Conceptual Modelling of Seasonal Energy Storage Technologies for Residential Heating in a Dutch Town Best

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Introduction

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Agenda

- Line of Reasoning
- Context: Best
- Research Questions
- Energy Storage Technologies
- Conceptual Models
- Key Findings
- Conclusion
- Future Research

Line of Reasoning

- ❑ Renewable Energy Sources
- ❑ Intermittency
- ❑ Excessive Energy in Peak Periods
- ❑ Seasonal Variations
- ❑ Seasonal Perspective in Literature
- ❑ Conceptual Modelling

Best

- ❑Southern Netherlands
- ❑Seasonal Variations
- ❑Simplified Need
- ❑Charge and Discharge Periods

- ❑Observation and Interviews
- ❑High Building Density
- ❑Political and Social

Jan Feb Mar Apr May Jun
Jul Aug Sep Oct Nov Dec

Research Questions

Question 1

What are the key considerations to account for when evaluating seasonal storage technologies in Best?

Question 2

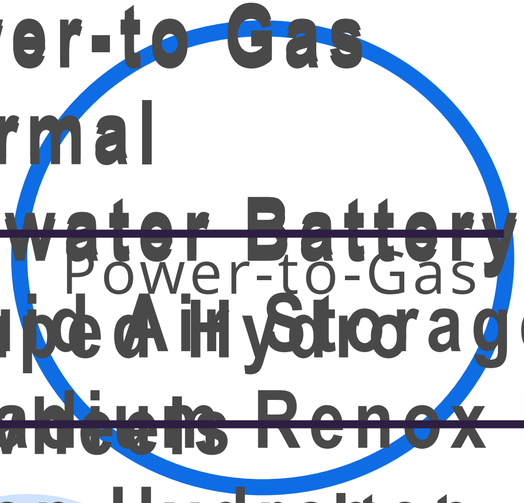
How can conceptual modelling contribute to the comparison and evaluation of storage technologies?

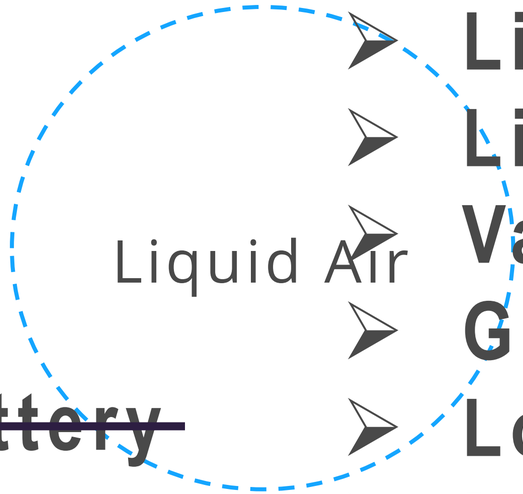
Question 3

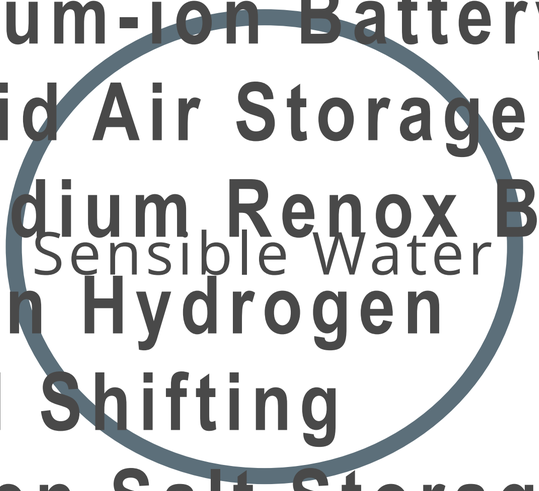
How do the various storage technologies perform based on the key considerations?

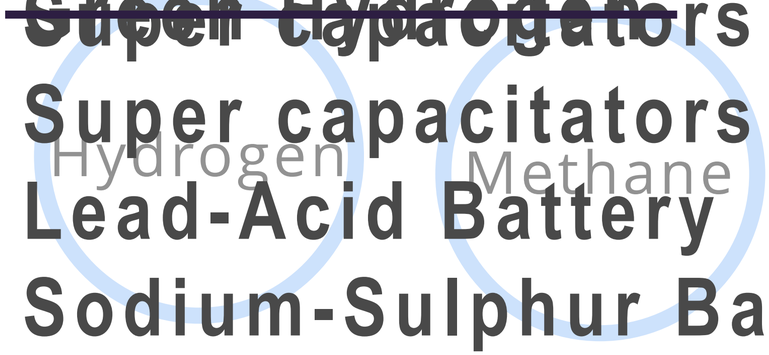
Energy Storage Technologies

- ~~Compressed Air~~
- Power-to Gas
- Thermal
- ~~Saltwater Battery~~
- ~~Pumped Hydro~~
- ~~Vanadium Renox Battery~~
- ~~Flywheels~~
- ~~Green Hydrogen~~
- ~~Super capacitators~~
- Super capacitators Magnetic
- Lead-Acid Battery
- Sodium-Sulphur Battery
- Flow Battery Nickel Battery
- Lithium-ion Battery
- Liquid Air Storage
- Vanadium Renox Battery
- Green Hydrogen
- Load Shifting
- Molten Salt Storage









Conceptual Models

- ❑ **Simplified Visualizations**
- ❑ **Calculations**
- ❑ **Comparison and Evaluation**

- ❑ **Heat Pumps (COP 3)**
- ❑ **Cost of Stored Energy (COSE)**

Heat Pumps

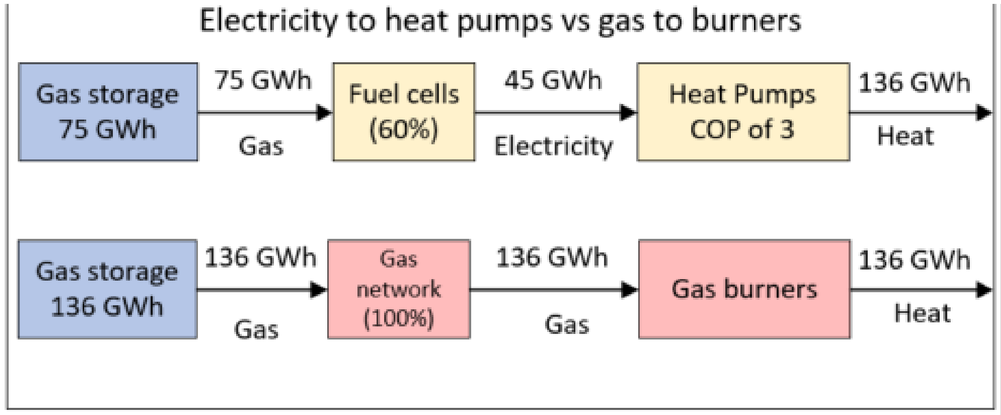
Air-to-Air heat pumps

Formulas

COSE_Thermal [€/kWh] = Total Lifetime Cost [€]/Total Supplied Heat Energy [kWh]

$$\text{COSE\_Thermal} = \frac{\text{CAPEX-P + CAPEX-S+(OPEX*Lifetime)}}{\text{Seasonal Heat Energy Output *Lifetime}}$$

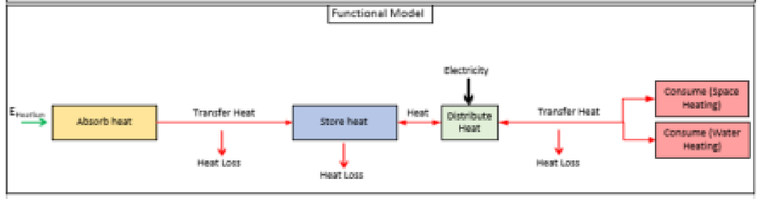
CAPEX-P = CAPEX Powerplant CAPEX-S = CAPEX Storage



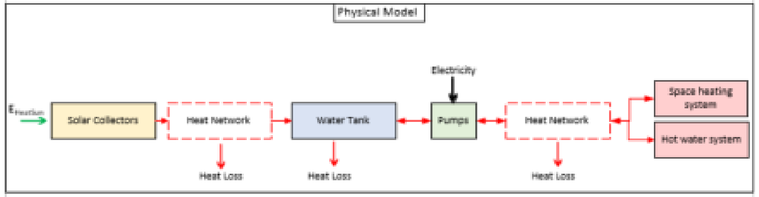
Thermal Sensible Energy Storage

Water			
- Efficiency	50 – 90% [1]	- Capacity	10 – 50 kWh/t [1]
- Power	0.001 – 10 MW [1]	- Life time	20 + years [2]
- Heat loss	Loss is included in the efficiency	- Specific heat	4.2 kJ/kg [2]
- Density	1000 kg/m³ [2]		

Functional Model



Physical Model



Energy flow from storage (Single residence)

Assuming a heat loss of 15% throughout the storage time. Heat networks (before and after) having a combined loss of 6%*.

Water Tank: 15,5 MWh 85% → 11,3 MWh Heated Water → Heat Network 5% → 10,9 MWh Heat

Size example for a single residence (Average gas consumption)

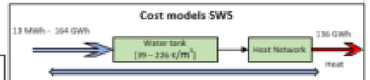
E_{stored} = Energy Need/(Storage efficiency*Heat network efficiency)

E_{stored} = 10 940 kWh/(85%*0,97) = 13 268 kWh
= 47,76 * 10^6 kJ

m = E_{stored}/c_p dt = 49,32*10^6kJ/4.2 kJ/kg*C* 70°C = 162 449 kg =162 449 l ≈ 162 m³

$E_{Storage} = c_p$ dt m dt = Temperature difference c_p = Specific Heat m = mass of water

Cost models SWS



Formulas

COSE_Thermal [€/kWh] = Total Lifetime Cost [€]/Total Supplied Heat Energy [kWh]

COSE_Thermal = (CAPEX Water tank) / (Seasonal Heat Energy Output *Lifetime)

Evacuat Storage Tanks [3]	
Volume [m³]	Cost [€/m³]
1500	226
5000	137
19000	59
60000	39

Residences/Tank	Volume [m³]	CAPEX	CAPEX/Residence	number residences in Best*CAPEX/residence	COSE_Thermal [€/kWh]
1	162	€ 36 612	€ 36 612	€ 451 755 468	€ 0.166
10	1620	€ 221 940	€ 22 194	€ 273 851 766	€ 0.101
50	8100	€ 1 109 700	€ 22 194	€ 273 851 766	€ 0.101
100	16200	€ 955 800	€ 9 558	€ 117 936 162	€ 0.043
500	81000	€ 3 159 000	€ 6 318	€ 77 957 802	€ 0.029
12332	1997784	€ 77 913 576	€ 6 318	€ 77 957 802	€ 0.029

SWS Distribution

Required Solar Collector area

Required solar Collector area = Energy need [kWh]/ Roundtrip Efficiency[%]/Solar Radiation [kWh/m²]

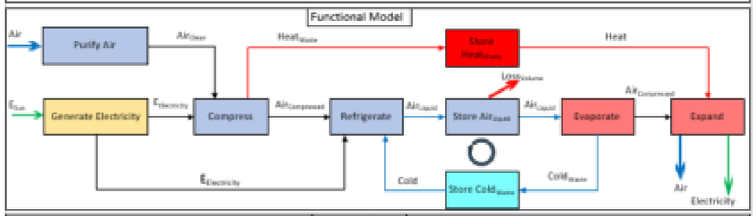
Energy Need [GWh]	Roundtrip Efficiency	Solar radiation [kWh/m²]	Area [m²]	Area [km²]
136	80 %	800	212500	0,21

(1) https://www.mdpi.com/2071-1050/10/1/191/htm
(2)https://iea-etsap.org/E-TechDS/PDF/E17IR%20ThEnergy%20Stor_AH_Jan2013_final_GSOK.pdf
(3) https://www.aimspress.com/fileOther/PDF/energy/energy-07-04-907.pdf
(4) https://www.diva-portal.org/smash/get/diva2:936741/FULLTEXT01.pdf
(5) https://pure.tue.nl/ws/files/47029560/798585-1.pdf

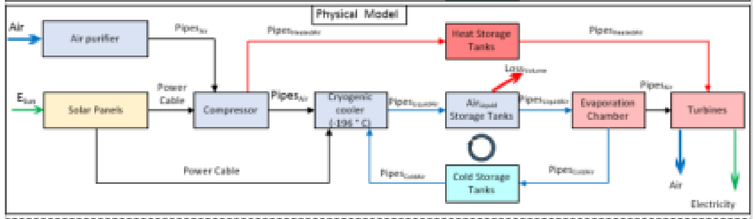
Liquid Air Energy Storage (LAES) Technical Specifications

- Efficiency:	60% [1] (Stand alone)	- LCOS (Literature):	100 – 300 €/MWh [4]
- Power	10MW [1] up to hundreds of MW	- Capacity	GWh potential [1] (> 10MWh)
- Volume loss:	0.05 % per day [4]	- Energy density [u]:	107 kWh/m³ [1][2]
- Roundtrip efficiency	54.6 % (6 months loss)	- Life time	30 + years [5]

Functional Model



Physical Model



LAES Storage Volume

Required energy stored = Energy need/(COP/(Storage Efficiency*Re-electrifying Efficiency)

E_{Stored} = 136 GWh/(1/(91%*70%)) = 70 GWh

Required storage volume [m³] = Storage Need [kWh]/Energy Density[kWh/m³]

Storage Need [GWh]	Energy Density [kWh/m³]	Volume [m³]
70	107	654206

Energy flow from storage

Assuming a 70% re-electrifying efficiency

Gas storage 70 GWh Loss: 9% → 64 GWh Gas → Re-electrifying 70% → 45 GWh Electricity → Heat Pumps COP of 3 → 136 GWh Heat

Size of LAES plant

With limited available data on this, we have used Highview Power Storage's estimates of a 20 MW output power plant as a reference [1]. This plant has a space requirement of 2023 m². We assume the double for the plant in this model, as the compressor and cryogenic cooler must be larger to produce the required amount of liquid air. LAES Poweplant size = 4000 m²

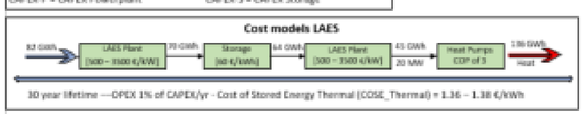
Formulas

COSE_Thermal [€/kWh] = Total Lifetime Cost [€]/Total Supplied Heat Energy [kWh]

COSE_Thermal = (CAPEX-P + CAPEX-S+(OPEX*Lifetime)) / (Seasonal Heat Energy Output *Lifetime)

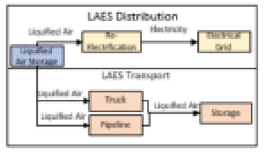
CAPEX-P = CAPEX Powerplant CAPEX-S = CAPEX Storage

Cost models LAES



CAPEX -P	CAPEX - S	OPEX [1% of CAPEX/year]	COSE_Thermal
10 - 70 M	4218 M	42M	1.36 - 1.38

LAES Distribution

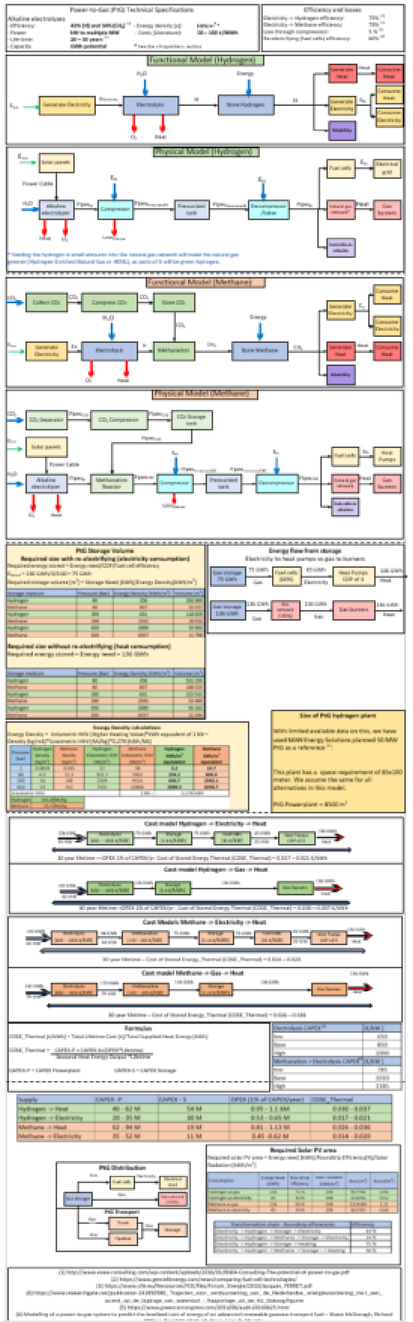


Required Solar PV area

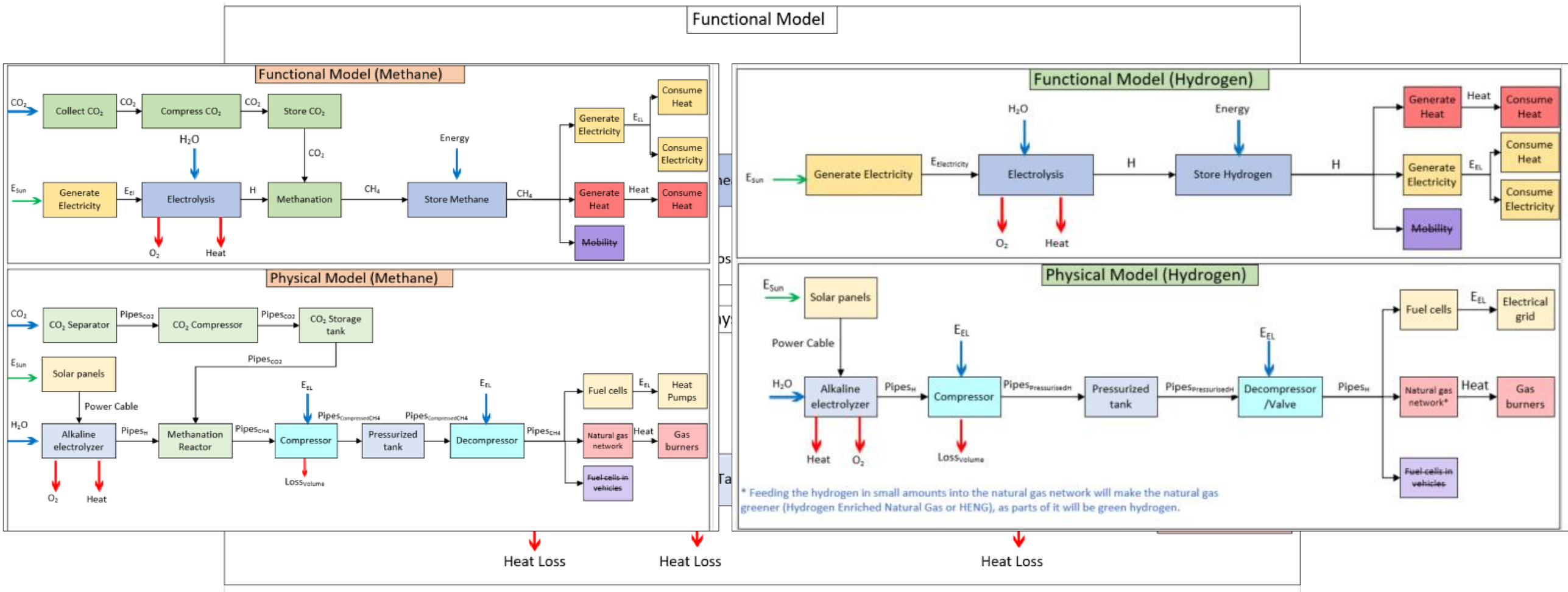
Required solar PV area = Energy need [kWh]/Roundtrip Efficiency[%]/Solar Radiation [kWh/m²]

Energy Need [GWh]	Roundtrip Efficiency	Solar radiation [kWh/m²]	Area [m²]	Area [km²]
45	55 %	200	412088	0,41

(1) https://warwick.ac.uk/fac/sci/eng/research/groupslist/electricalpower/images/newsevents/hies2017/presentations/hies2017_highview.pdf
(2) https://www.researchgate.net/publication/304505403_Liquid_Air_Energy_Storage_A_Potential_Low_Emissions_and_Efficient_Storage_System
(3) https://kth.diva-portal.org/smash/get/diva2:1216213/FULLTEXT01.pdf
(4) https://www.rechargenews.com/transition/liquid-air-storage-offers-cheapest-route-to-24-hour-wind-and-solar/2-1-635666
(5) https://ease-storage.eu/wp-content/uploads/2016/07/EASE_TD_Mechanical_LAES.pdf
(6) https://www.store-project.eu/documents/results/en_GB/report-summarizing-the-current-status-role-and-costs-of-energy-storage-technologies

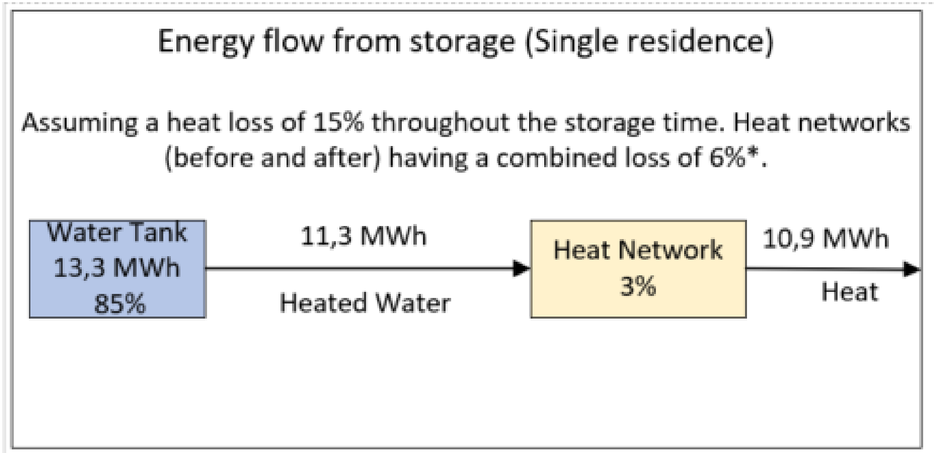


Functional and Physical Models

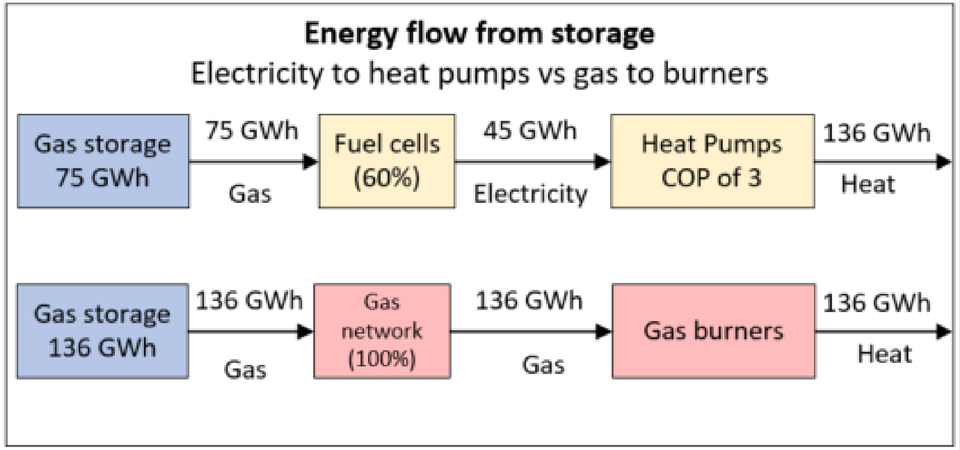


Energy Flow from Storage

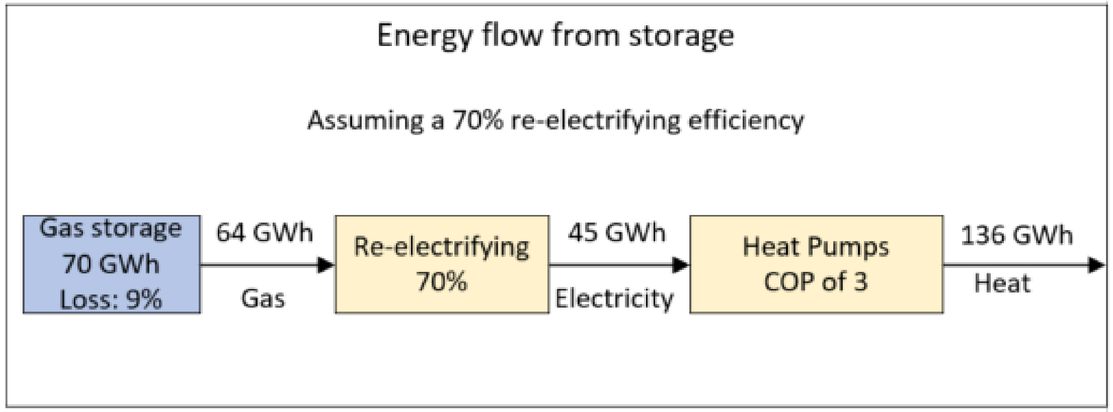
Sensible Water Storage



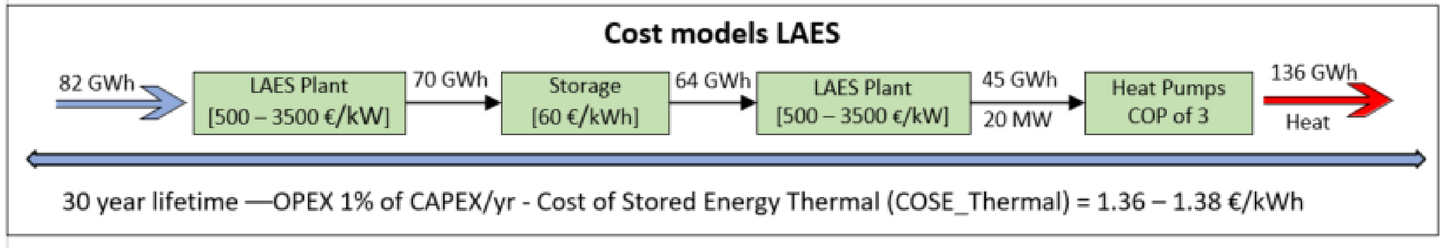
Power-to-Gas

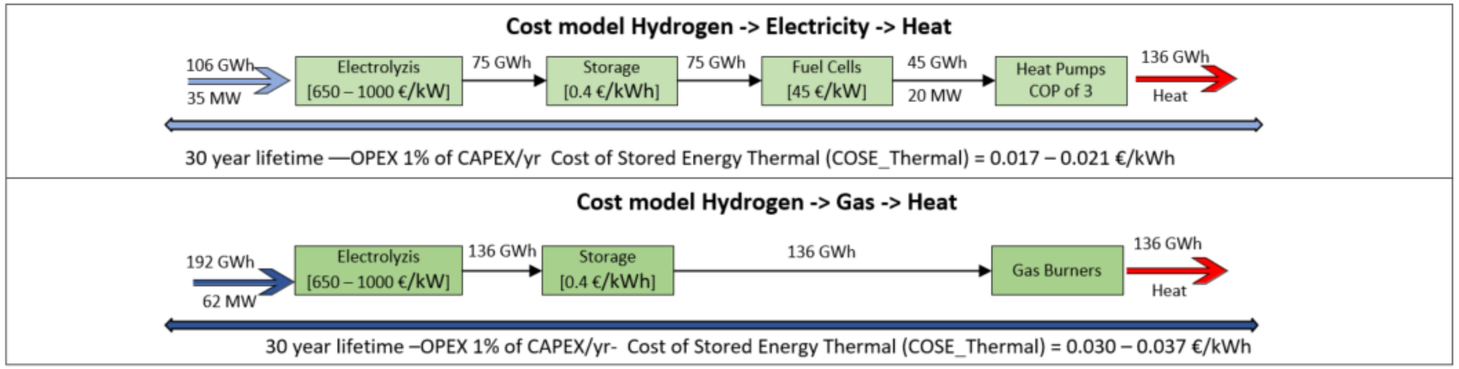


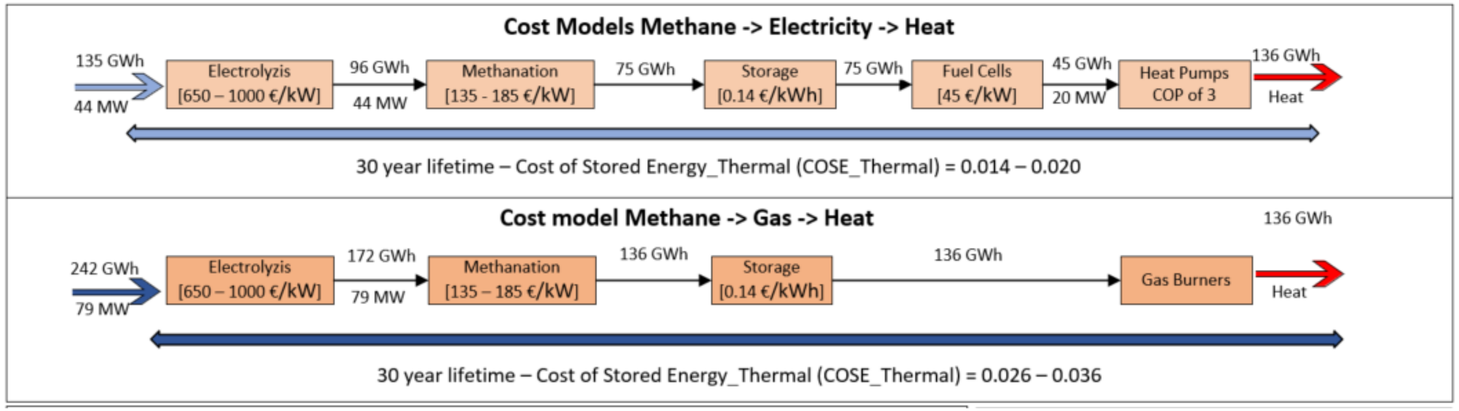
Liquid Air Storage

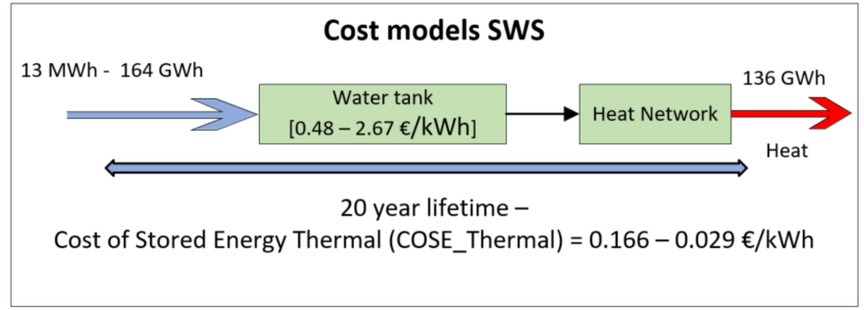


Economics

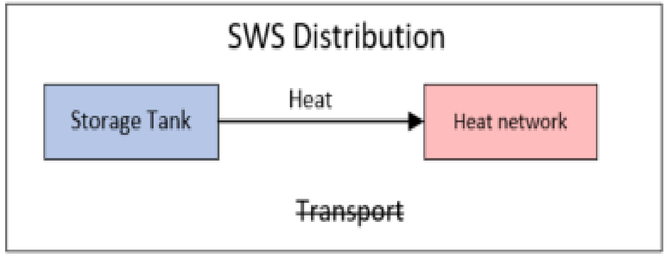

Cost models LAES
82 GWh
LAES Plant
[500 – 3500 €/kW]
70 GWh
Storage
[60 €/kWh]
64 GWh
LAES Plant
[500 – 3500 €/kW]
45 GWh
20 MW
Heat Pumps
COP of 3
136 GWh
Heat
30 year lifetime —OPEX 1% of CAPEX/yr - Cost of Stored Energy Thermal (COSE_Thermal) = 1.36 – 1.38 €/kWh

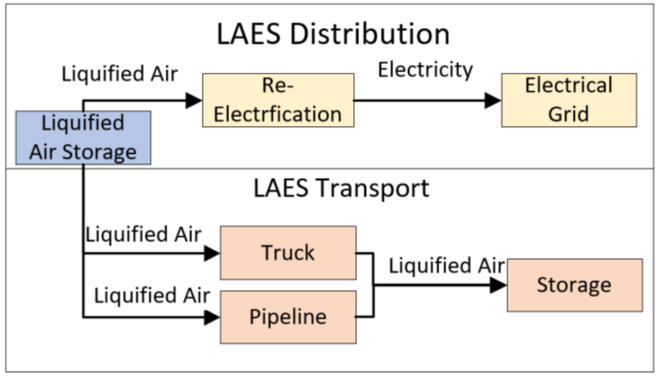

Cost model Hydrogen -> Electricity -> Heat
106 GWh
35 MW
Electrolyzis
[650 – 1000 €/kW]
75 GWh
Storage
[0.4 €/kWh]
75 GWh
Fuel Cells
[45 €/kW]
45 GWh
20 MW
Heat Pumps
COP of 3
136 GWh
Heat
30 year lifetime —OPEX 1% of CAPEX/yr Cost of Stored Energy Thermal (COSE_Thermal) = 0.017 – 0.021 €/kWh
Cost model Hydrogen -> Gas -> Heat
192 GWh
62 MW
Electrolyzis
[650 – 1000 €/kW]
136 GWh
Storage
[0.4 €/kWh]
136 GWh
Gas Burners
136 GWh
Heat
30 year lifetime –OPEX 1% of CAPEX/yr- Cost of Stored Energy Thermal (COSE_Thermal) = 0.030 – 0.037 €/kWh

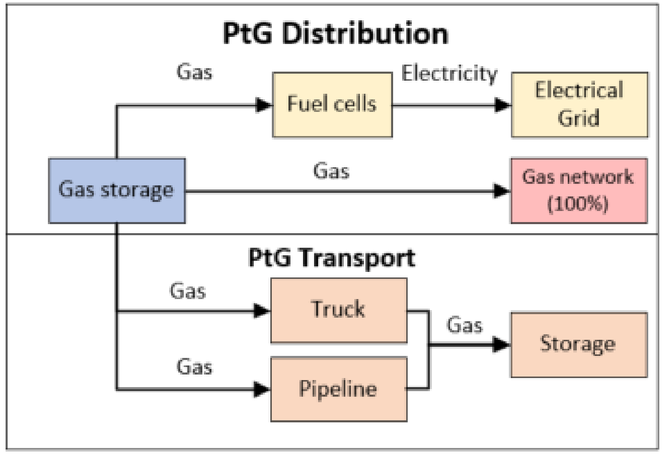

Cost Models Methane -> Electricity -> Heat
135 GWh
44 MW
Electrolyzis
[650 – 1000 €/kW]
96 GWh
44 MW
Methanation
[135 - 185 €/kW]
75 GWh
Storage
[0.14 €/kWh]
75 GWh
Fuel Cells
[45 €/kW]
45 GWh
20 MW
Heat Pumps
COP of 3
136 GWh
Heat
30 year lifetime – Cost of Stored Energy_Thermal (COSE_Thermal) = 0.014 – 0.020
Cost model Methane -> Gas -> Heat
136 GWh
242 GWh
79 MW
Electrolyzis
[650 – 1000 €/kW]
172 GWh
79 MW
Methanation
[135 – 185 €/kW]
136 GWh
Storage
[0.14 €/kWh]
136 GWh
Gas Burners
Heat
30 year lifetime – Cost of Stored Energy_Thermal (COSE_Thermal) = 0.026 – 0.036


Cost models SWS
13 MWh - 164 GWh
Water tank
[0.48 – 2.67 €/kWh]
Heat Network
136 GWh
Heat
20 year lifetime –
Cost of Stored Energy Thermal (COSE_Thermal) = 0.166 – 0.029 €/kWh

Transport and Distribution







Required Solar Panel Area

Sensible Water

Energy Need (GWh)	Roundtrip Efficiency	Solar radiation [kWh/m^2]	Area [m^2]	Area (km^2)
136	80 %	800	212500	0.21

Liquid Air

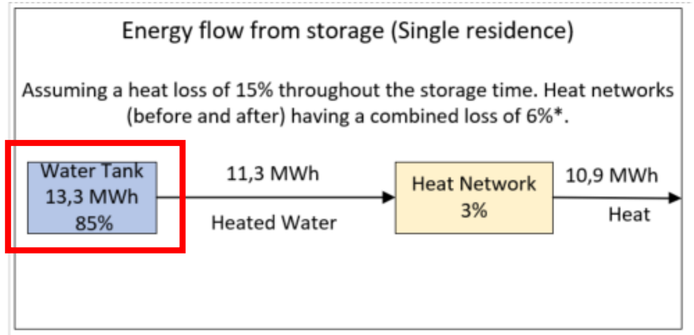
Energy Need (GWh)	Roundtrip Efficiency	Solar radiation [kWh/m^2]	Area [m^2]	Area (km^2)
45	55 %	200	412088	0.41

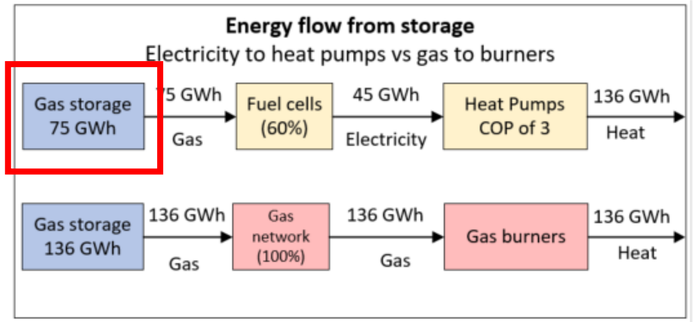
Power-to-Gas

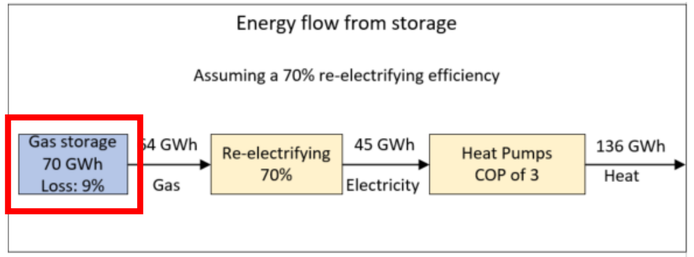
Consumption	Energy Need (GWh)	Roundtrip Efficiency	Solar radiation [kWh/m^2]	Area [m^2]	Area (km^2)
Hydrogen as gas	136	71 %	200	957746	0.96
Hydrogen as electricity	45	43 %	200	523256	0.52
Methane as gas	136	56 %	200	1214286	1.21
Methane as electricity	45	34 %	200	661765	0.66

Key Findings

Stored Power







Energy Density

82 kWh/m^3

Pressure [bar]	Hydrogen kWh/m^3 equivalent	Methane kWh/m^3 equivalent
1	3.2	10.7
80	256.2	806.9
200	630.7	2592.1
650	2089.3	6356.7

107 kWh/m^3

Storage Costs

Water tank
[0.48 – 2.67 €/kWh]

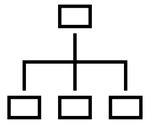
Storage
[0.4 €/kWh]

Storage
[0.14 €/kWh]

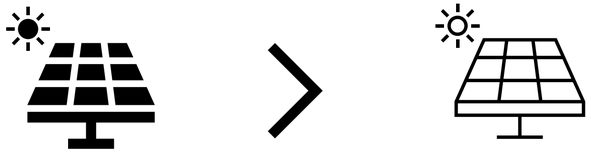
Storage
[60 €/kWh]

Conclusion

Conceptual Models

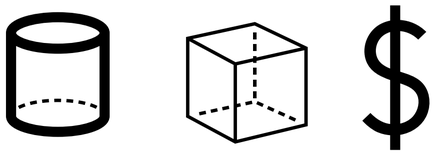


Comparison of Technologies

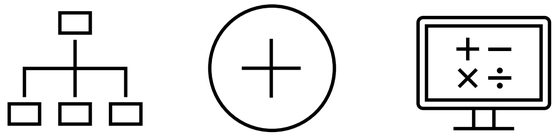


Key Considerations

Key Findings



Models Combined with Data



Power-to-Gas (Methane)

Future Research

- ❑ Move up in the model hierarchy
- ❑ Combination of technologies
- ❑ Communication to stakeholders

Learnings

- ➢ Simplifying requires more knowledge
- ➢ Focus on the models not the technology
- ➢ Seasonal perspective

Thanks!