & Components
Interoperable flexible trading platforms for energy services and grids Energy monitoring and policy Energy scenarios and strategies	Decision tools for grid operators High voltage direct current grids (HVDC) 4th generation heat networks Micro- and nanogrids with direct current (DC)	Design of energy districts Innovative buidling concepts	Battery management technologies New technology for short term storage Long term storage Thermal storage	**High-efficient & easthetic PV-modules & -panels** **GaN and *passives* for power electronics** **Energy conversion technology**

Roadmaps

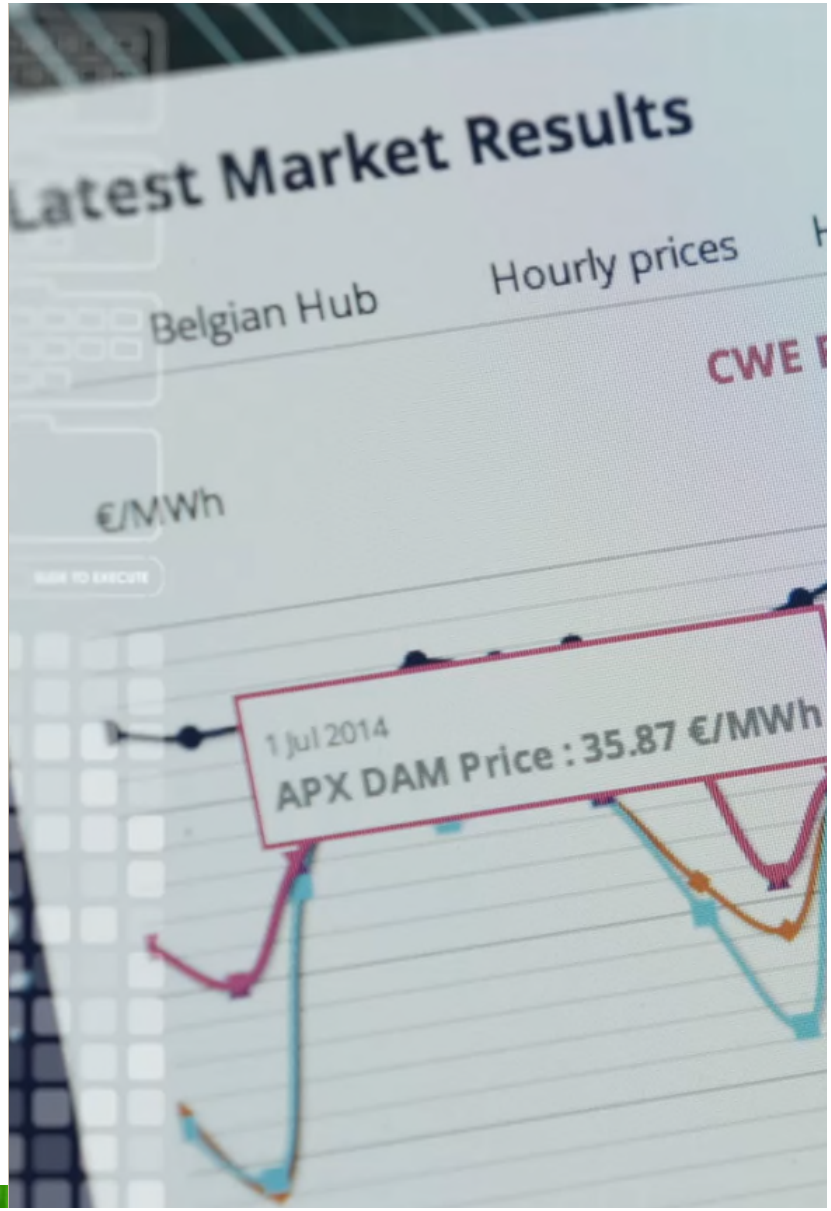
Strategy & Markets

Strategies and markets

- Interoperable flexible trading platforms for energy services and grids
- Energy monitoring and policy
- Energy scenarios and strategies

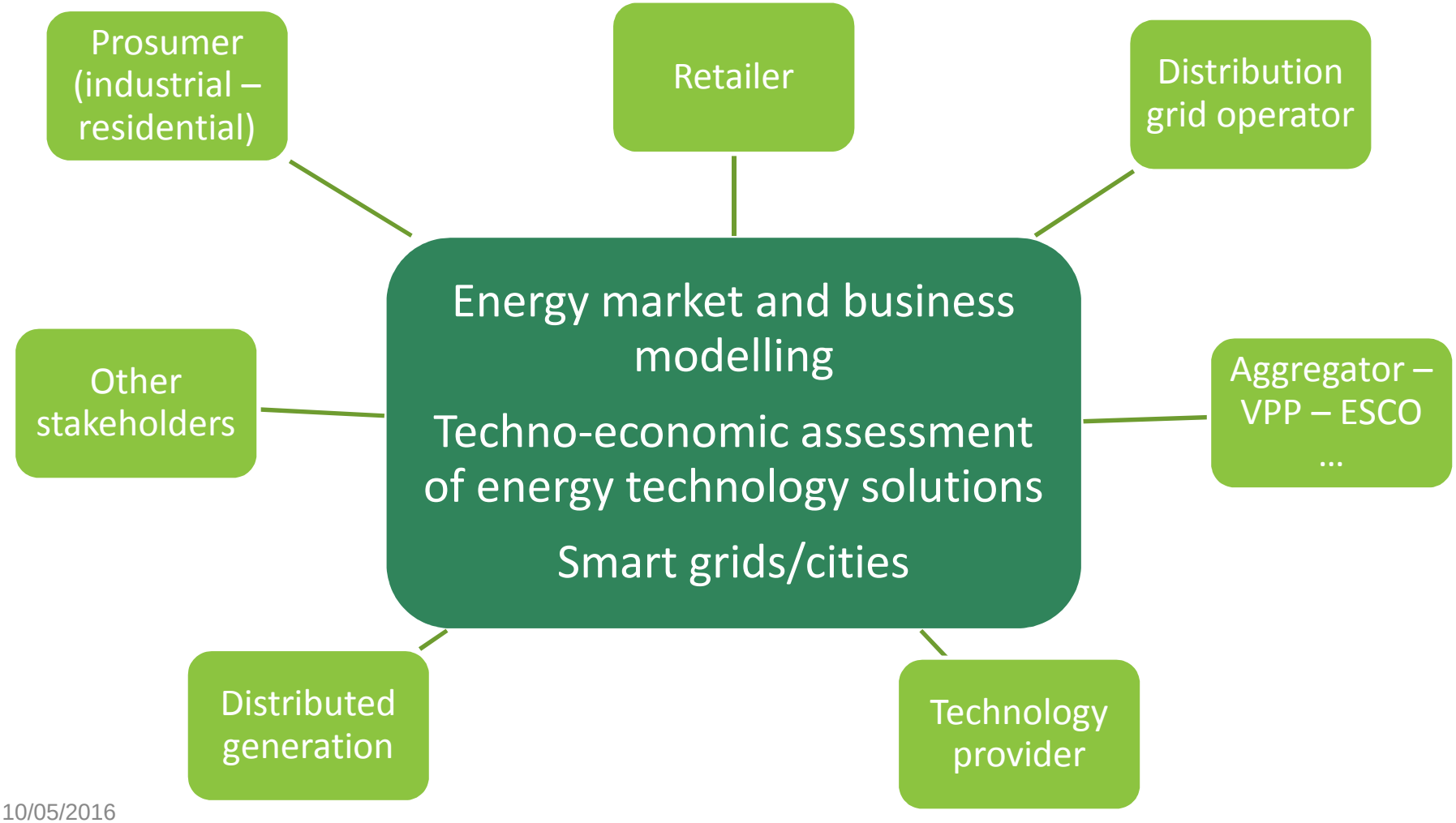
Interoperable flexible trading platforms for energy services and grids

- New concepts for electricity markets
- Interoperability
  - Communication
  - IT
- Virtual Power Plants
- Energy System Analysis
- Living Labs



Interoperable flexible trading platforms for energy services and grids

European Energy Markets

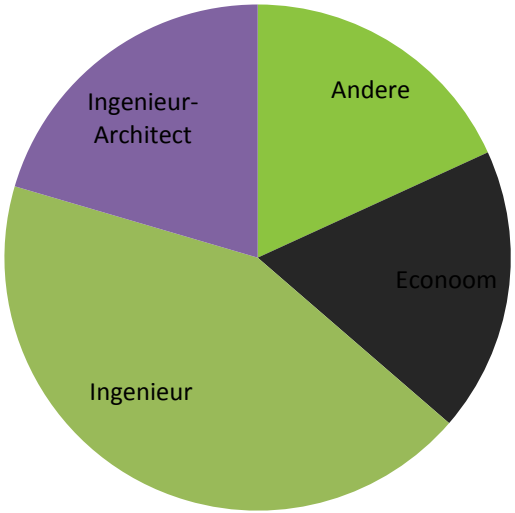


Energy monitoring and policy

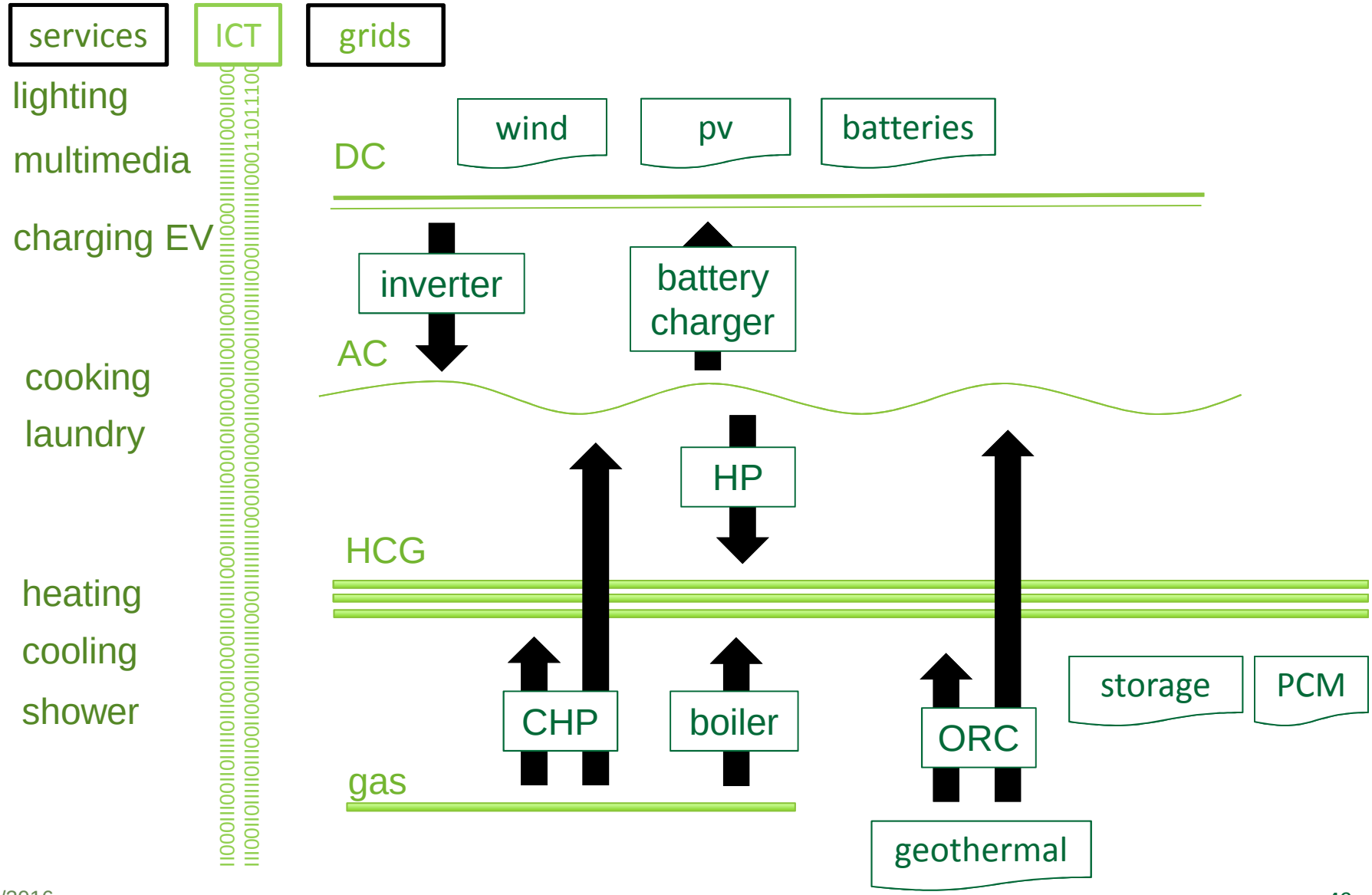
- Energy Scenarios
  - Prognosis for future energy system taking into account existing and/or new policy measure
  - Techno-economic scenario's to evolve to high share of renewables
  - Role of different stakeholders and sectors in energy transition
  - Market introduction of new energy technologies
- Energy policy
  - Impact of policy measures on renewable energy and energy efficiency
  - Optimal integration of renewable energy in dense urban areas

Energy scenarios and strategies

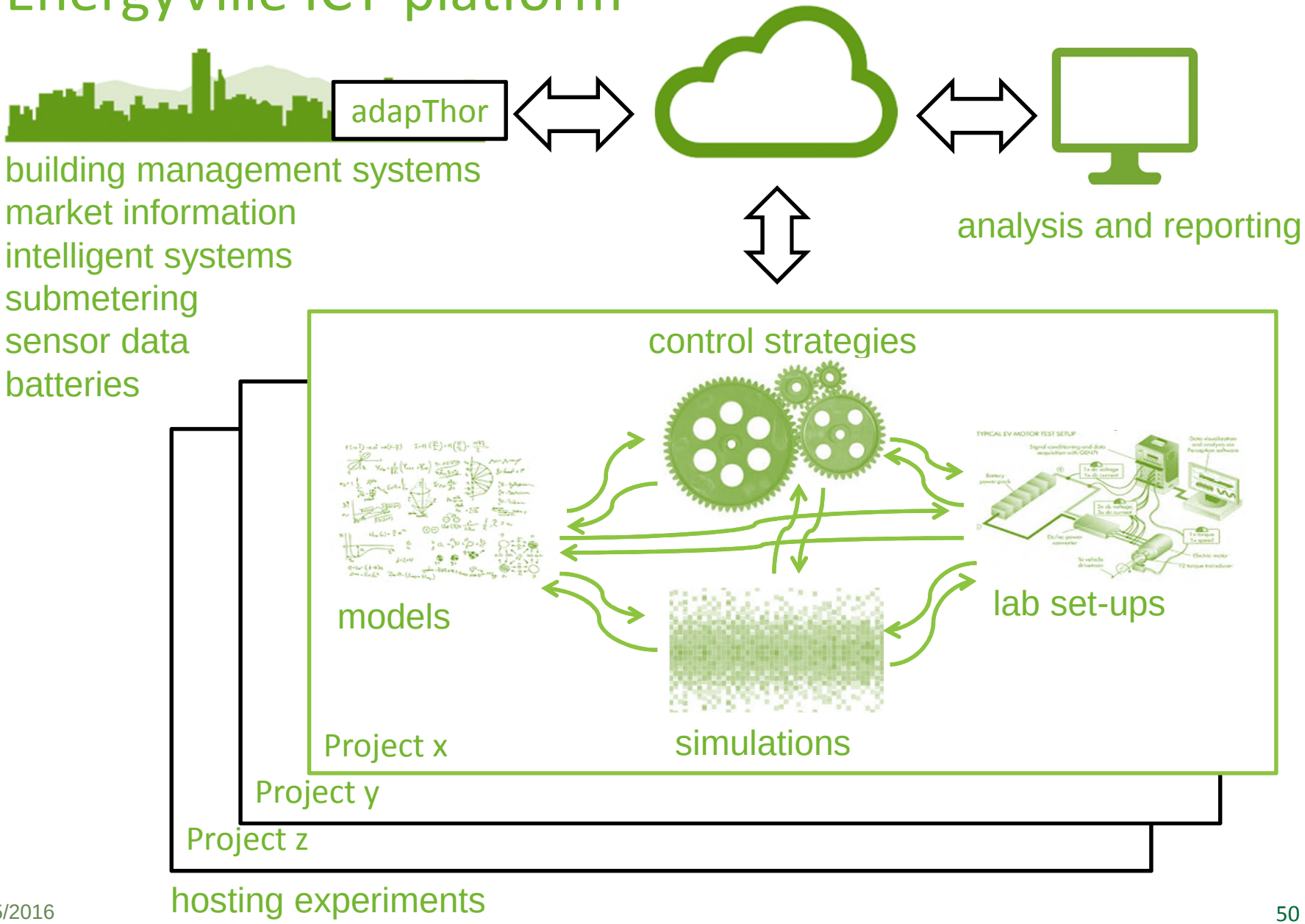
- Scenario, simulation and decision tools
  - Energy modelling (IEA, Markal-Times)
  - Energy simulation tools for built environment
  - Sustainability assessment (LCA, LCC, sustainable buildings and districts, ..)
  - Stakeholder management
- Policy knowledge (EU, national/regional)
  - ex ante/post evaluation, data & time series
  - Domains : energy (RE, EE), climate, building ecolabelling, transport, ..



Energy as a service in multi-commodity systems



EnergyVille ICT-platform



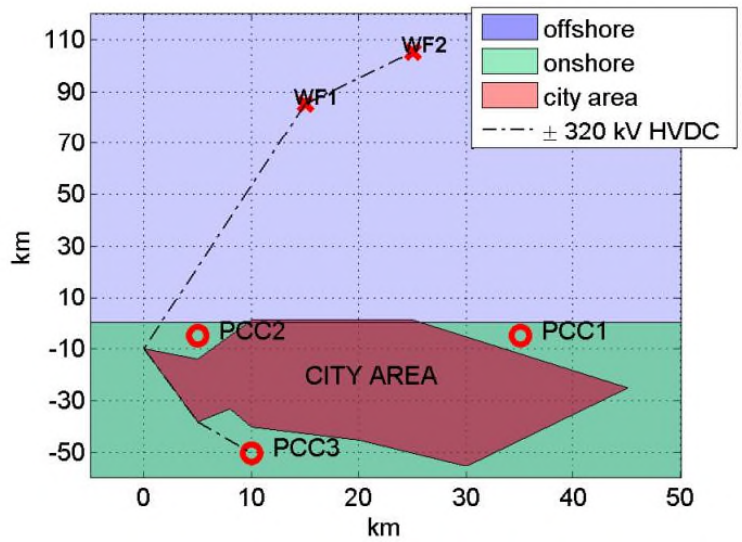
Energy networks

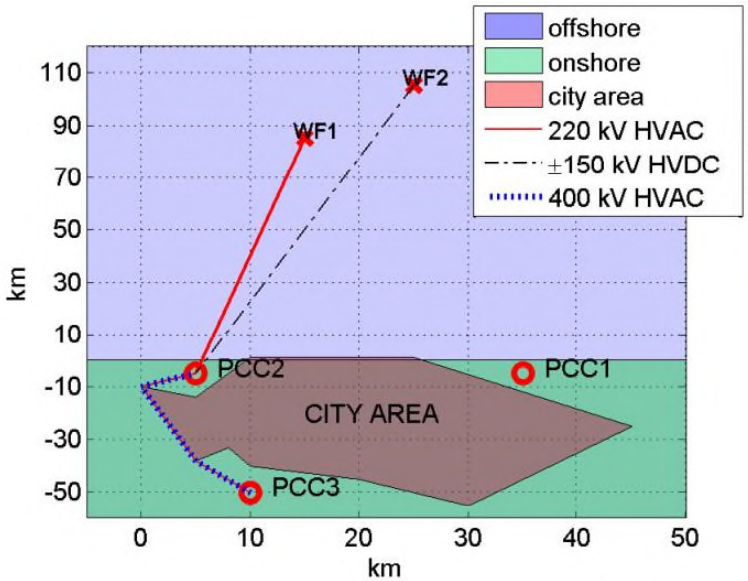
Energy Networks

- Decision tools for grid operators
- High voltage direct current grids (HVDC)
- 4th generation heat networks
- Micro- and nanogrids with direct current (DC)

Decision tools for network operators

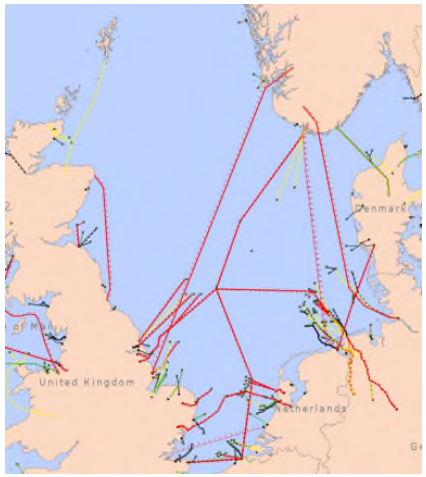
- Grid investments
- Generation unit commitment
- New operational modes for systems
- Grid code compliance
- Control of RES to participate in ancillary services
- Maintaining system reliability under uncertainty

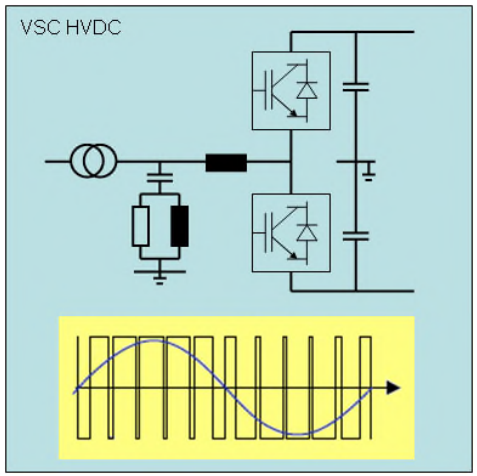




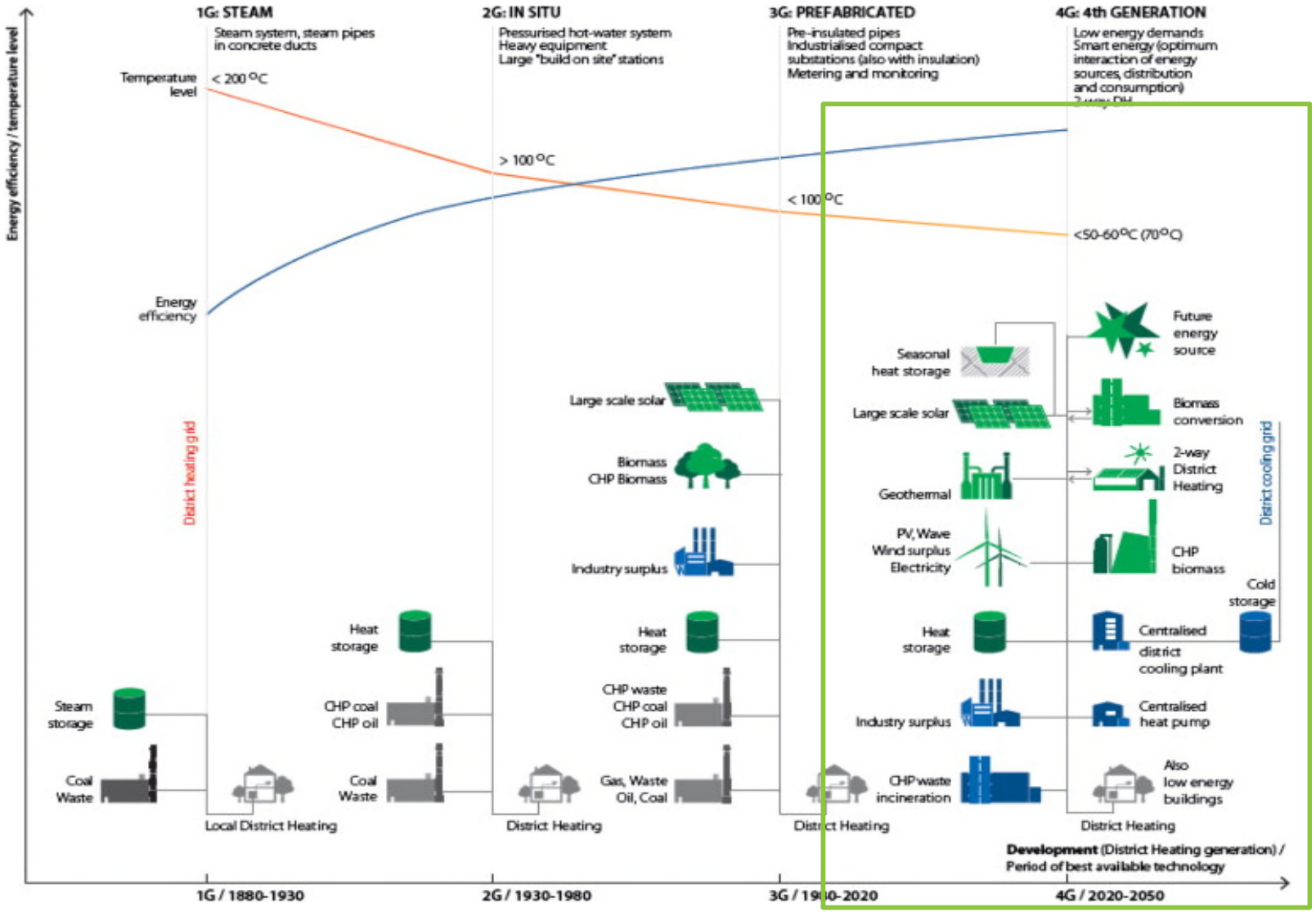
High voltage direct current grids (HVDC)

- New revival
- Additional controllability in the power system
- Offshore grid development
- Long distance underground connections
- Towards an HVDC supergrid





4th generation heat networks



4th generation heat networks

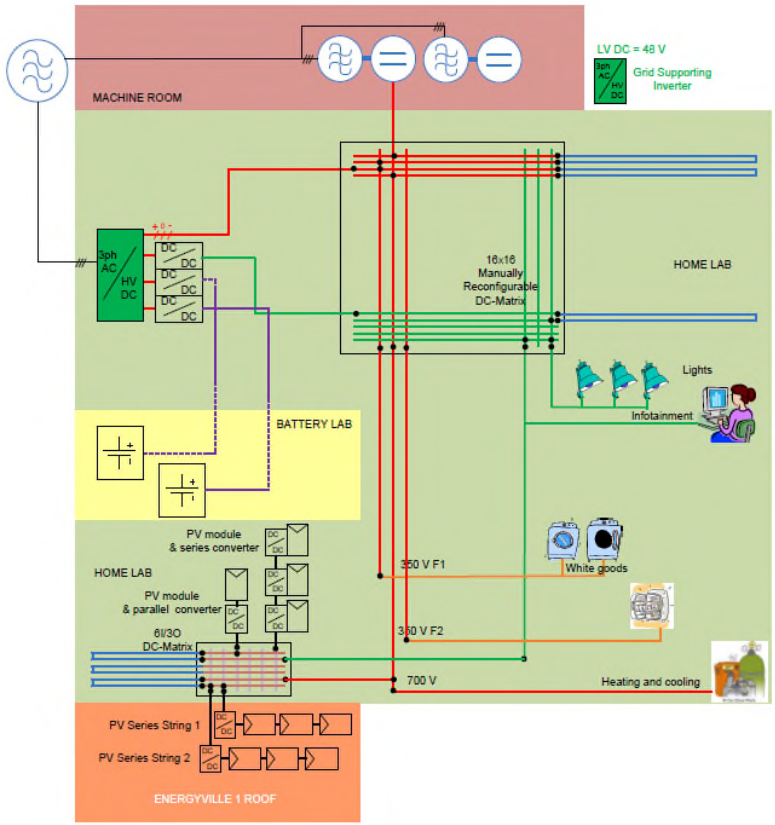
Optimisation of Thermal Energy Systems

- Smart Control
- Optimal Energy Demand
- Advanced Thermal Energy Storage
- Integration of Energy Conversion Technologies

- Integrated System
- Dynamic Behaviour
- Create Flexibility
- RES Integration
- Optimal Interaction
- Energy Efficiency
- Storage Solutions
- Cost Efficiency

Micro- and nanogrids with direct current (DC)

- Small, efficient and reliable DC/DC converters
- Optimized architecture and DC grid control
- Safety, reliability and protection of DC grids
- Interconnection with the AC grid



Demos & Living Labs

- Minewater, Heerlen
- IWT Proeftuin project 'De Schipjes'
- small-scale thermal network on THOR site, connected to our Thermo Technical Lab
- Concrete house, Olen
- Eandis, BTES controller
- Waste-to-Energy: Plasma Reactor (KU Leuven), demo-site enhanced landfill mining (Group Machiels)
- Demonstration of ORC concepts on the geothermal power plant on Balmatt-site of VITO, co-generating heat and electricity

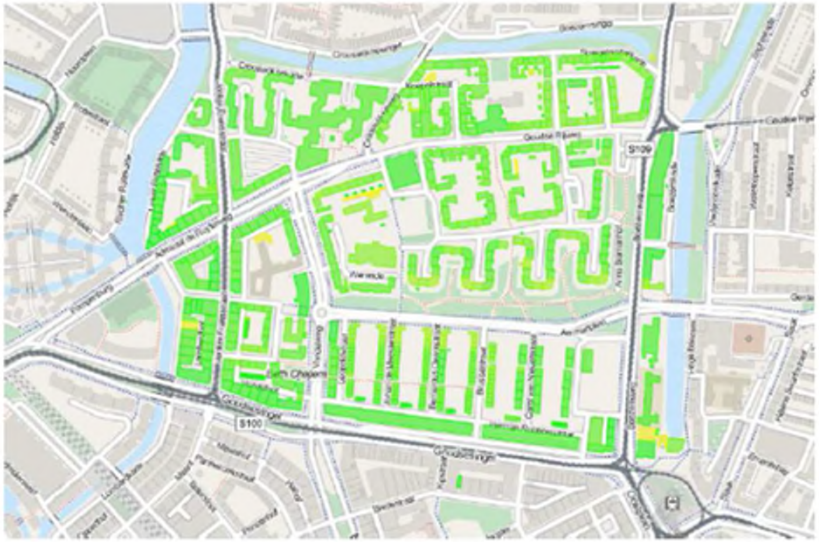
Buildings & Districts

Buildings and districts

- Design of energy districts
- Innovative building concepts

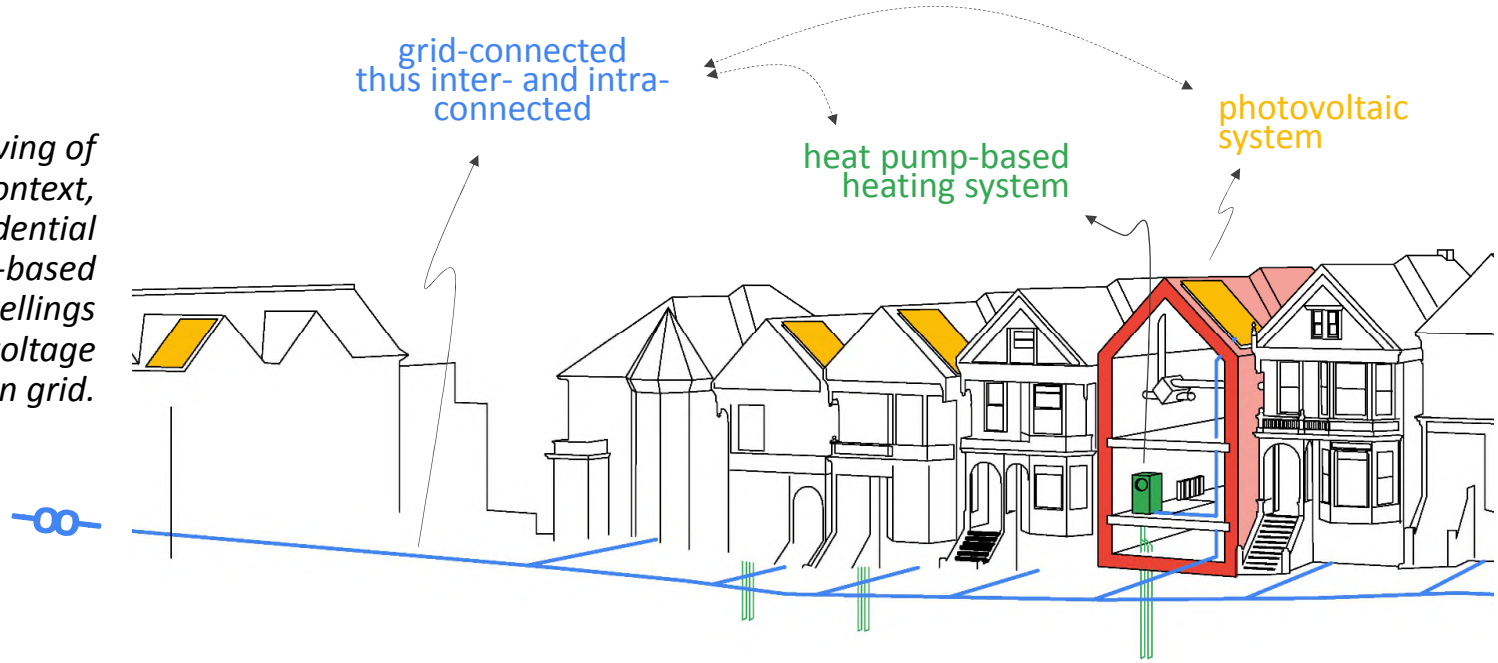
Design of energy districts

- Local energy & climate policy
- Tools for district planning
- Integration of renewable energy : smart grids, district heating and cooling
- Smart city living labs



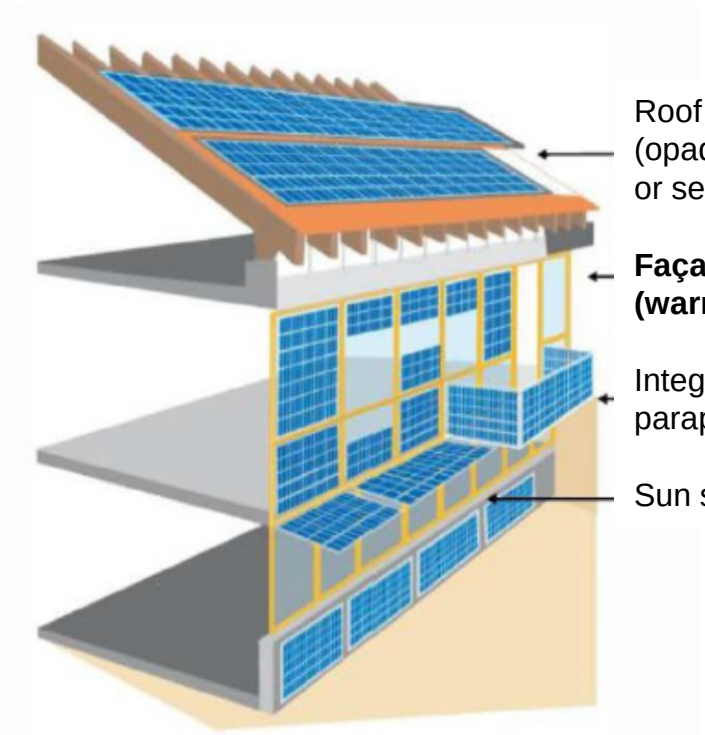
Design of energy districts

Overview drawing of the researched context, i.e. residential heat pump-based low-energy dwellings in the low-voltage distribution grid.



On externalities of heat-pump based low-energy dwellings at the low-voltage distribution grid, R. Baetens, 2015

Innovative building concepts

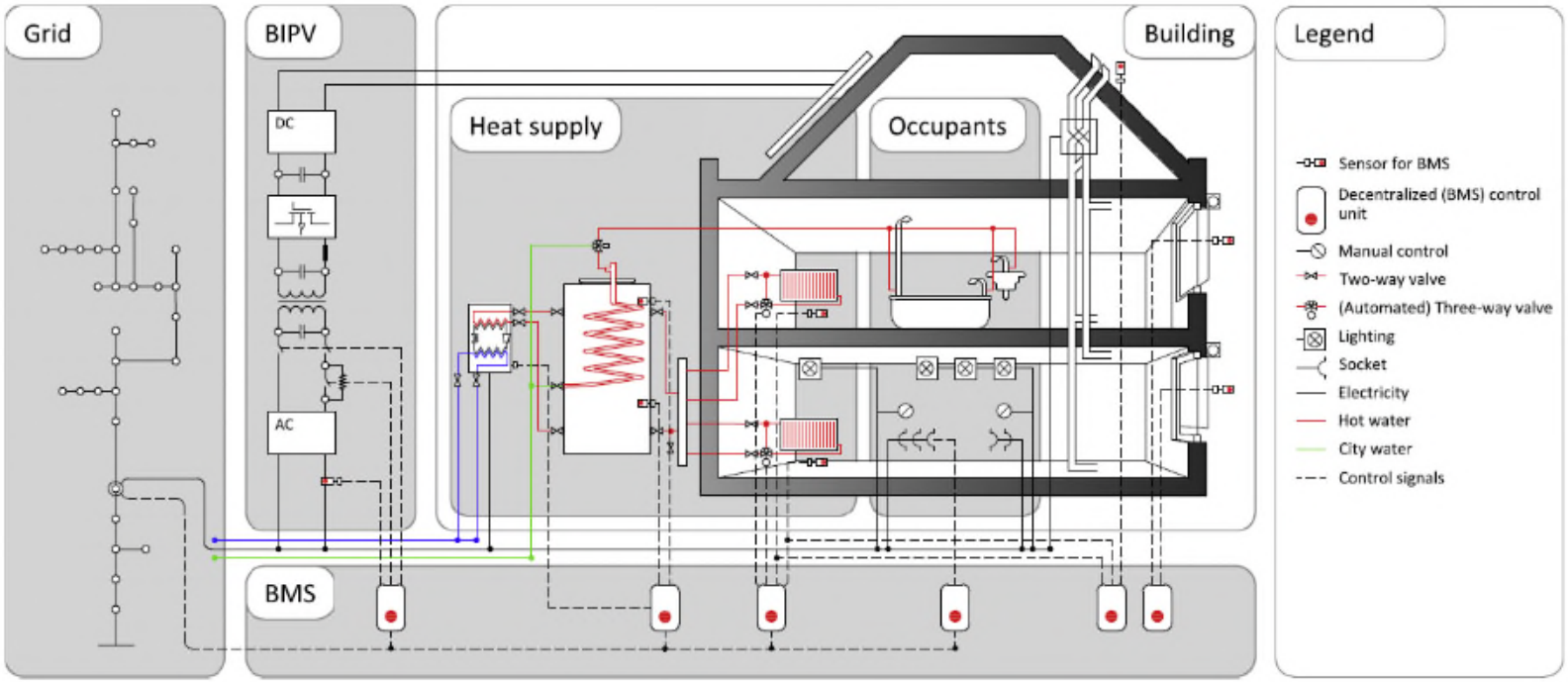


- Today: PV modules ‘added’ to buildings typically on the roof
- BIPV = multifunctional use
  - building component
  - generates electricity
  - Highly application-specific solutions

Innovative building concepts

Integrated District Energy Assessment by Simulation

- Modelica Library
- Interaction with electrical or thermal loads & generators
- Interaction with low-voltage distribution grid



Energy Storage

Energy storage

- Battery management technologies
- New technology for short term storage
- Long term storage
- Thermal storage

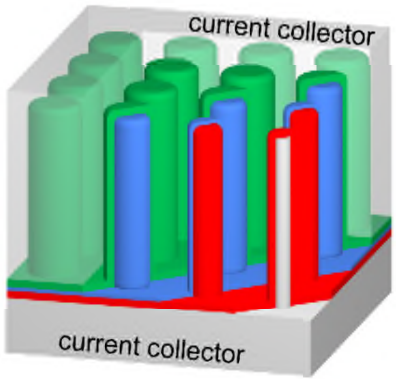
Battery management technologies

- Battery modelling
- Patented technology for battery management systems
- Grid connection: power conversion and switching
- Testing, evaluation and dimensioning of storage systems
- Energy management

New technology for short term storage

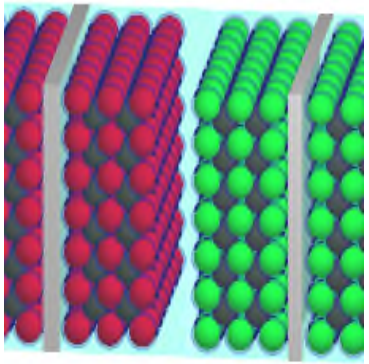
- Development of core technology and systems for thin-film batteries and composite batteries
- Adressing the issues of electronic and ionic conductivity though architecture and materials

Thin-film batteries (Wh-level)



Ultra-fast charging and modular batteries for IoT, wearables and electronics where space and battery capacity is restricted

Composite batteries (kWh-level)



High-energy batteries for local storage and transportation where safety and durability is important

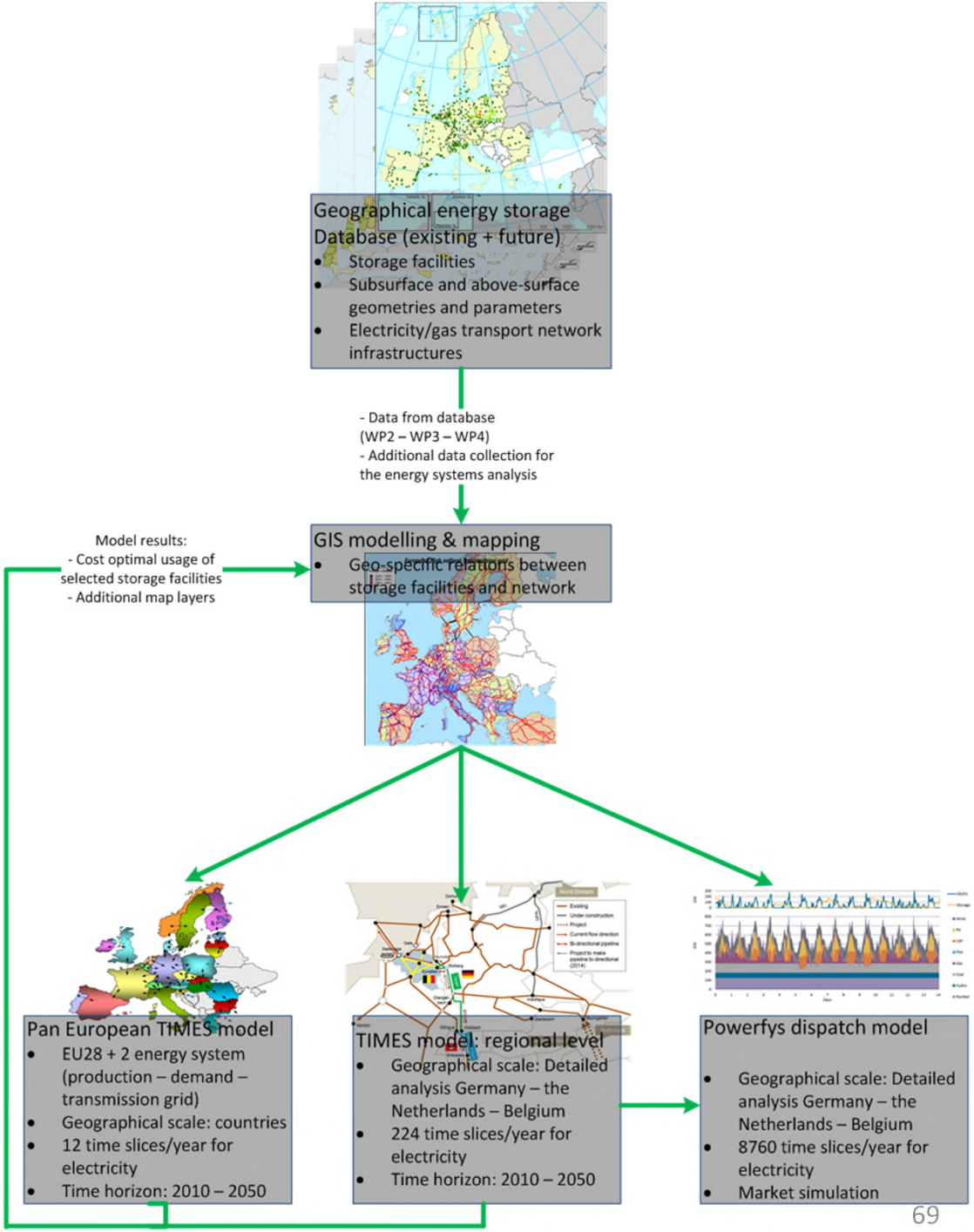
Long term storage

Database of storage facilities (existing & new)

- batteries, pumped hydro, LNG, ..

Modelling Energy System of EU28

Define cost efficient use of storage scenario's



Thermal storage

- TES as a COMPONENT in a system
  → component optimization with system constraints

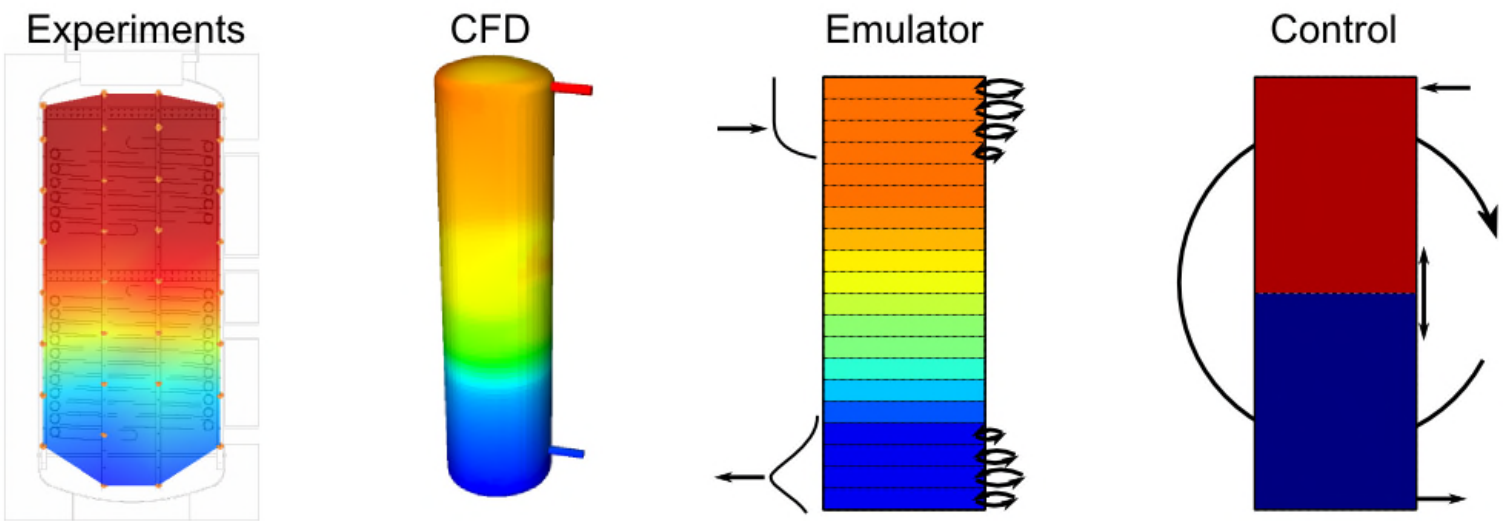
- TES on building level: GEOTABS
  → rethinking design and control

- TES in SMART GRIDS
  → unlocking flexibility by active demand response

- TES in THERNET
  → making optimal use of RES, waste heat and efficient conversion

Thermal storage

- Use of water buffers (cheap and widely available)
  Validated tank model, incl. buoyancy and mixing (emulator model)
  - Which level of model detail is needed for accurate energy cost calculations?



Thermal storage

- Thermally activated building systems (TABS)

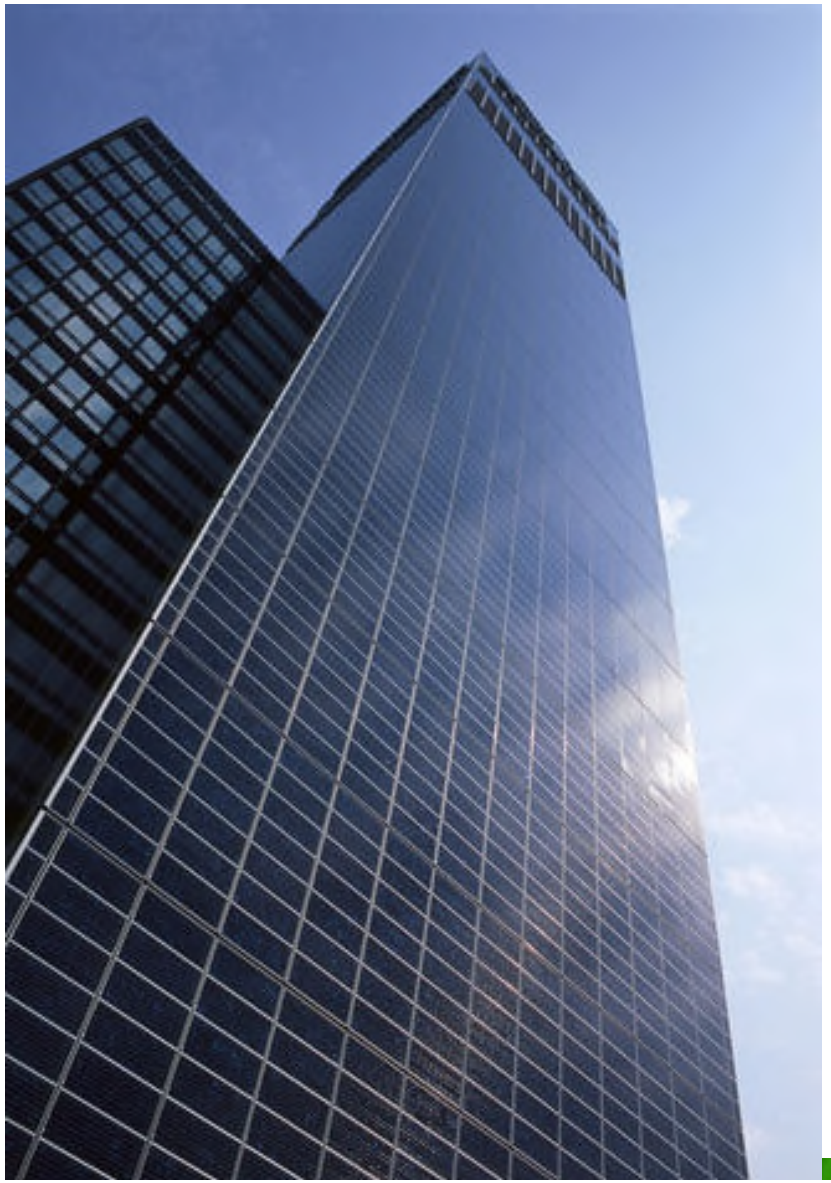
- State-of-Charge (SoC) definition based on minimal number of states (minimal amount of sensors)
  - Optimal exploitation of the energy storage capacity by model predictive control

Materials and Components

Materials and components

- High efficient & easthetic PV-modules & -panels
- GaN and passives for power electronics
- Energy conversion technology

High efficient & easthetic PV-modules & -panels



- Drivers for façade-integrated PV
  - Tall nearly zero energy buildings
    - potential market 10^x GW/yr
  - Aesthetics
  - Lower overall cost: building + PV

High efficient & easthetic PV-modules & -panels

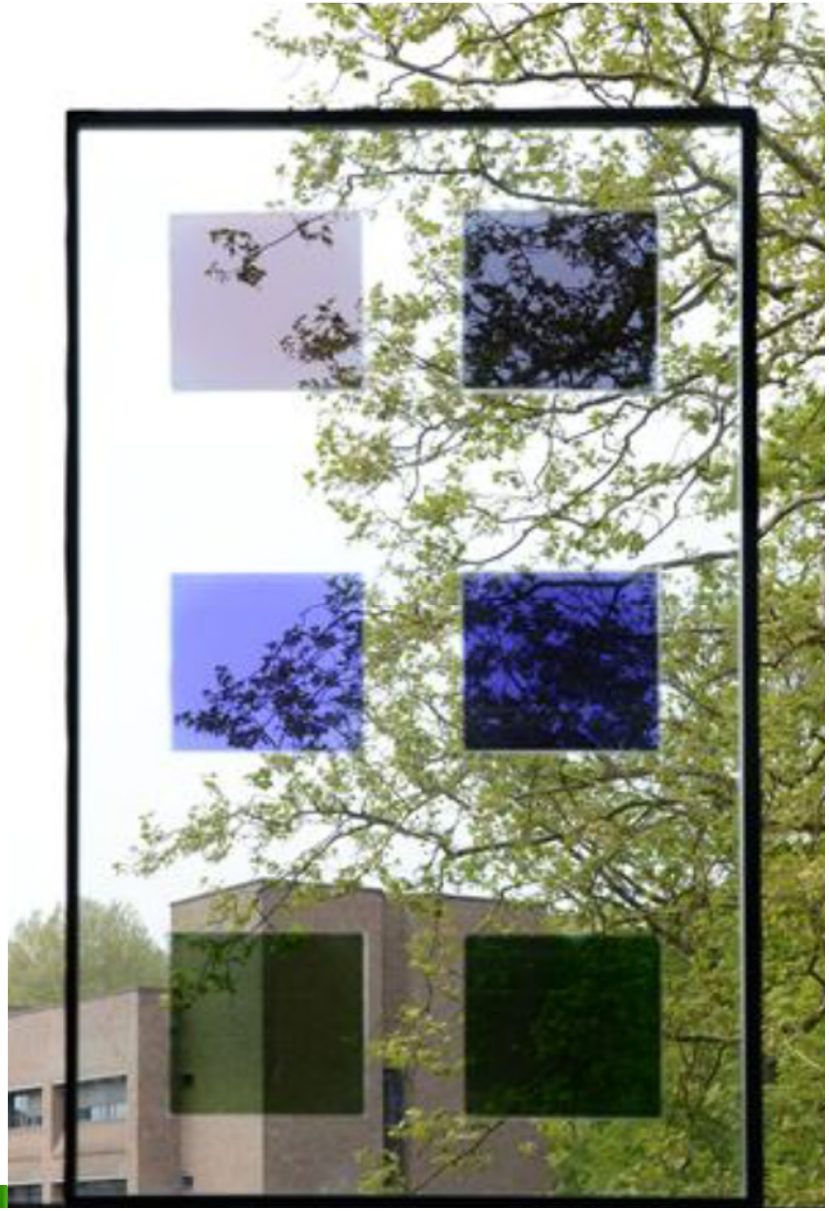
Demonstrators & facilities

- Back-contact (MWT) Si-PV modules
  - Rooftop & rooftile
  - Improved aesthetics
  - Higher efficiency
  - Cost-effective Si-PV

High efficient & easthetic PV-modules & -panels

Demonstrators & facilities

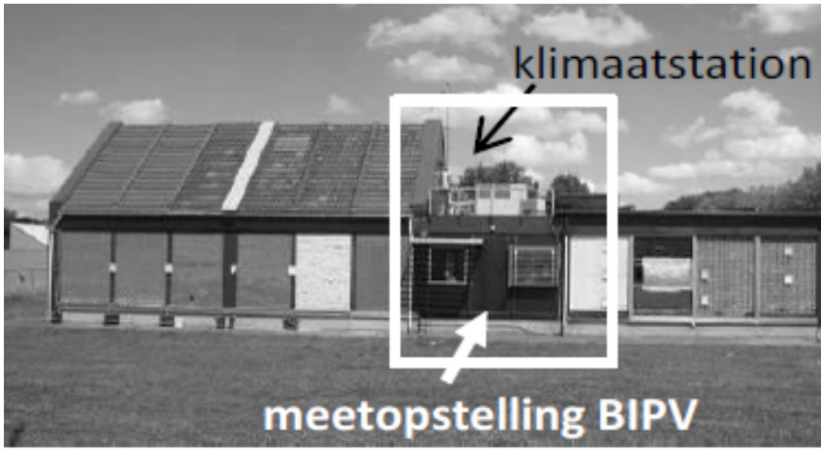
- Organic PV
  - Façades
  - Semi-transparent
  - Color-on demand

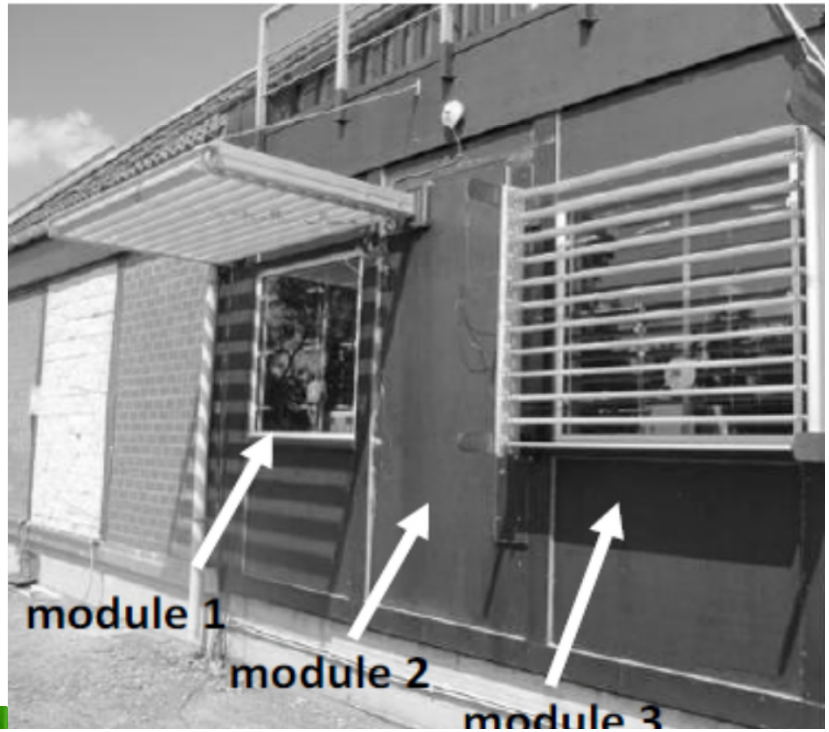


Towards Building-Integrated PV (BIPV)

Demonstrators & facilities

- Testing and modelling interation PV vs. Building
  - Hygrothermal & mechanical
  - Model validation
  - Lab validation



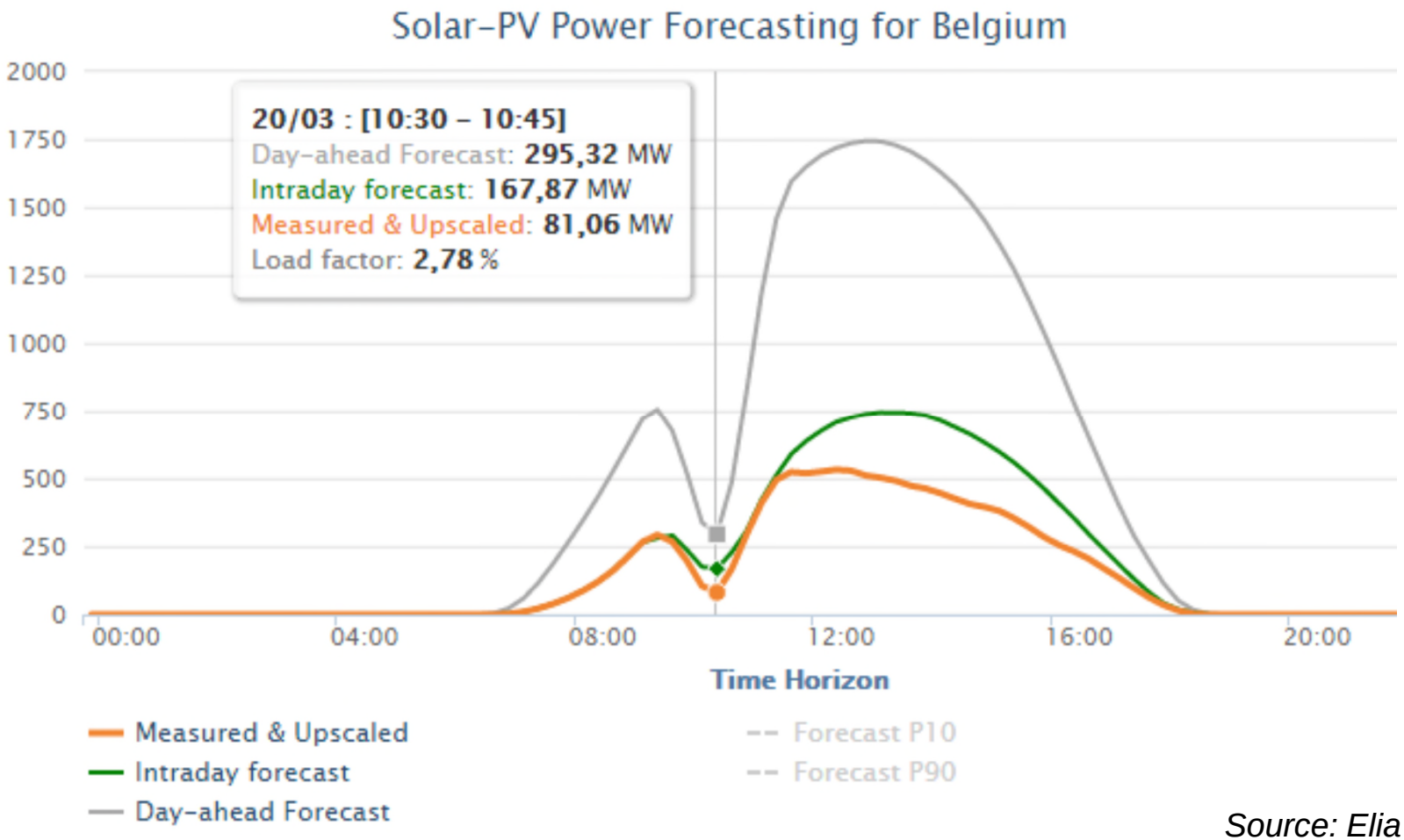


High efficient & easthetic PV-modules & -panels

- Short-term energy forecasting
  - Errors > 10%
  - Implications for producer, grid operator, …

Meteo forecast errors + Imperfect PV plant energy yield models = PV plant production forecast error

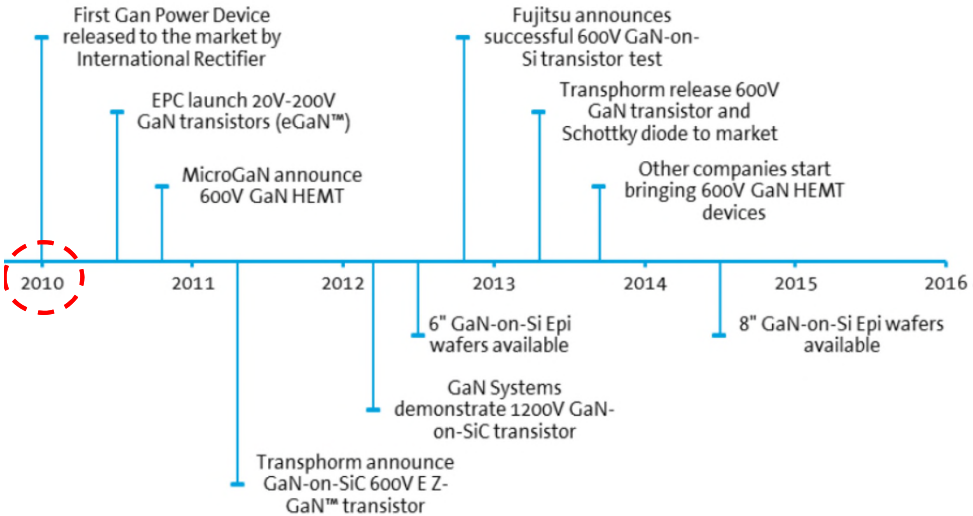
The challenge of predicting PV production



Source: Elia

GaN and passives for power electronics

- Based on Gallium Nitride (GaN)
- High-electron-mobility transistor (HEMT)
- “Wide-bandgap“: higher-energy electronic band gaps
- Heterostructure structure: field-effect transistor with junction between materials with different gaps



- Device manufacturers and developers:

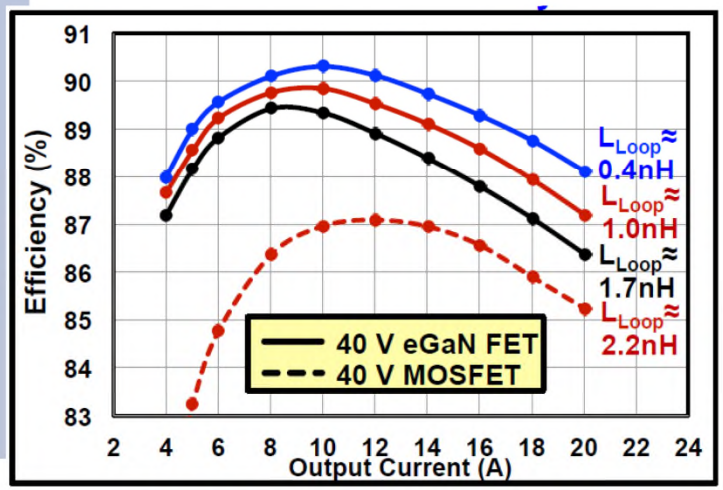
GaN and passives for power electronics

Drivers

- Lower losses
- Higher switching frequencies
- Higher operating temperature
- Enables smaller systems; size, weight and cost reductions
- Robust, reliable, radiation-hard
- High breakdown voltage
- GaN prices nearer to Si
- GaN has no body diode
- Device integration on Si

Inhibitors

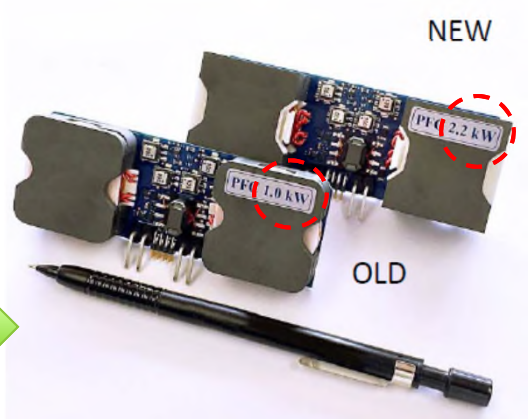
- High SiC material costs
- Design inertia: the reluctance to change
- Not drop-in swap for Si
- Normally-off switches required
- Proof of reliability
- High-temperature, high-frequency packaging
- Availability; few 2nd sources
- GaN defects
- GaN-on-Si material mismatch



V_{IN}=12 V, V_{OUT}=1.2 V, f_{sw}=1 MHz, L=300 nH

Power density improvement for a PFC power supply

- GaN allows 2.2kW in old 1kW



Efficiency improvement compared to Silicon and due to optimized layout

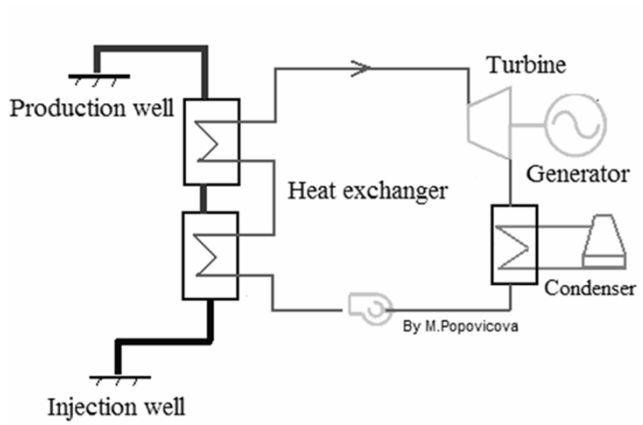
GaN and passives for power electronics

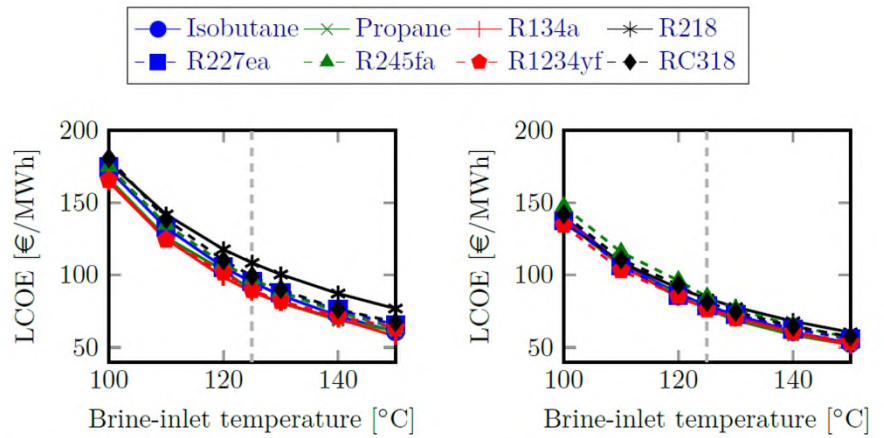
- DC loads ↗: electronics, LED, electric vehicles, …
- Advantages:
  - Area
  - Material cost
  - Reliability
  - Conversion losses
- Emerging industrial interest

Energy conversion technology

Research Focus

- Optimised design for ORC/HP with increased (electric and thermal) efficiency
- Characterisation of dynamic behaviour to improve the interaction with the thermal network



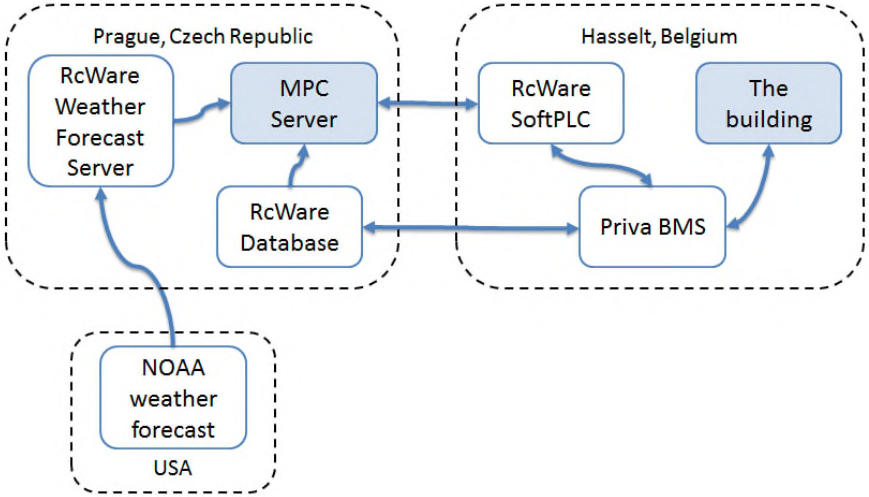


(a) Single-pressure recuperated cycle with ACC (b) Single-pressure recuperated cycle with WCT

Energy conversion technology

Advanced energy concepts: GEOTABS, hybrid heat pump systems, ...

- Efficiency has been proven by simulations and field tests
- Rethinking control strategy → MPC proof-of-concept for GEOTABS



Source: Hollandsch Huys - Airdeck

Collaboration with industry

- Possible collaboration frameworks

Contract Research

Technology transfer

Spin-off

Common R&D project

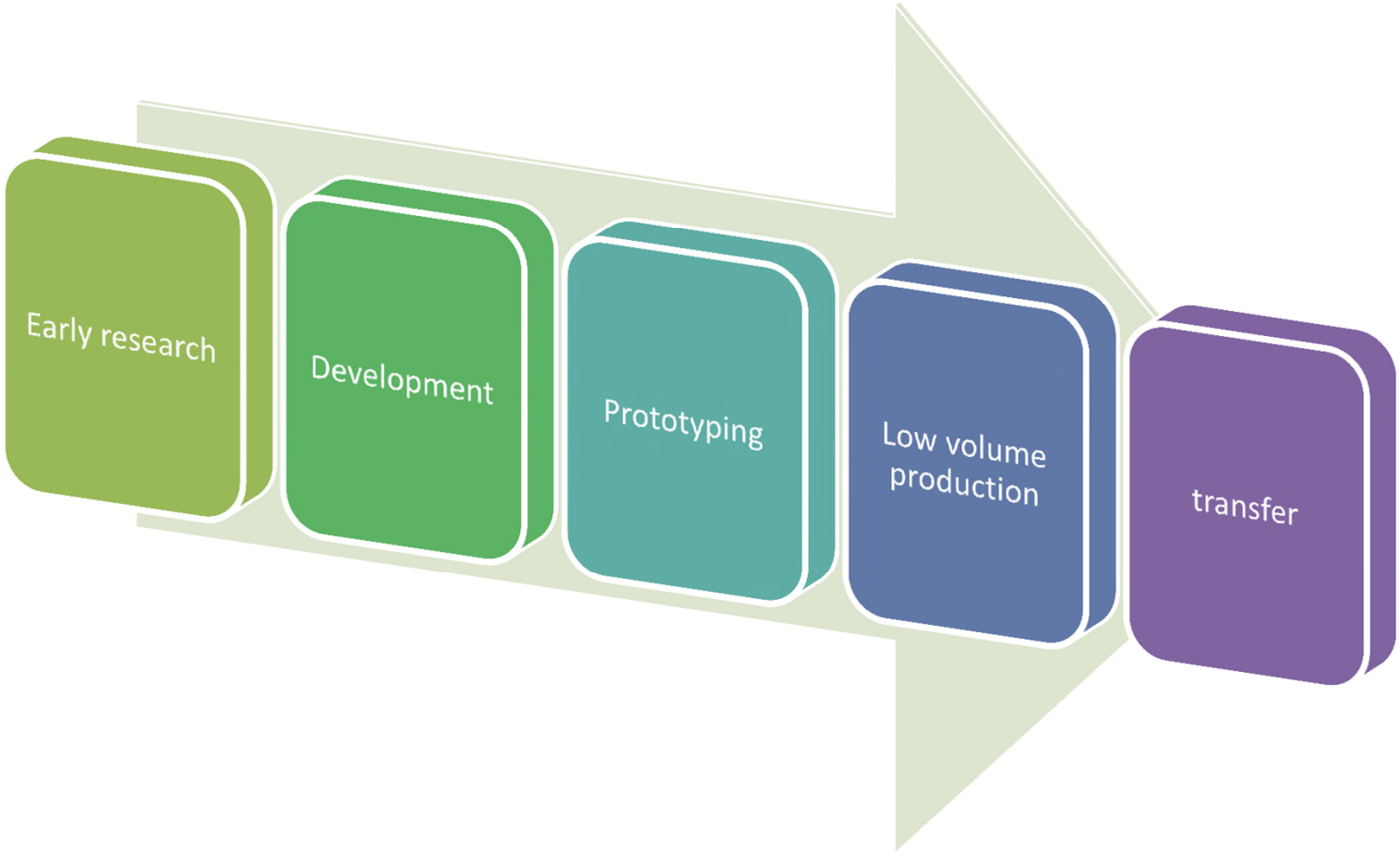
Open innovation

Cooperation in publicly financed projects

Academic Chair

Technology Readiness Level

Innovation chain



More info?

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