2014 IERE – GDF Suez Brussels Workshop

Energy at home

4th June 2014

MESB

Micro Energy Storage in Buildings

Prof P Hendrick

Ir G Oliveira Silva

Aero-Thermo-Mechanics Dept.

- Turbo reactor lubrication
- UAVs
- Helicopters
- CFD simulation
- Mechanical design and conception
- Aeronautical and spatial propulsion
- Renewable energy: fuel cell, wind turbine
- Energy storage: Hydrogen, Pumped hydro, compressed air.

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Presentation outline

- Introduction
  - Why energy storage?
  - Research proposal
- Results after 1 year
  - Pumped-Hydro Energy Storage (PHES)
  - Compressed Air Energy Storage (CAES)
  - Thermal
  - Hydrogen
  - Electrochemical batteries
- Future work

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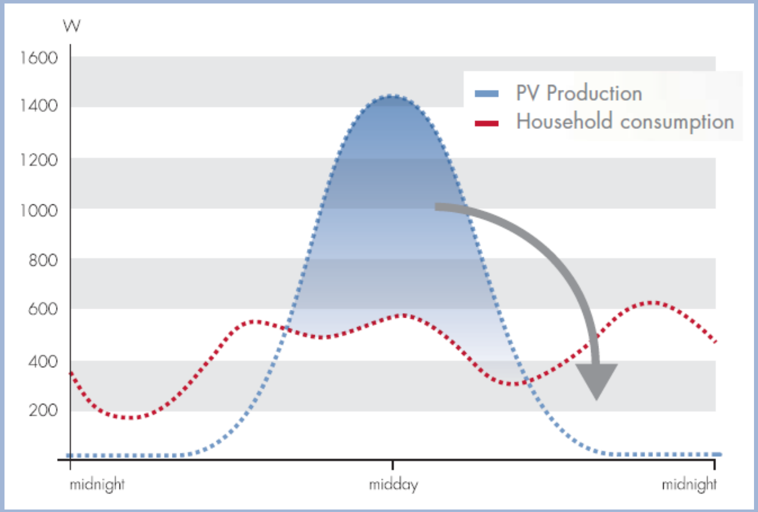
Introduction

Intermittent energy production → Imbalance between energy production and energy consumption → Energy storage



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ULB Aero/Thermo/Mechanics Brussels Retrofit XL — Innoviris Strategic Platform Environment

INTRODUCTION

WHY MICRO ENERGY STORAGE?

- LESS STUDIED AREA
  - BETTER RETURNS ON INITIAL R&D
- PROMOTE PRIVATE INVESTMENT
  - LIBERALIZATION OF THE ENERGY SECTOR
- REPLICATE PHOTOVOLTAICS' SUCCESS
  - LOWER COSTS
  - OPENING OF NEW MARKETS
  - MAKE TECHNOLOGY WIDELY AVAILABLE

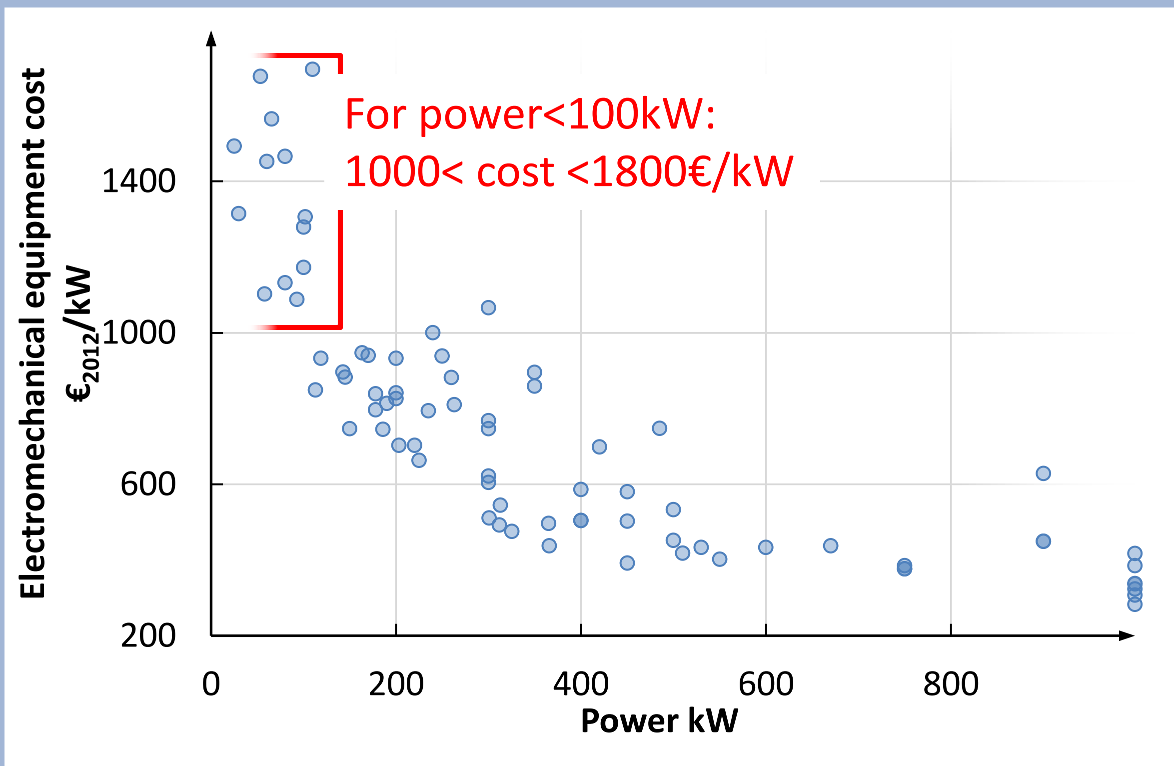
SEVERAL PROJECTS:

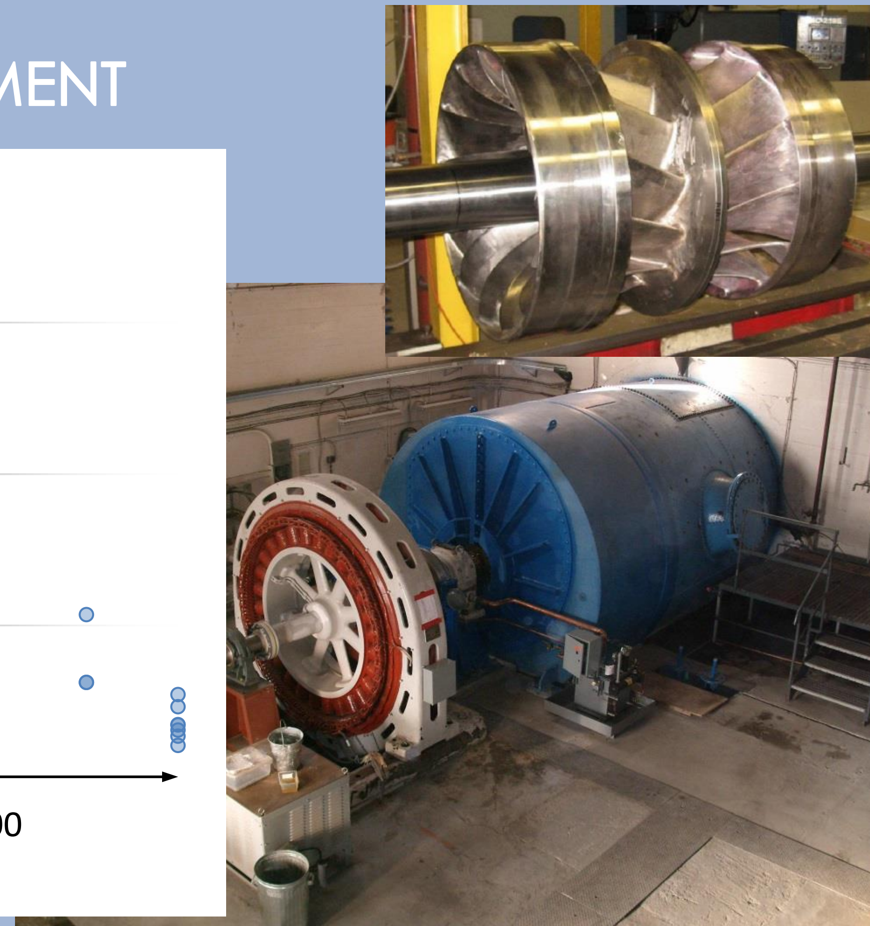
millener

Sol-ION PROJECT

TO+12 RESULTS - PHES

ELECTROMECHANICAL EQUIPMENT





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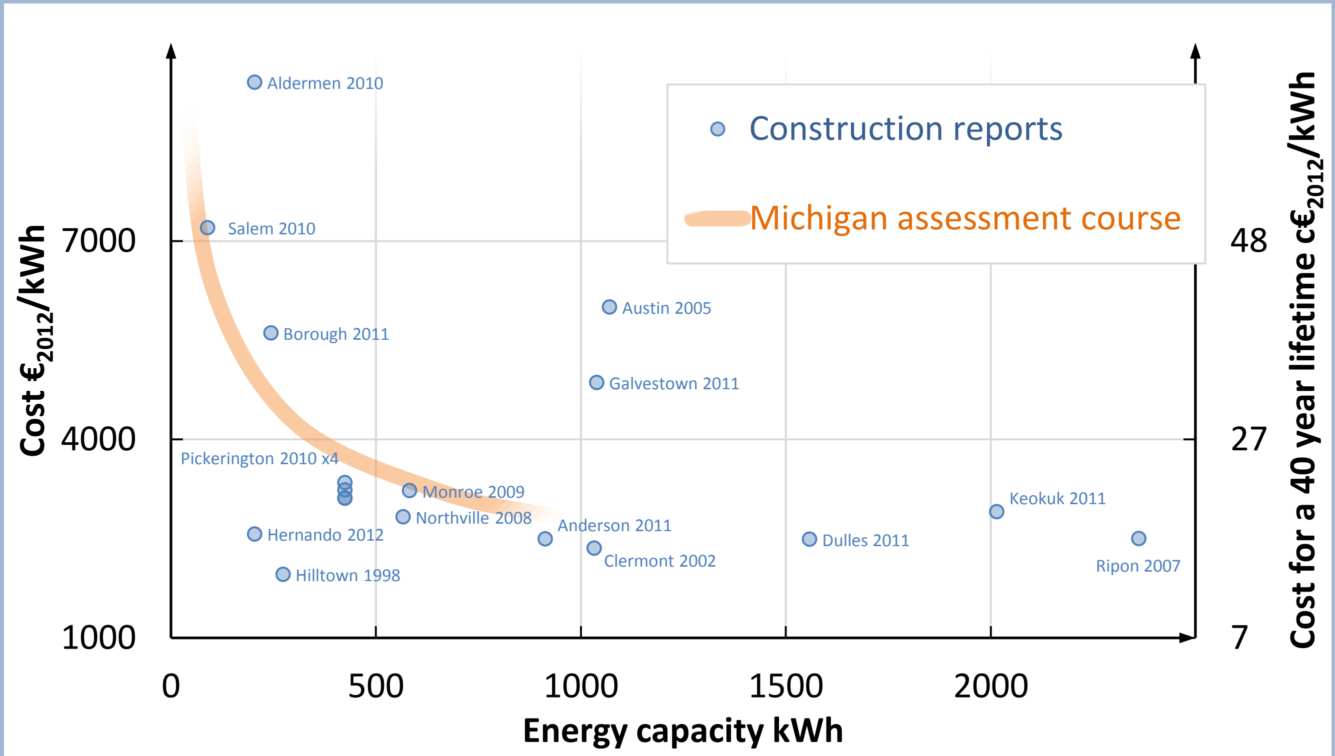
INNOVIRIS STRATEGIC PLATFORM
ENVIRONMENT

TO+12 RESULTS - PHES

WATER TOWER



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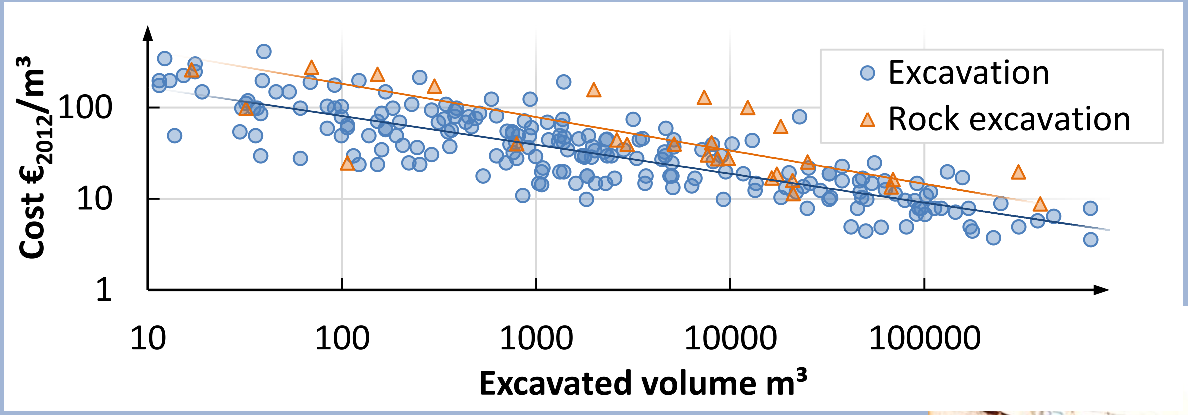
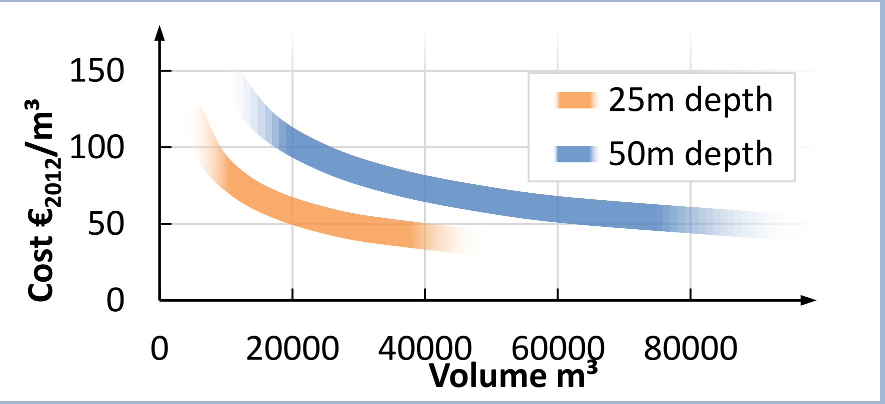
T0+12 RESULTS - PHES

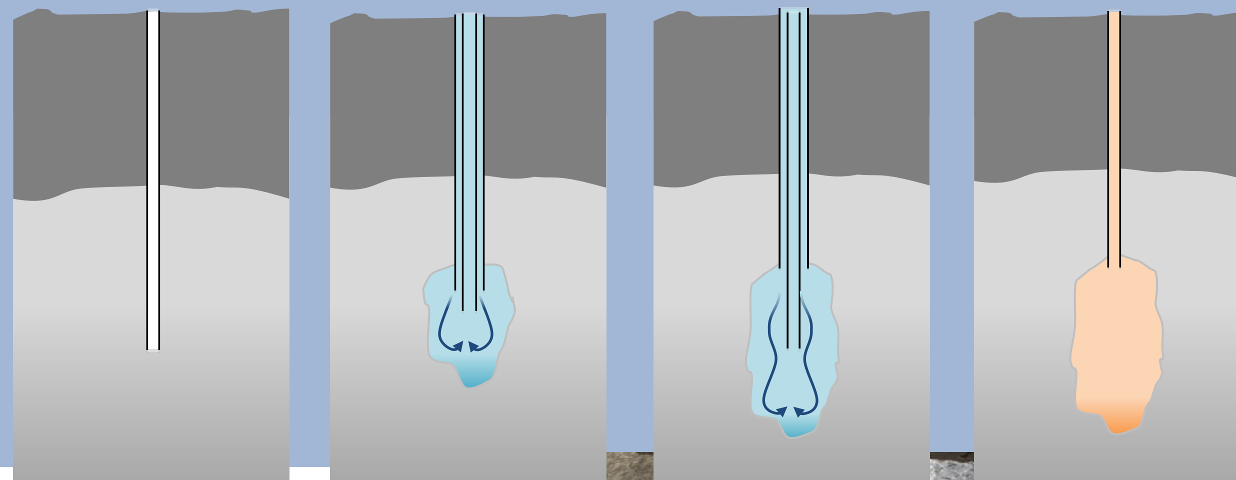
UNDERGROUND RESERVOIRS

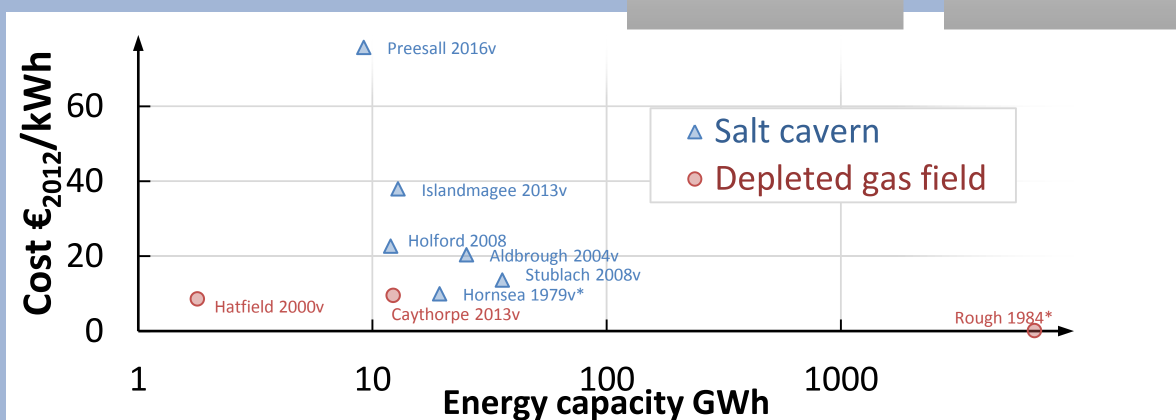




TO+12 RESULTS - PHES

UNDERGROUND RESERVOIRS





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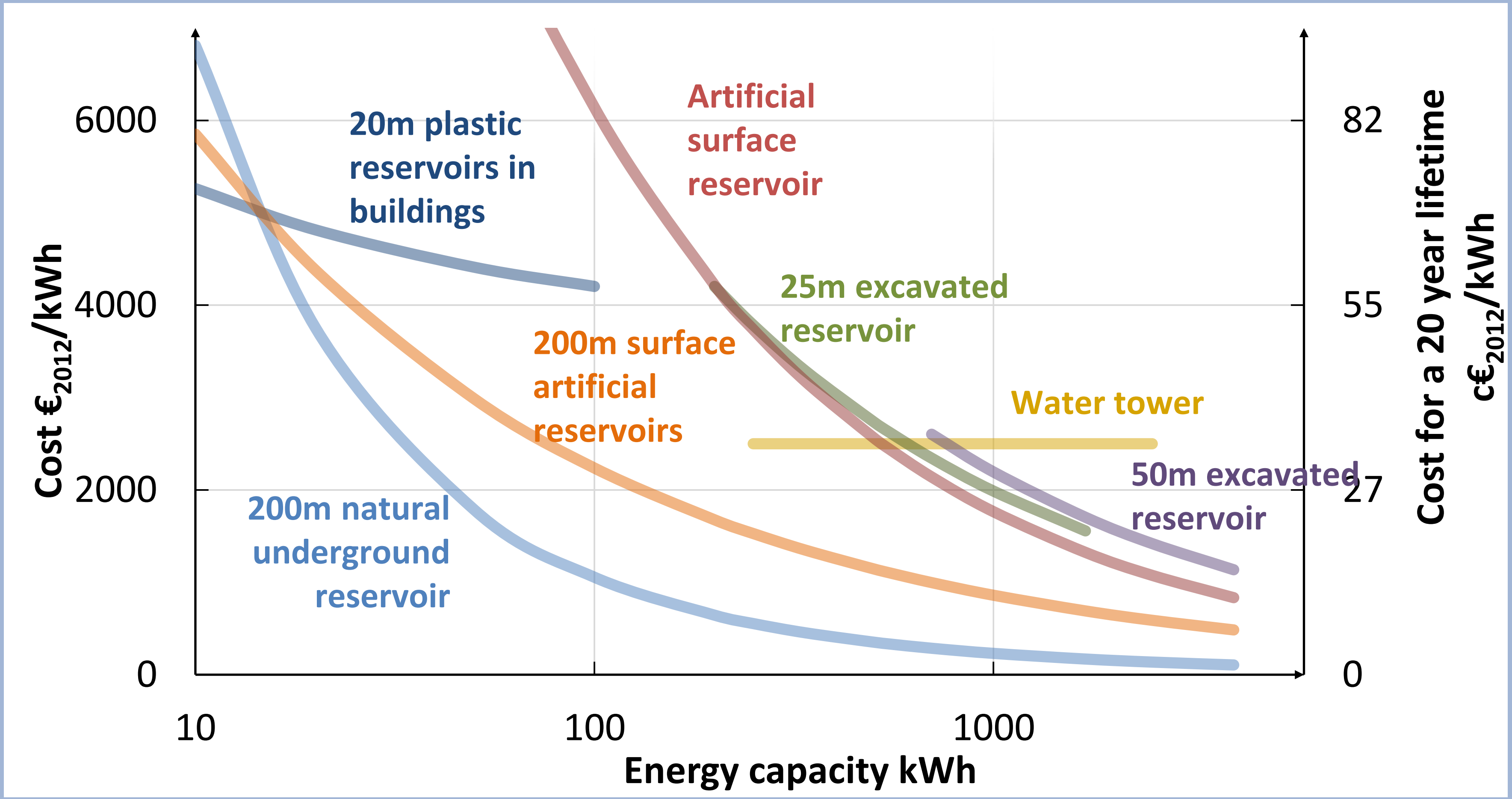
TO+12 RESULTS - PHES



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TO+12 RESULTS - PHES

CONCLUSIONS

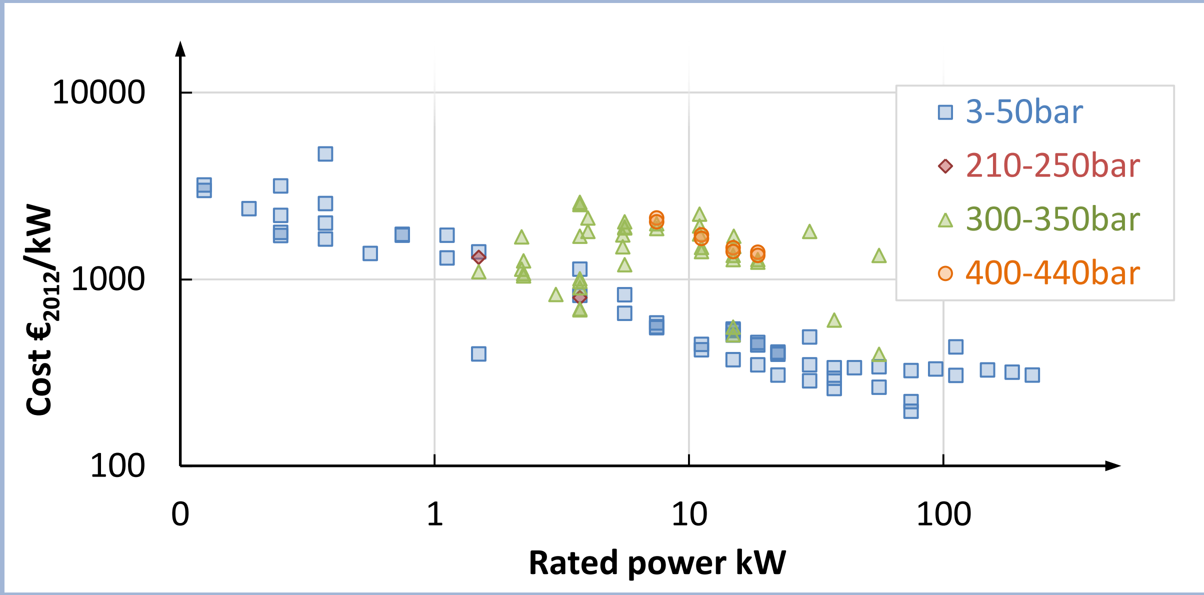
- COSTLY FOR SMALL-SCALE ENERGY STORAGE (<1MWH)
- BEST SOLUTIONS:
  - NATURAL UNDERGROUND RESERVOIRS
  - ARTIFICIAL RESERVOIRS WITH LARGE HEIGHT DIFFERENCE (>200M)
  - LARGE DIAMETER EXCAVATED RESERVOIRS (>50M DIAMETER)

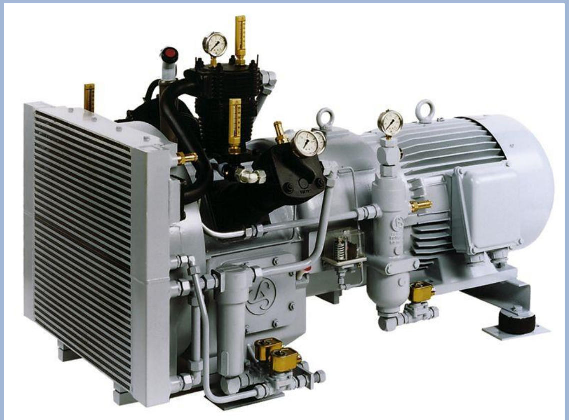
QUESTIONS

- CAN IT BE INTEGRATED WITH OTHER SERVICES (THERMAL STORAGE FOR EXAMPLE)?
- GEOLOGICAL STRUCTURES CONSTRAINTS
- EQUIPMENT LIFETIME AND MAINTENANCE
- IN BUILDINGS: STRUCTURAL REINFORCEMENT?

TO+12 RESULTS - CAES

AIR COMPRESSORS/ TURBINES





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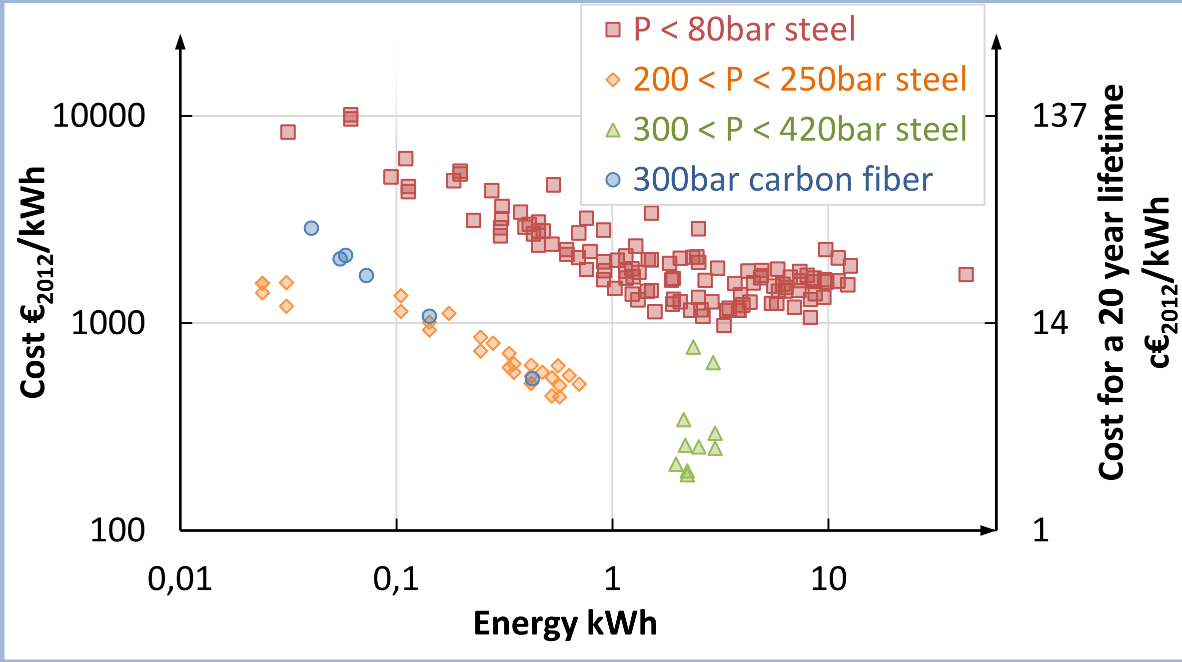
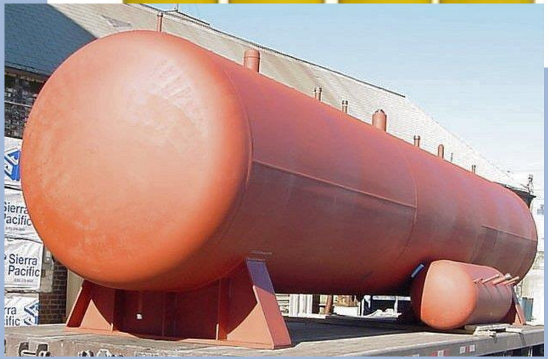
TO+12 RESULTS - CAES

COMPRESSED AIR TANKS





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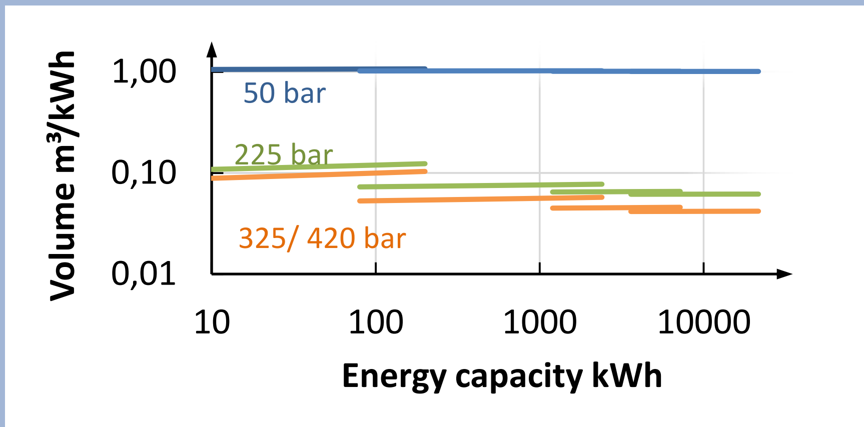
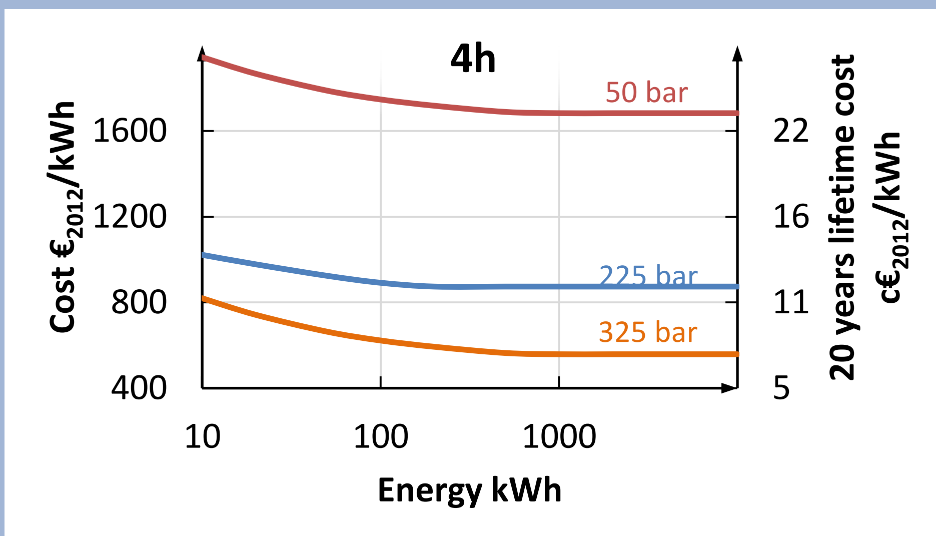
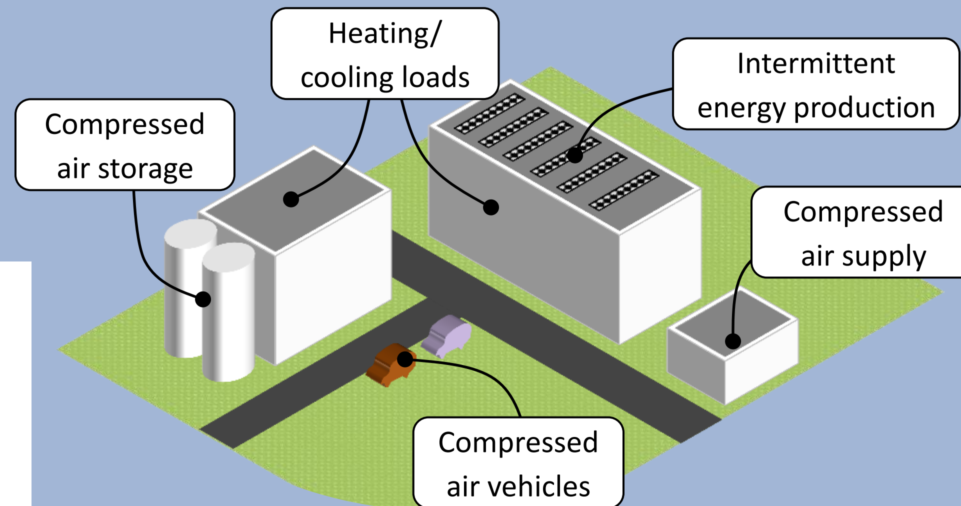
TO+12 RESULTS - CAES







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TO+12 RESULTS - CAES

CONCLUSIONS

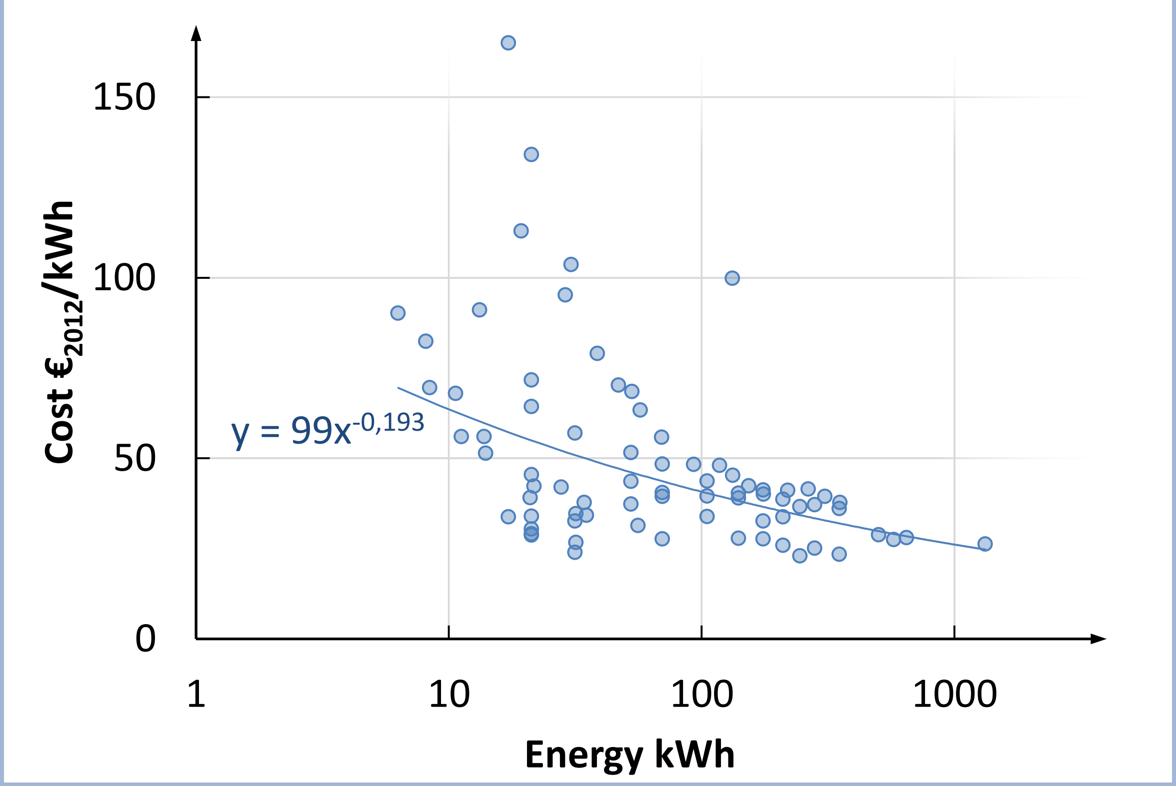
- COST ACCEPTABLE FOR SMALL-SCALE ENERGY STORAGE (>100KWH)
- THERMAL MANAGEMENT MANDATORY
- HIGH-PRESSURES RECOMMENDED (BEST CASE: 325BAR)

QUESTIONS

- INTEGRATION OF OTHER SERVICES (THERMAL, COMPRESSED AIR)
- GEOLOGICAL STRUCTURES CONSTRAINTS
- COMPRESSORS REVERSIBILITY (TURBINE)
- EFFECT OF PRESSURE VARIATION
- EQUIPMENT LIFETIME AND MAINTENANCE COSTS
- NOISE

TO+12 RESULTS - THERMAL

SENSIBLE HEAT THERMAL STORAGE



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TO+12 RESULTS - THERMAL

CONCLUSIONS

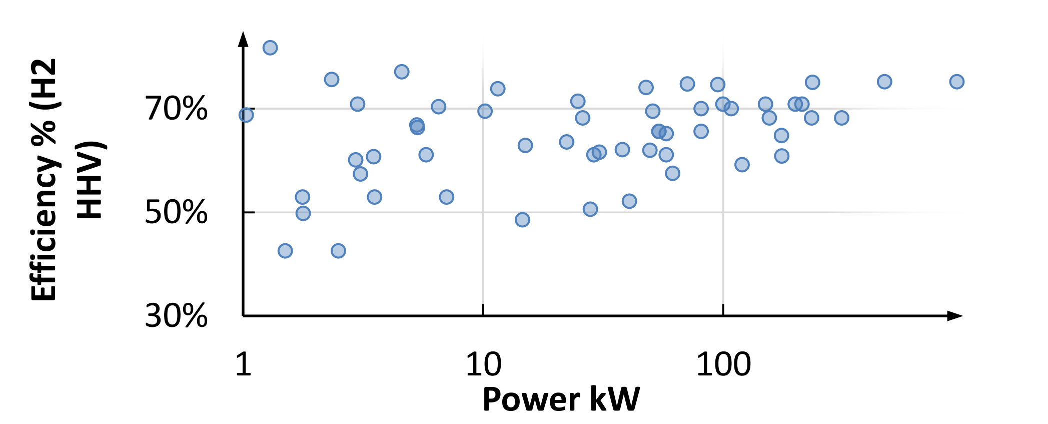
- VERY LOW COST (0,6C€/KWH)
- HEAT AS A BYPRODUCT
- PHASE-CHANGE TECHNOLOGIES (LATENT HEAT) UNDER DEVELOPMENT
- LOW GRADE ENERGY WHEN COMPARED TO ELECTRICITY

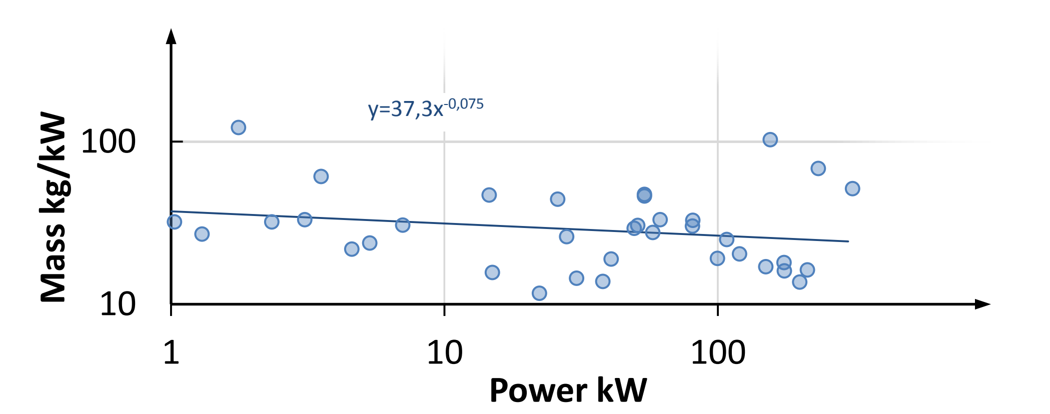
QUESTIONS

- INTEGRATION ON OTHER STORAGE SYSTEMS (FUEL CELLS, ETC)
- OTHER TECHNOLOGIES: DISTRICT HEATING, UNDERGROUND
- LATENT HEAT STORAGE
- EQUIPMENT LIFETIME AND MAINTENANCE COSTS
- HEAT ORIGIN

T0+12 RESULTS - HYDROGEN

ELECTROLYZER





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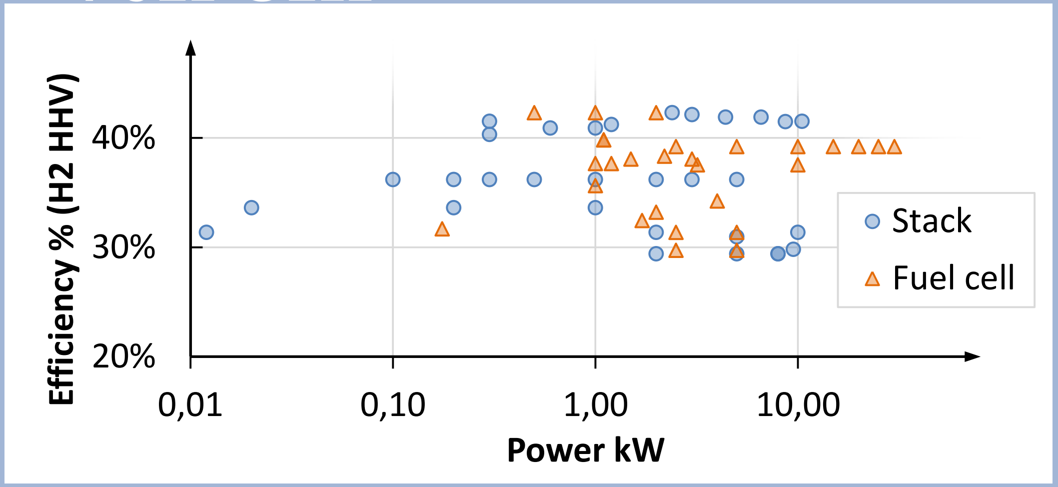
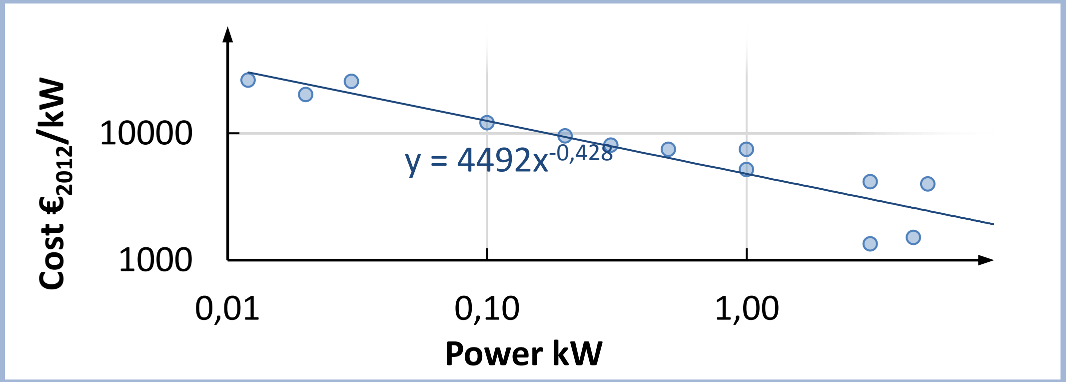
TO+12 RESULTS - HYDROGEN

FUEL CELL





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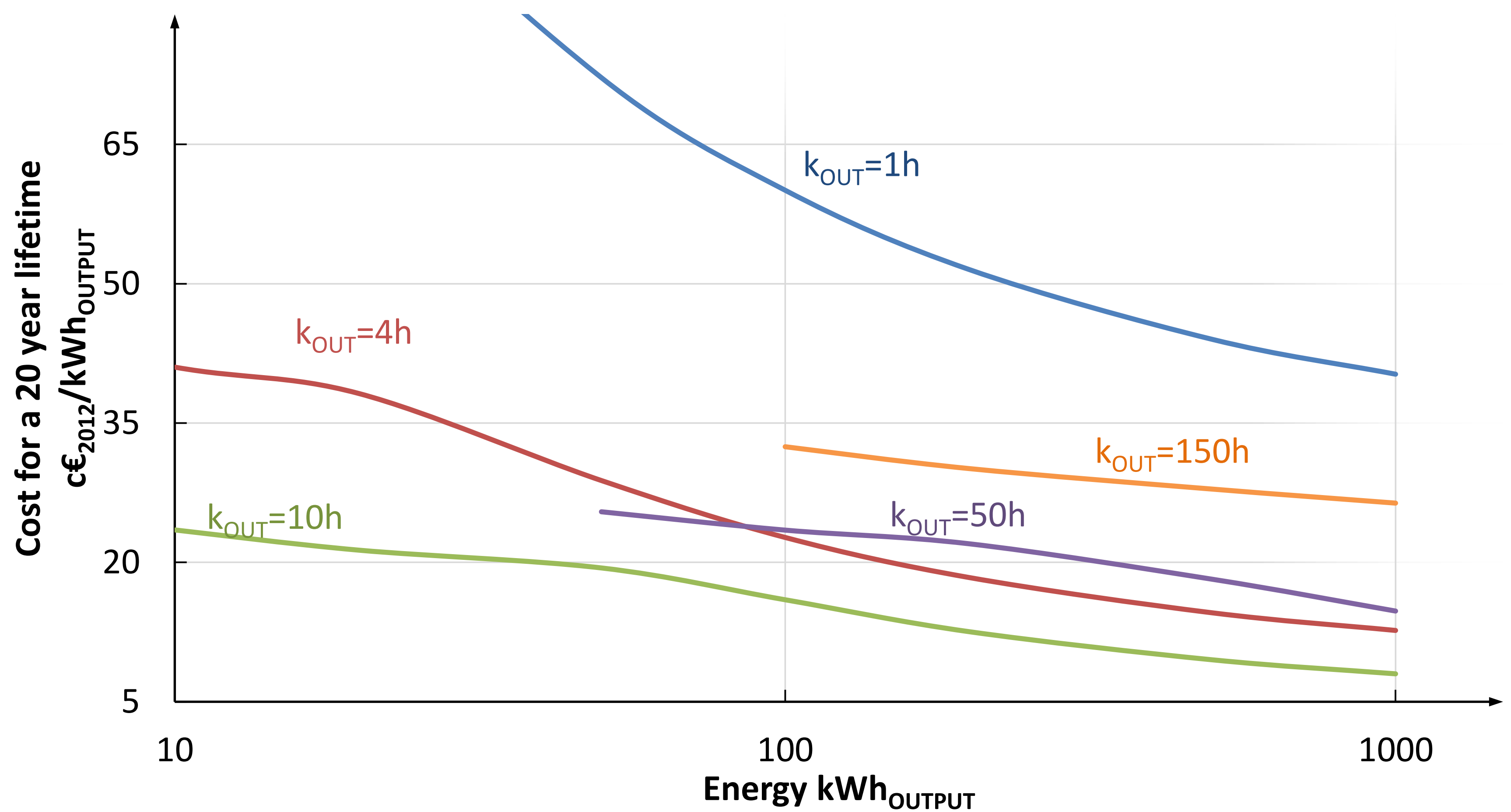
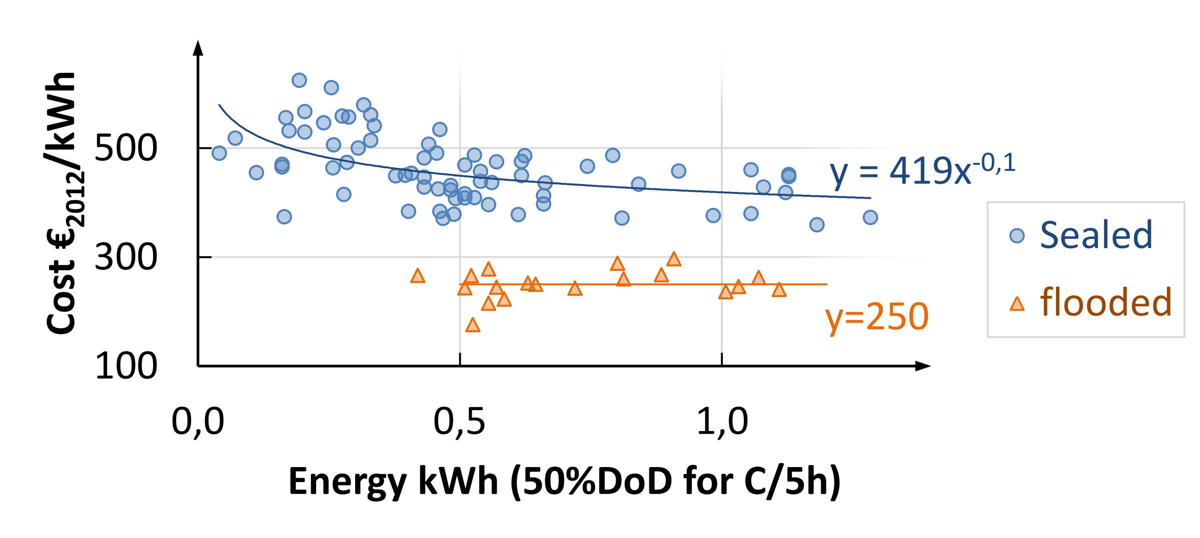
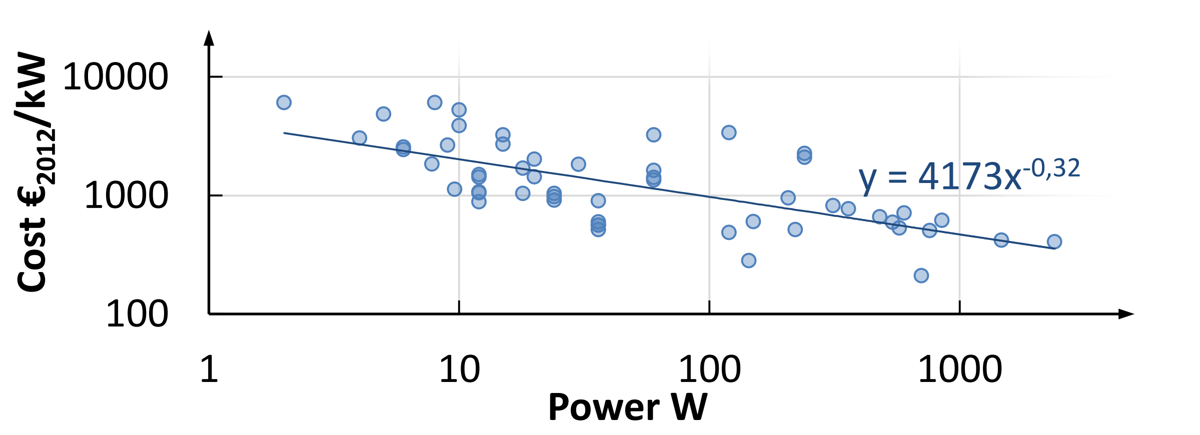
TO+12 RESULTS - HYDROGEN



TO+12 RESULTS - BATTERIES





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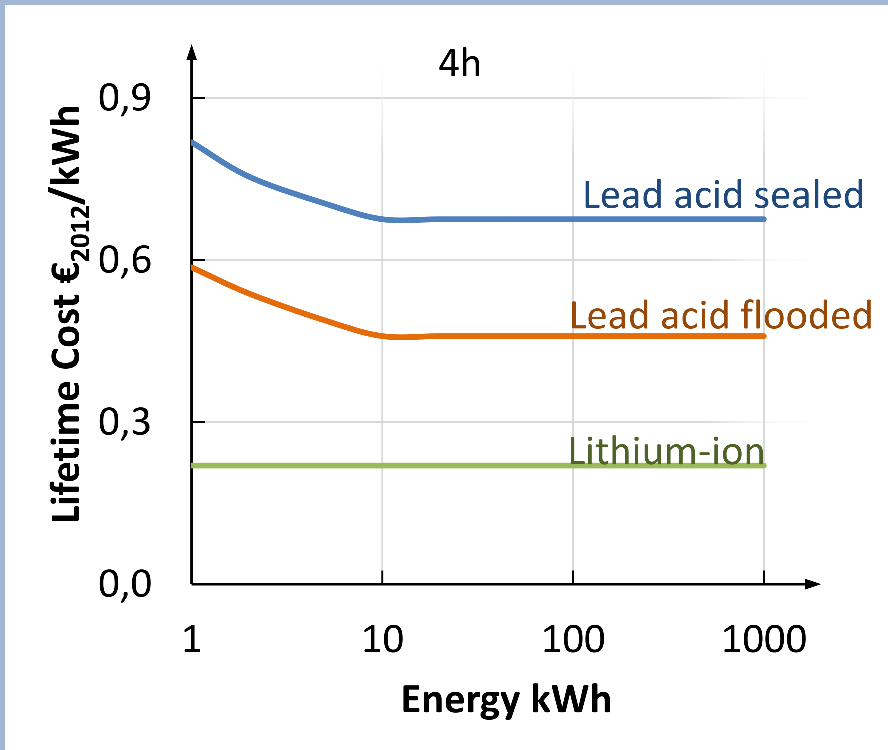
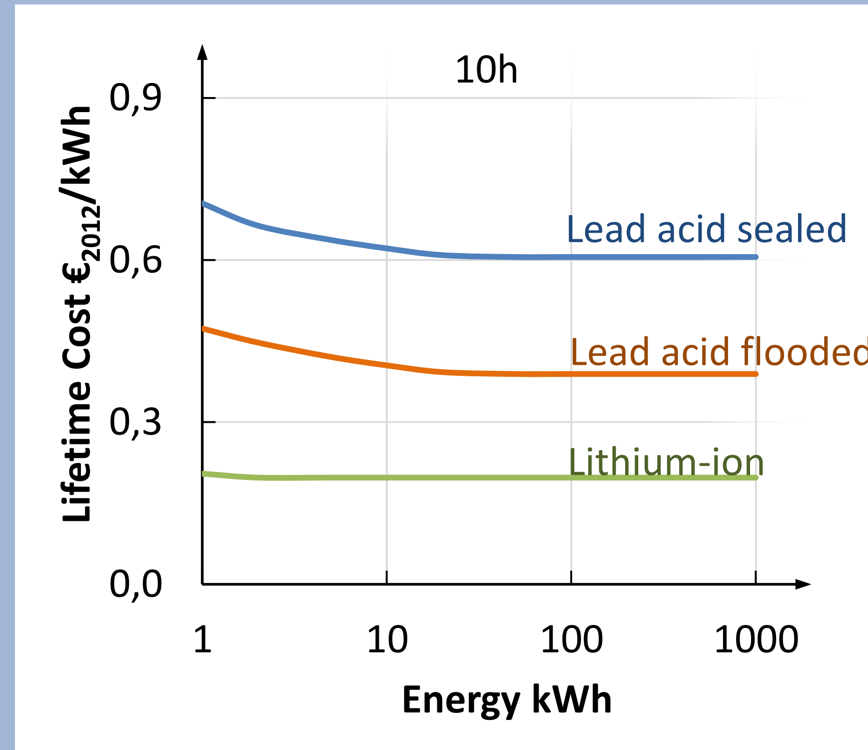
T0+12 results - Batteries





Lifetime cost $€_{2012}$/kWh	Lead acid sealed	Lead acid flooded	Lithium-ion
4h	0,68	0,46	0,22
10h	0,61	0,39	0,20

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T0+12 results - Batteries

Conclusions

- Low cost for Li-Ion

Questions

- Lifetime
- O&Maintenance costs

T0+12 RESULTS - CONCLUSION

	20 year lifetime cost	Volume	Mass
Pumped hydro Reservoirs at 20m. 4h system.	72-57c€/kWh 57 (100kWh)	36,6m³/kWh 1830m³ (100kWh)	36600kg/kWh 3660Ton (100kWh)
CAES 325bar system	14-12c€/kWh 4h 10-9c€/kWh 10h	0,08-0,11m³/kWh 10m³ (100kWh)	78-88kg/kWh 8Ton (100kWh)
Hydrogen 200-420bar. 8h charge/4h disch.	41-13c€/kWh 23 (100kWh)	0,101m³/kWh 10m³ (100kWh)	24 to 17kg/kWh 2Ton (100kWh)
Thermal Hot water. ΔT=60º	0,87-0,36c€/kWh 0,55 (100kWh)	0.014 m3/kWh 1,4m³ (100kWh)	14kg/kWh 1,4Ton (100kWh)
Flooded lead-acid battery 50%DoD	46c€/kWh from 10kWh	25l/kWh 2,5m³ (100kWh)	55kg/kWh 5,5Ton (100kWh)
Sealed lead acid battery 50% DoD	68c€/kWh from 10kWh	28l/kWh 2,8m³ (100kWh)	62kg/kWh 6,2Ton (100kWh)
Li Ion battery 80%DOD	20c€/kWh from 10kWh	9l/kWh 0,9m³ (100kWh)	14kg/kWh 1,4Ton (100kWh)

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T0+12 RESULTS - CONCLUSION

Energy (Wh)		Lifetime cost (c€$_{2012}$/kWh) Area costs were considered to vary from 2700€$_{2012}$/m^2 (Brussels) to 1700€$_{2012}$/m^2 (Liège)			
		2k	10k	100k	1M
Technology	Pumped hydro Reservoirs at 20m. 4h system.	-	756 - 503	742 – 489	-
	CAES 325bar system	-	13 - 12	11 - 10	10 – 9
	Hydrogen 200-420bar. 8h charge/4h disch.	-	42 - 41	24 - 23	14 – 13
	Lead acid flooded 50%DoD	54	46	46	46
	Lead acid sealed 50% DoD.	75	68	68	68
	Lithium-ion 80%DoD.	22	22	22	22
	Thermal Hot water. ΔT=60º.	-	1,2 – 1,1	0,9 – 0,8	0,7 – 0,6

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TO+12 RESULTS – A WORD ON COST

$$\sum_{t=0}^{n}\left(\frac{Expenses_t}{(1+r)^t}\right)=\sum_{t=0}^{n}\left(\frac{Benefits_t}{(1+r)^t}\right)$$

$$sCost_{OUT0}=\frac{Cost_0}{E_{OUT}\,n}+\frac{sCost_{IN0}}{\eta}$$

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T0+12 results– Project's database

Database of existing and planned energy storage systems providing suppliers, techniques, costs, etc.

	Date, company and location	Technical parameters	Technology description
Existing	1978 Huntorf plant	290MW/ 3h (33)	Compressed air stored in a salt dome with 310.000m³ at up 100bar. Combustion of natural gas during expansion proces
	1991 Alabama Electric Cooperative McIntosh, Alabama	110MW/ 26h 65M$1991 (34)	Compressed air is stored in a 538.000m³ solution mined sal cavern at pressures up to 75bar. Combustion of natural gas during expansion process (34).
	2011 Highview Power Storage Slough, Berkshire, UK	350kW / 7h (44) 50% efficiency (35) 70% efficiency if using 115ºC waste heat (35)	Air is liquefied for storage (33).
	2012 General compression Gaines, Texas, USA	2MW (28) / 250h (33) 70-75% (30)	Compressed air is stored in a cavern (29).
Projects	2013 SustainX Seabrook, New Hampshire, USA	2MW 95% efficiency 20 year lifetime (36) 13M$2012 (33)	Sprayed water CAES for heat management. Use of standard steel pipes for compressed air storage (36).
	2013 Alliant Techsystems Inc Promontory, Utah, USA	80kW / 30-60min 3,6M$2012 (33)	Above ground compressed air energy storage (33).
	2013 RWE Power Stassfurt, Germany	360MWh/ 90MW 70% efficiency 40M€ for 3,5years (37)	Compressed air stored in subterranean caverns (37).
	2013 Hydrostor Toronto, Ontario, Canada	1MW / 4MWh (27) >25year lifetime 65-75% efficiency 100€2012/kWh - installation (38)	Compressed air is stored in underwater bags (27).
	2016 Apex CAES Anderson, South California, USA	317MW 350-400M$2012 (38)	Compressed air stored in subterranean salt dome (38).
	Pacific Gas and Electric Co. Kern, California, USA	300MW 355M$2012 (33)	Compressed air stored in subterranean porous-rock deplete gas field (33) (39).
	New York Power Authority New York, United States	9-10MW/ 4h30 (33) (39)	Compressed air stored in steel piping (39). Possible combusti natural gas during expansion (39).
	Hydro One Toronto, Canada	3-5MW/ 1-2h 8-10M$2012 (39)	Molten salt thermal energy storage system at 540 to 820ºC stored above ground at a pressure up to 110bar (39).
	NPPD Nebraska, USA	135MW/ 10h (39)	Compressed air stored in a depleted natural gas field with a volume of 850 million m³ to a pressure up to 60bar (39).

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Future work - Systems

Fuel cell	Performance model / reversibility / heat use
Thermal	Heat exchange / phase-change modeling / heat pump
Pumped hydro	Small variable reversible pump/ flow control
Compressed air	Small variable reversible high-pressure compressor/ Storage tanks / Compressed air use (vehicles/ ICE)
Flywheels	Modeling / bearings

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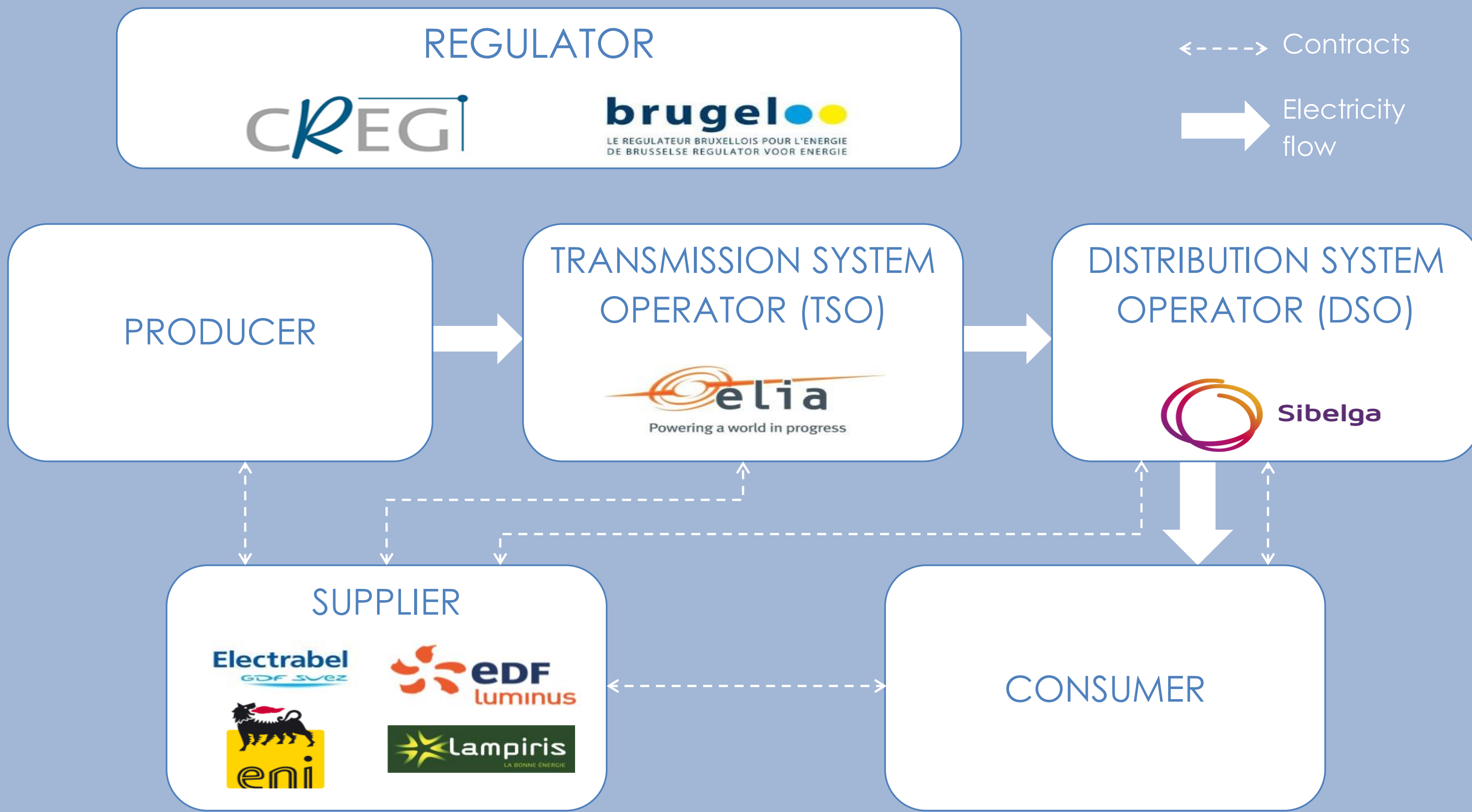
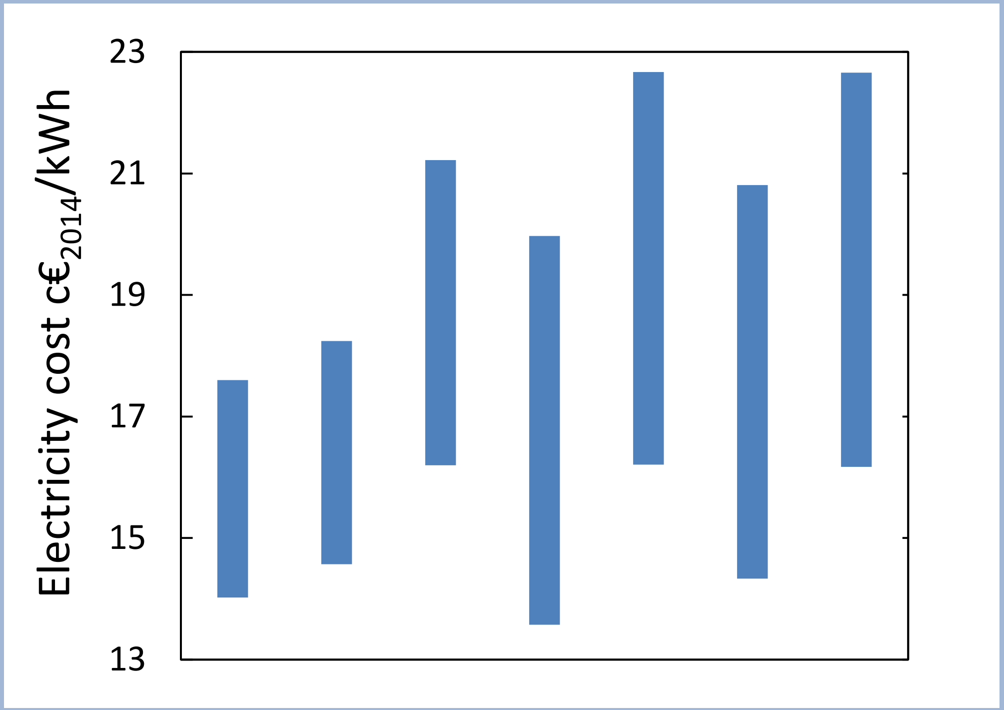
Future work – storage integration



Future work – storage integration

- Output smoothing of variable energy sources
- Voltage control
- Frequency control
- Black start
- Commodity storage
- Self-consumption
- Investment deferral
- Energy efficiency



Electricity cost for bi-hourly tariffs in Brussels in February 2014.

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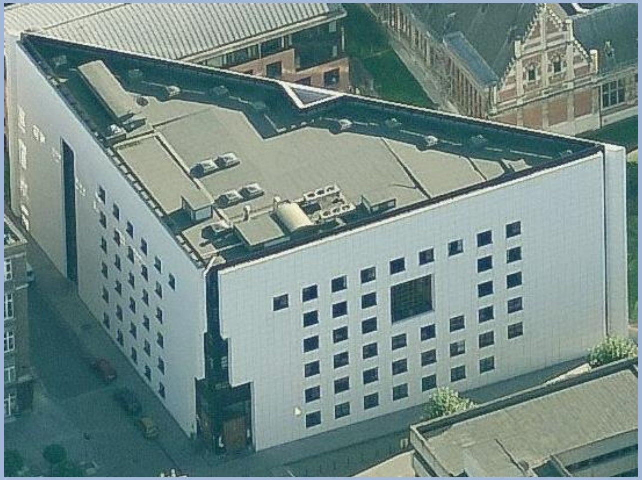
Future work - Case Studies

ULB Solbosch campus

Analysis of several buildings.
Interaction with owners and builders.



ULB's Library of social sciences

Private residence

ULB's Mandela student residence

Publications & presentations

8TH International Renewable Energy Storage Conference
18-20 November 2013
Berlin, Germany

Meetings on Sustainable Construction & Efficient Energy Buildings
21ST January 2014
Brussels, Belgium

Some references

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THANK YOU!

Questions? Comments?

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