universität innsbruck

Eurotherm Seminar #112
Advances in Thermal Energy Storage

EUROTHERM

Planning and Constructing Cost-Effective Very Large-Scale Hot Water TES for District Heating Systems

Eurotherm 2019
Lleida

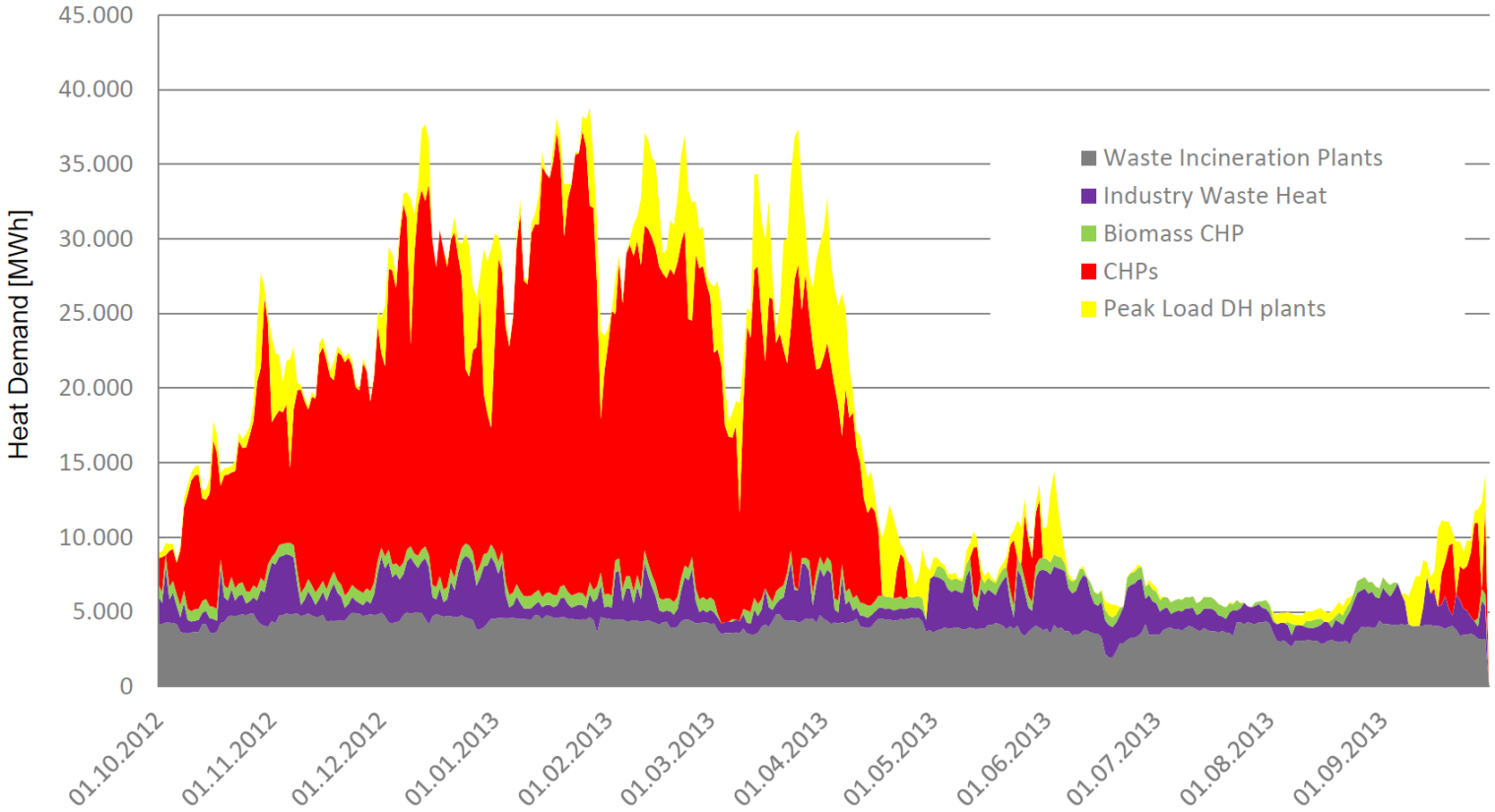
Fabian Ochs, Abulrahman Dahash, Michele Bianchi Janetti

Austrian FFG Flagship Project (Energieforschung)

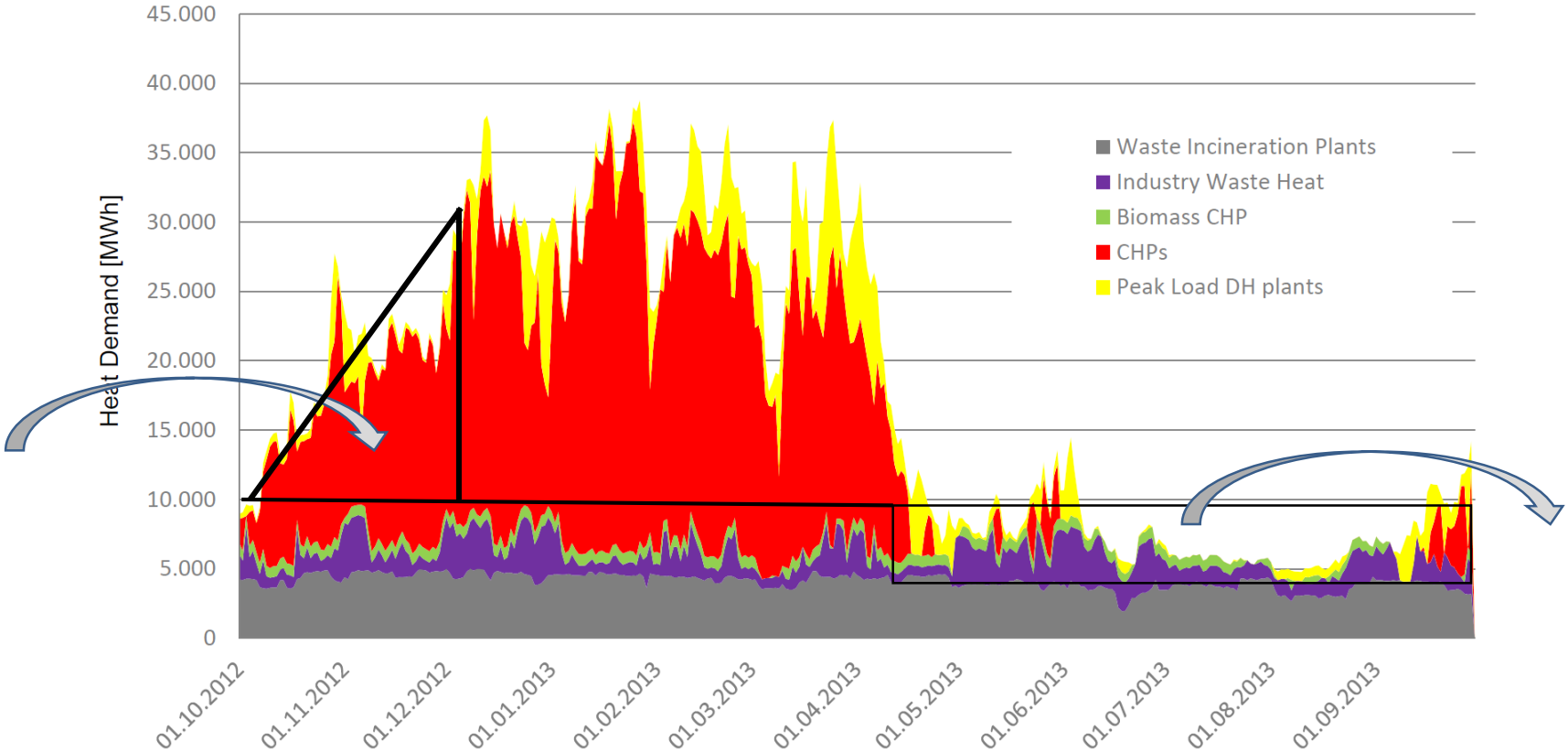
giga_TES
Giga-Scale Thermal Energy Storage for Renewable Districts

Total cost: 4.4 M€
Funding requested: 3.3 M€
Duration: 36 Months

Example District Heating Vienna – Strong Seasonal Variations

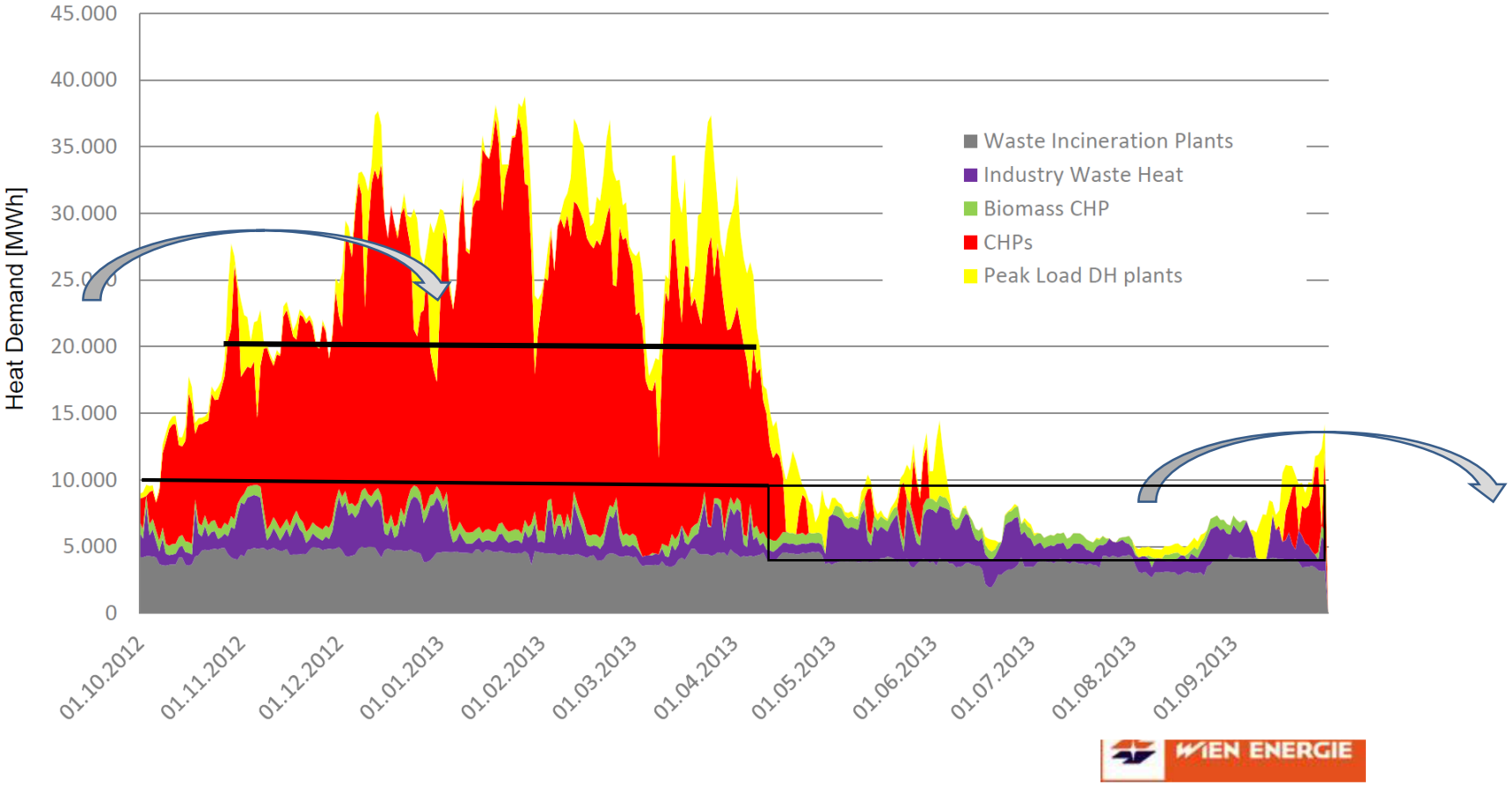


Example District Heating Vienna – Strong Seasonal Variations; Integration of TES (1)



WIEN ENERGIE

Example District Heating Vienna – Strong Seasonal Variations; Integration of TES (2)



State of the art: Tank TES

Tank: up to 50.000 m³ practical experiences

DH TES Theiß:
50 000 m³ Water
(former oil tank)

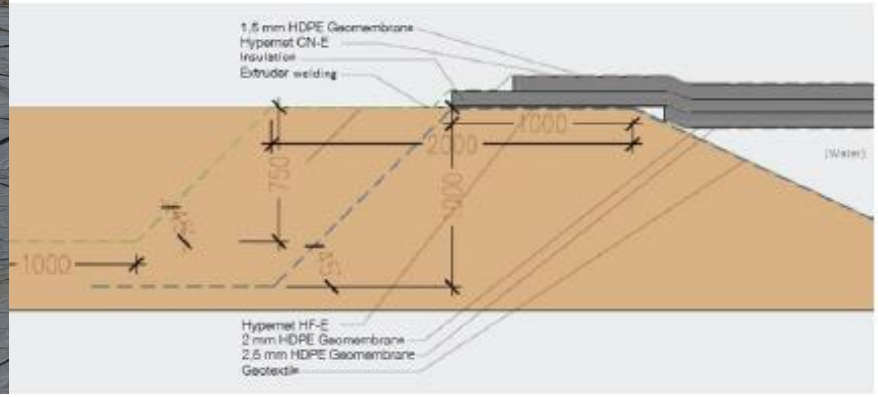
Source: Bilfinger VAM Anlagentechnik GmbH, 2013

Concrete:
Segmented and solid
Above and underground

Source: Mangold, 2011

Experiences in Denmark – pit TES

- 2012 Dronninglund (60000 m^3)
- 2013 Marstal (75000 m^3)
- 2015 Gram (122000 m^3)
- 2015 Vojens (195000 m^3)



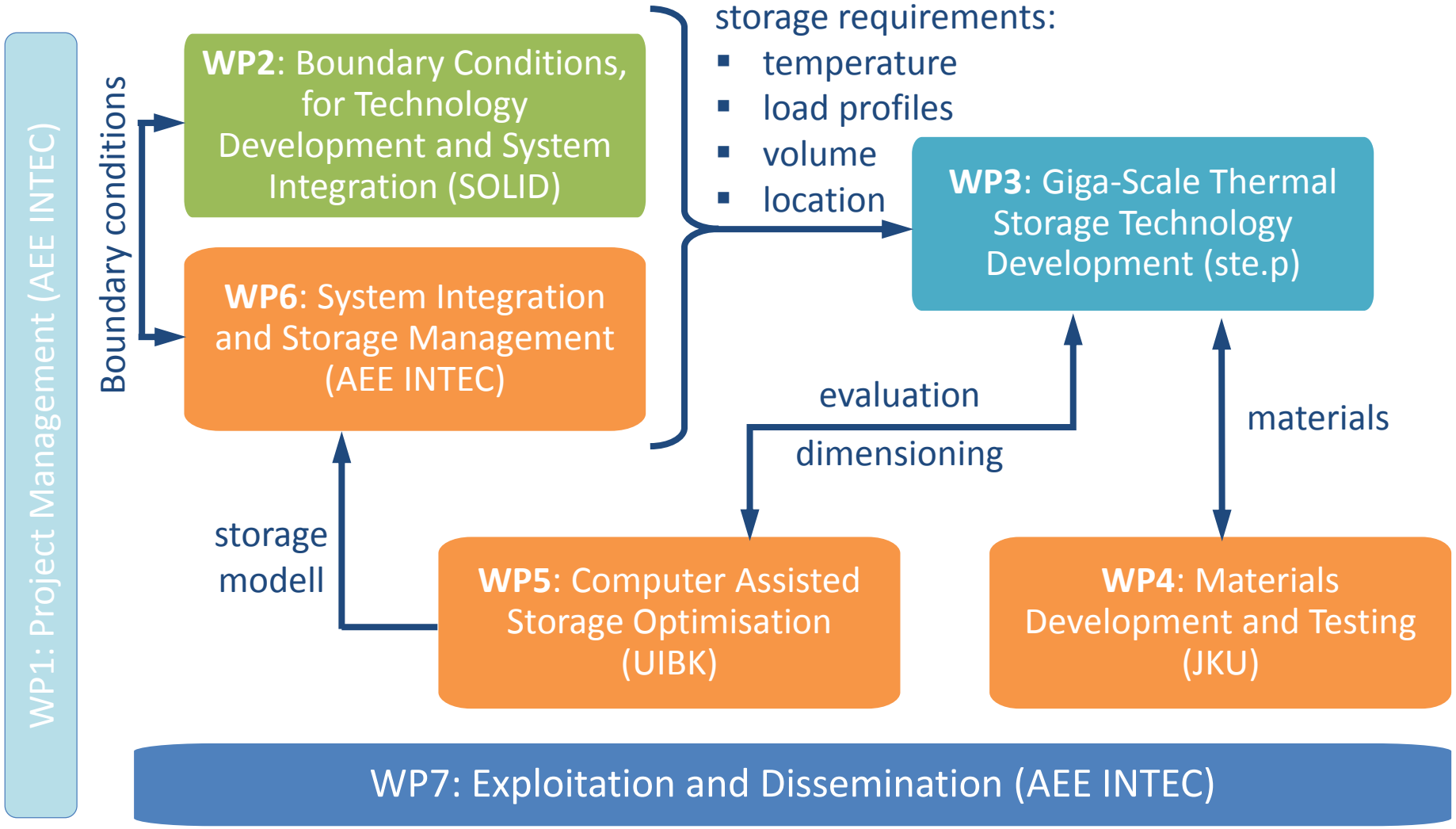
Source: PlanEnergi

Objective

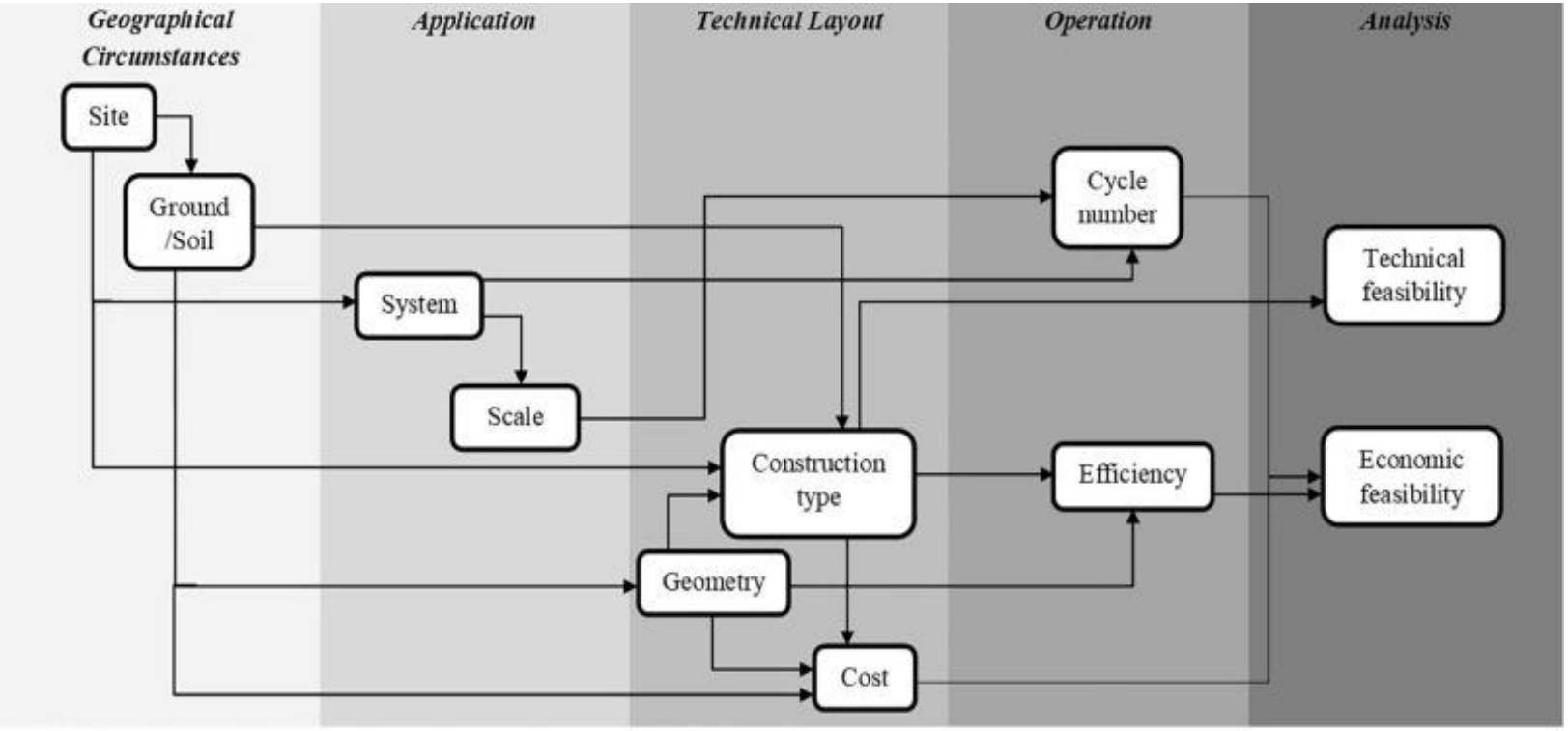
Generate knowledge on materials and technologies, with which dedicated concepts for large scale TES for district heating can be designed, that:

- provide cost-effective solutions for very large scale TES
- are integrated in the urban environment
- provide more storage capacity
- are energetically efficient
- are well integrated in the overall district heating system
- have long lifetime

Work Package structure



TES design and optimization - Influencing parameters



- Position: urban, rural
- Area: residential, industrial
  - Structural strength
  - Thermal properties
  - Groundwater

- District/block heating system
- Solar, Biomass, Heat pumps
- Heating profile, charging and discharging profiles
- Maximum and minimum operation temperatures
- Operation and maximum pressure

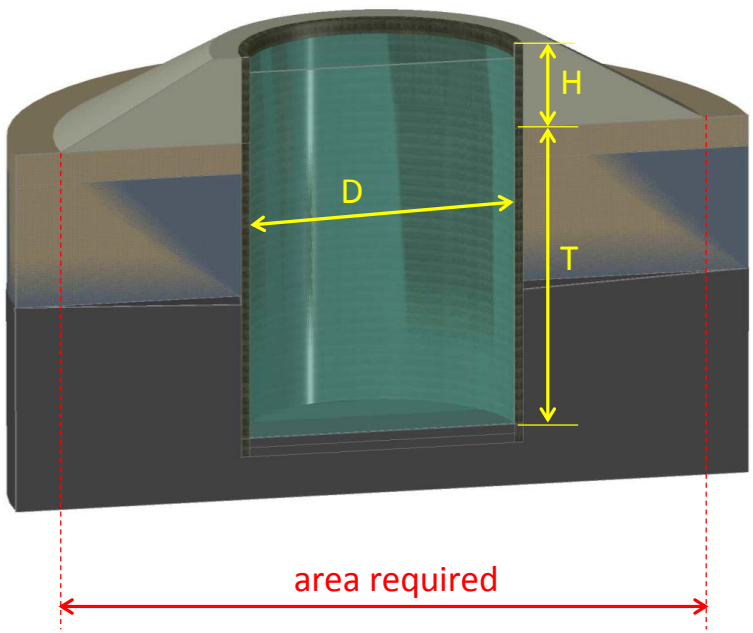
- Cylinderical/coned stump shape/truncated pyramid
- A/V ratio
- h/d ratio
- freestanding, fully or partially buried
- Insulation

- Buffer storage
- Long-term storage
- Multi-functions storage

Dahash, Ochs, Bianchi Janetti and Streicher, **Advances in seasonal thermal energy storage for solar district heating applications: A critical review on large-scale hot-water tank and pit thermal energy storage systems**, *Applied Energy*, vol. 239, pp. 296-315, 2019.

Design, geomety and construction

Variant 1 „shaft“

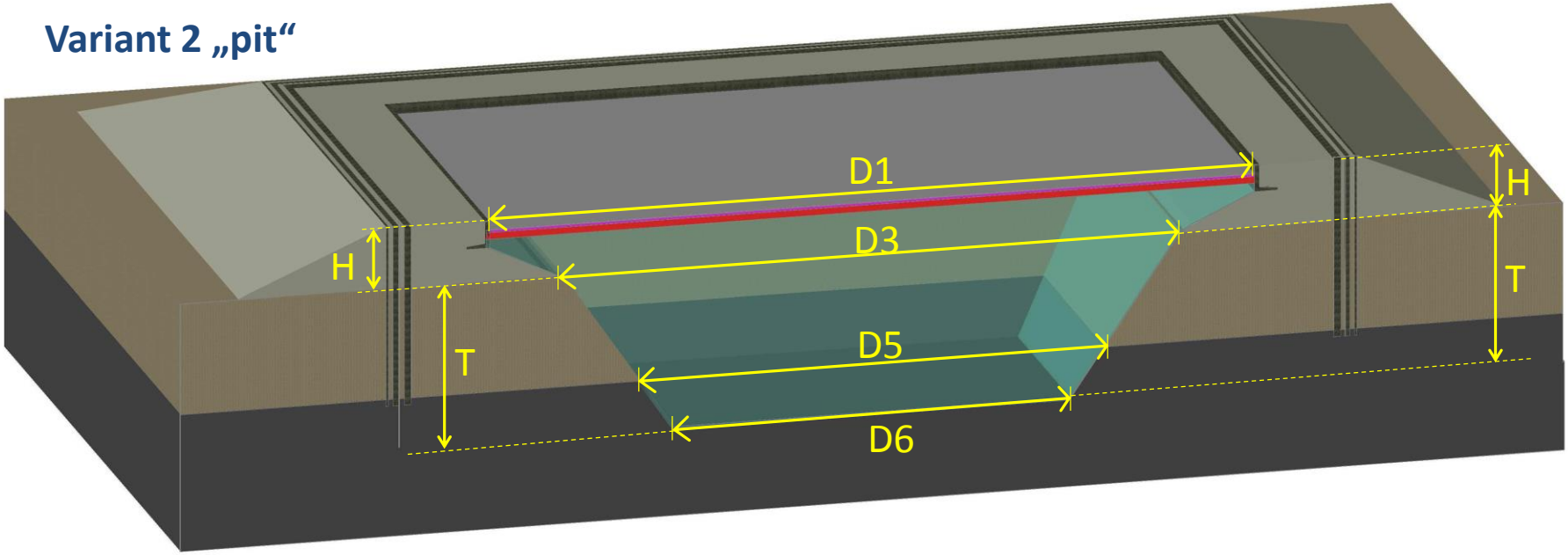


V = 100.000 m² → 105 x 105 m = 11.025 m²
V = 200.000 m² → 125 x 125 m = 15.625 m²

Volume	Embankment (above ground)	V1 – shaft		
		T	D_i	A/V
100.000 m³	**H = 15 m** crown width 4 m base width 27,5 m	**50 m**	**44 m**	**12 %**
200.000 m³		**50 m**	**62 m**	**9 %**
500.000 m³	= 2 x 200.000 m³ + 1 x 100.000 m³			
1 Mio m³	= 5 x 200.000 m³			
2 Mio m³	= 10 x 200.000 m³			

Design, geomety and construction

Variant 2 „pit“



Volume	Embankment (above ground)	V2 – pit						A / V
		T	β	D1	D3	D5	D6	
200.000 m³	**H = 15 m** crown width 5 m base width 41 m slope angle 2:3 retaining wall, h = 6m	20 m	33,7°	116 m	85 m	-	25 m	17 %
		10 m	33,7°	121 m	129 m	-	39 m	17 %
500.000 m³		30 m	33,7°	160 m	139 m	54 m	39 m	12 %
1 Mio m³		50 m	30,5°	207 m	176 m	91,5 m	7 m	10 %
2 Mio m³		50 m	30,5°	265 m	234 m	149 m	64 m	8 %

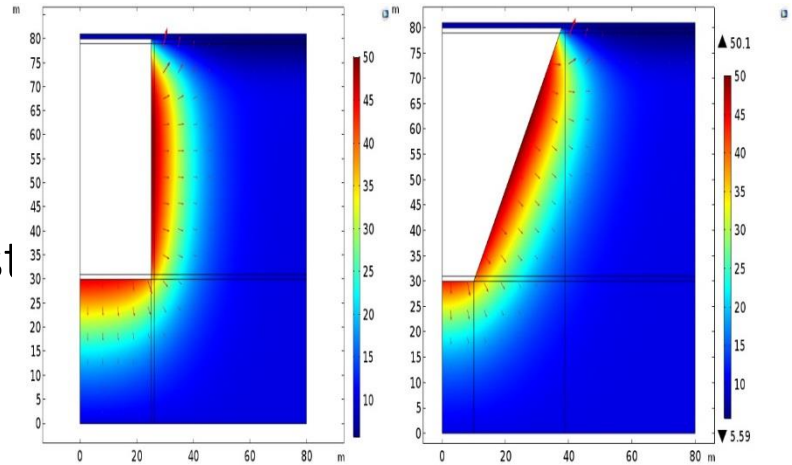
Modelling and simulation of large-scale TES

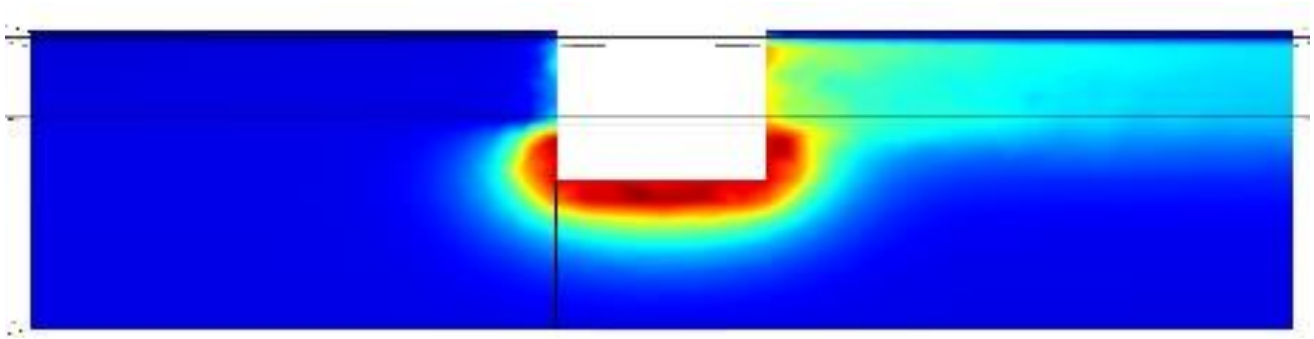
COMSOL Multiphysics®

1 D Fluid Domain with buoyancy model

and

- 2 D axial symmetric models (tank, cone st
- 3 D models (pyramid stump)
- 3 D models with ground water flow

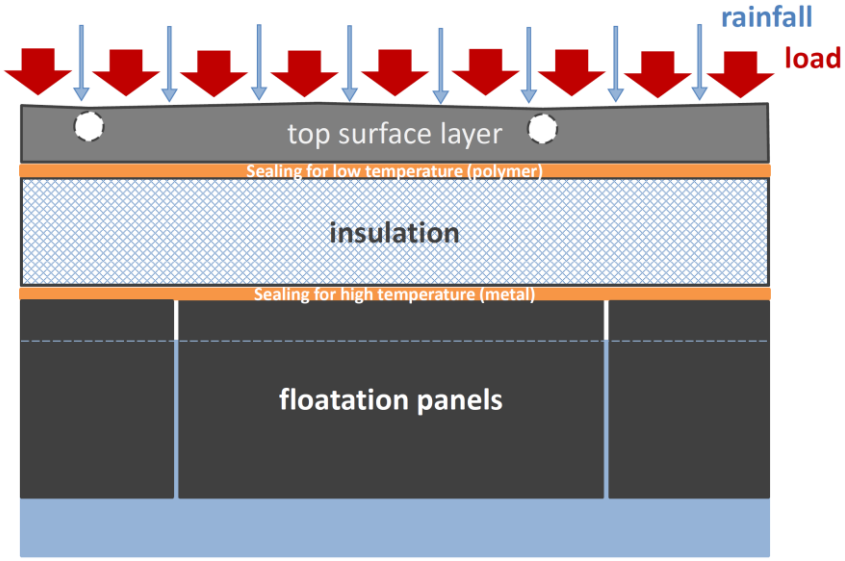




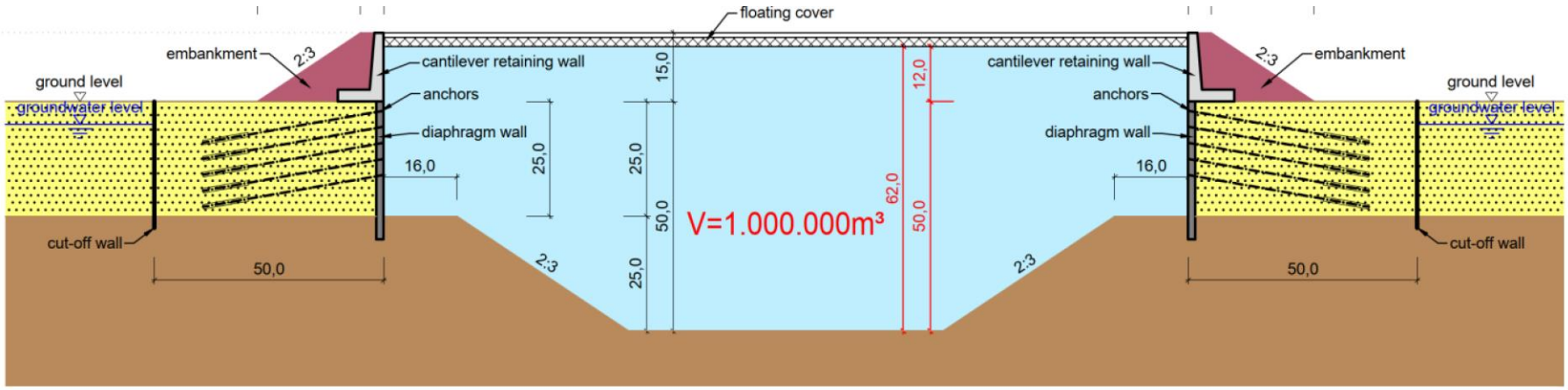
Abdulrahman Dahash, Michele Bianchi Janetti and Fabian Ochs
DETAILED 3-D MODELS OF A LARGE-SCALE UNDERGROUND THERMAL ENERGY STORAGE WITH CONSIDERATION OF GROUNDWATER CONDITIONS
ISEC 2018, Graz

→ see also Poster U208

Trafficable floating cover



- Space in densely populated areas is rare and expensive
- Requirement for a trafficable (i.e. useable) cover



TES operation

Temperature Profiles (simplified)

Storage operation

Idle (stillstand)

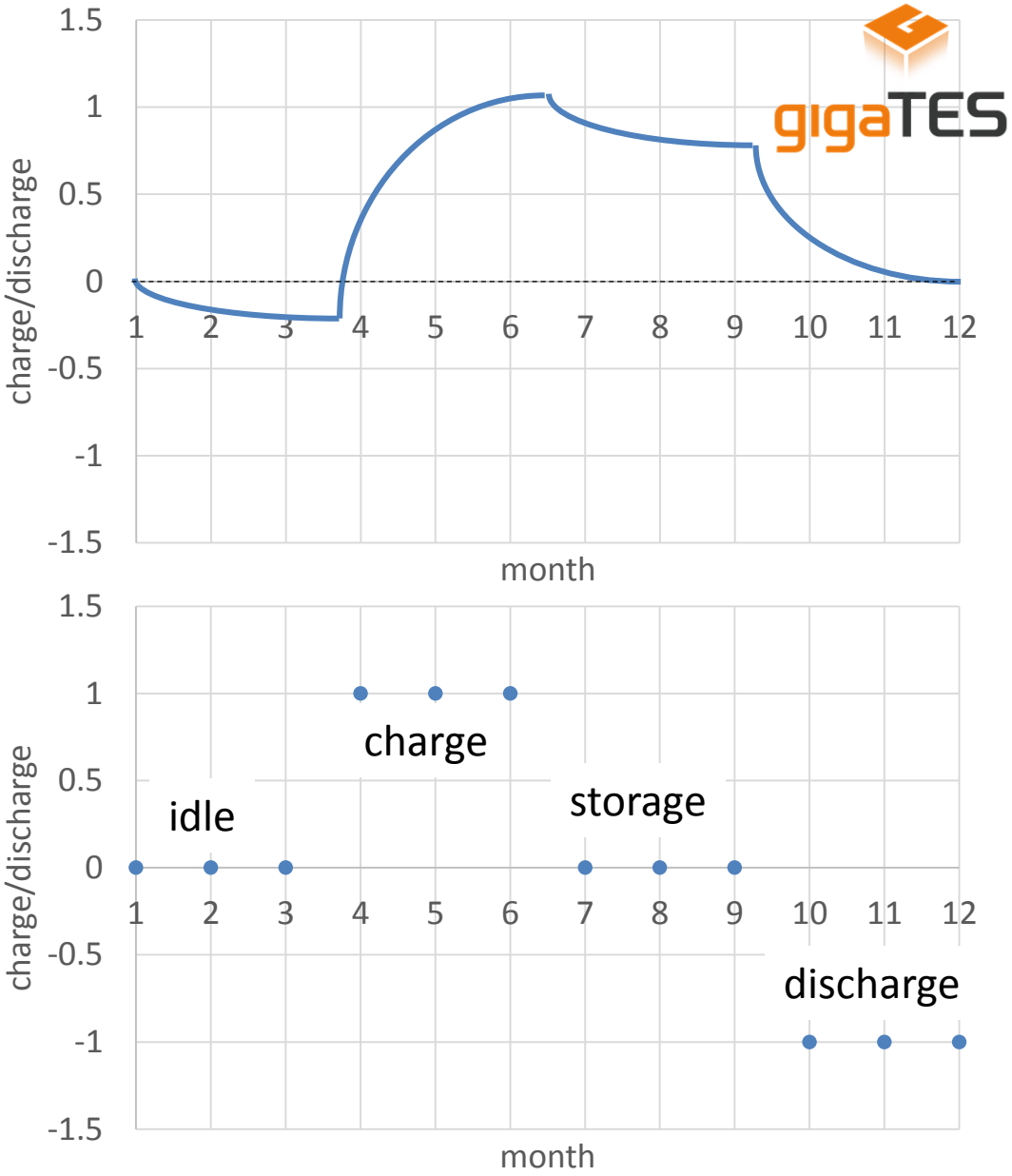
Charging

Storing (thermal losses)

Discharging

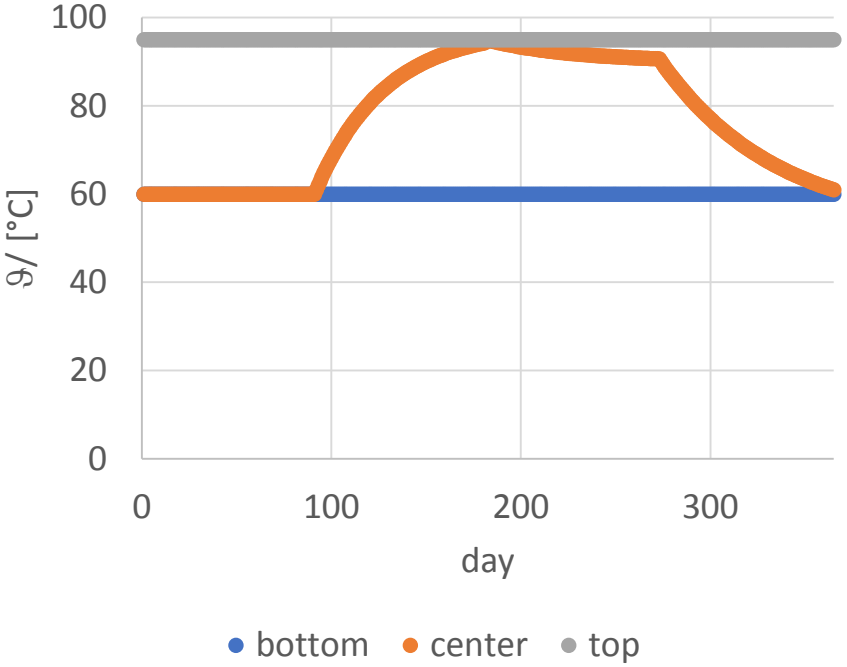
to return flow temp. level (e.g. 60 °C)

with heat pump to e.g. 30 °C

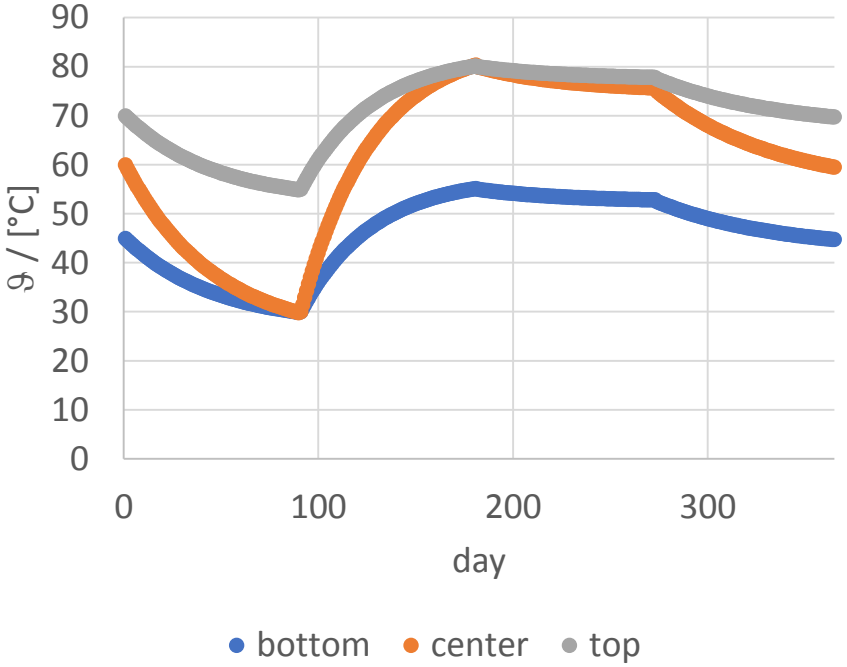


Temperature profiles (simplified)

District Heating
DH (90/60 °C) → HT



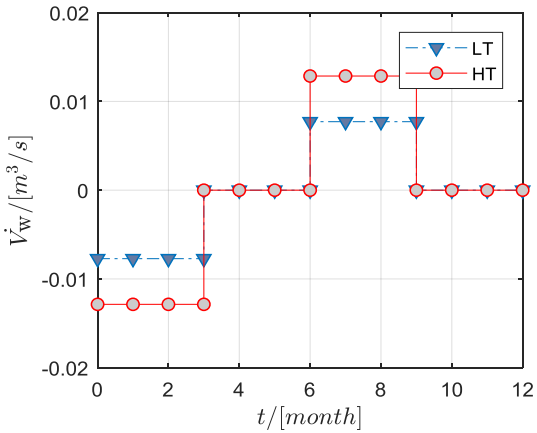
Block Heating
BH (80/30 °C) → LT

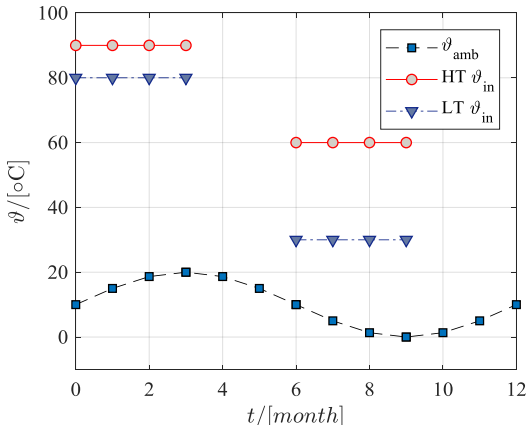


Variations

Storage operation:

- High temperature (HT) 90/60 °C
- Low temperature (LT) 80/30 °C





Storage construction:

- Tank (with diaphragm wall), pit (sloped wall) or shallow pit (30 °)
- Stainless steel (HT operation) or polymer liner (LT operation)
- with or without insulation (wall and bottom)
- with or without cut-off wall
- with or without trafficable cover

Key Performance Indicators - KPIs

Storage Capacity

$$Q_{TES} = \mathrm{V} \cdot \rho \cdot c_p \cdot \Delta T$$

Storage Efficiency

$$\eta_{TES} = 1 - \frac{Q_{loss}}{Q_{TES}}$$

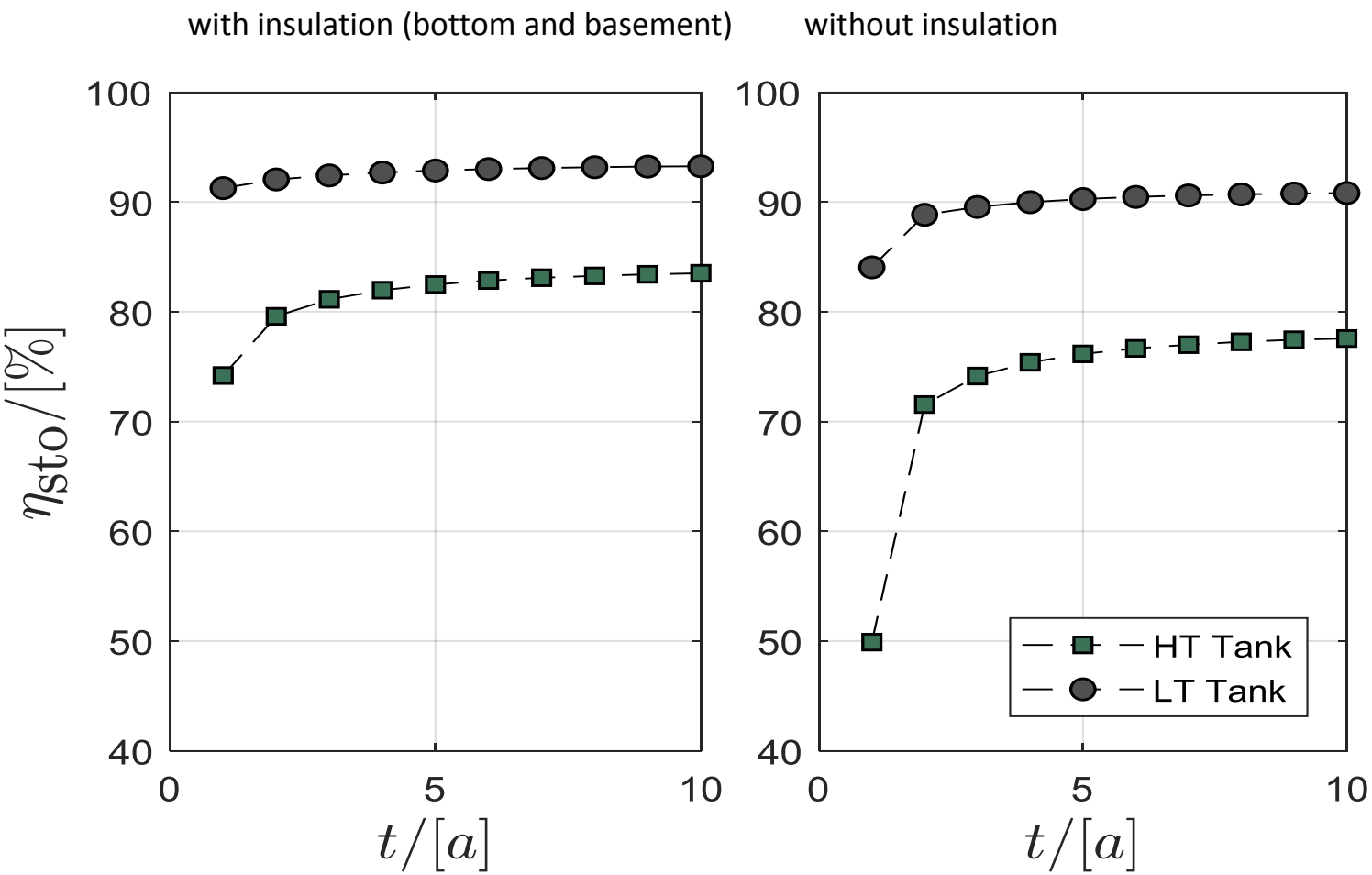
Effective Volume

$$V_{eff} = \eta_{TES} \cdot V$$

Annuity factor

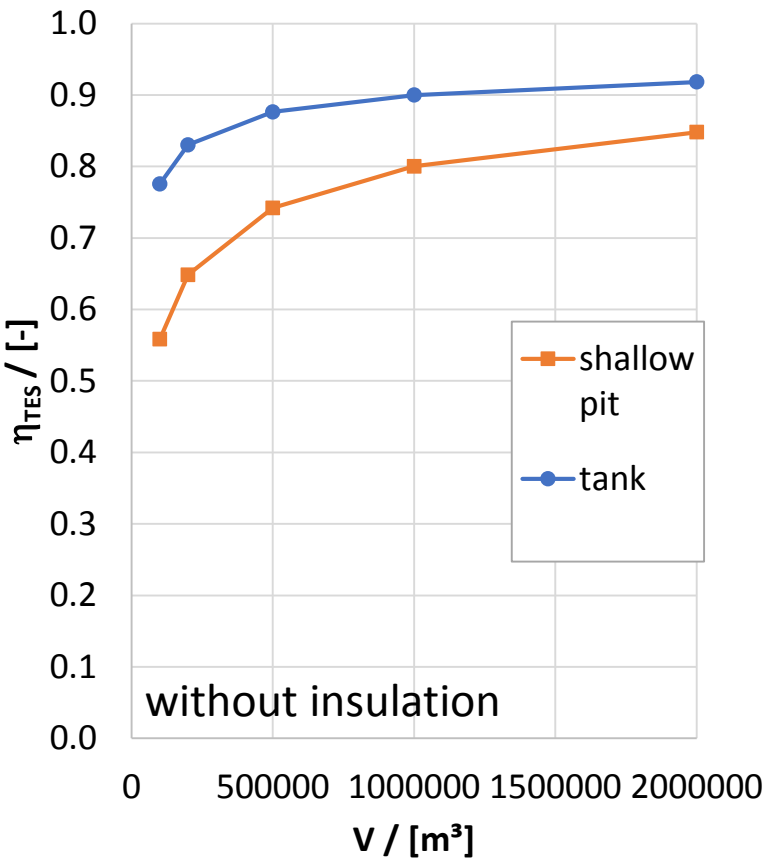
$$ANF_{n,i} = \frac{(1+i)^{\mathrm{n}} \cdot i}{(1+i)^{\mathrm{n}} - 1}$$

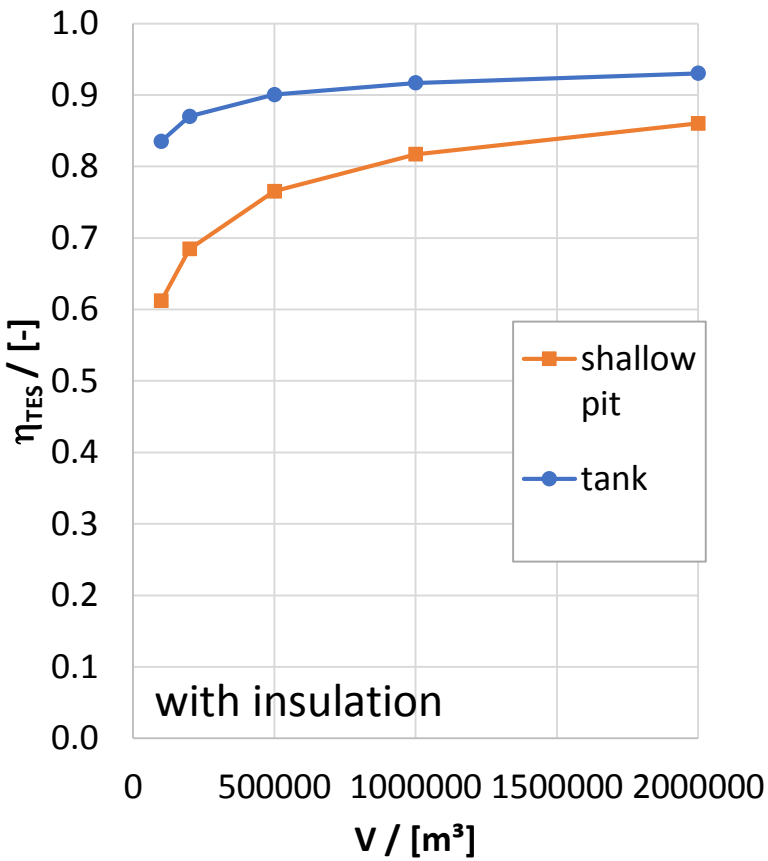
Evolution of TES performance for HT and LT



Tank, 100 000 m³

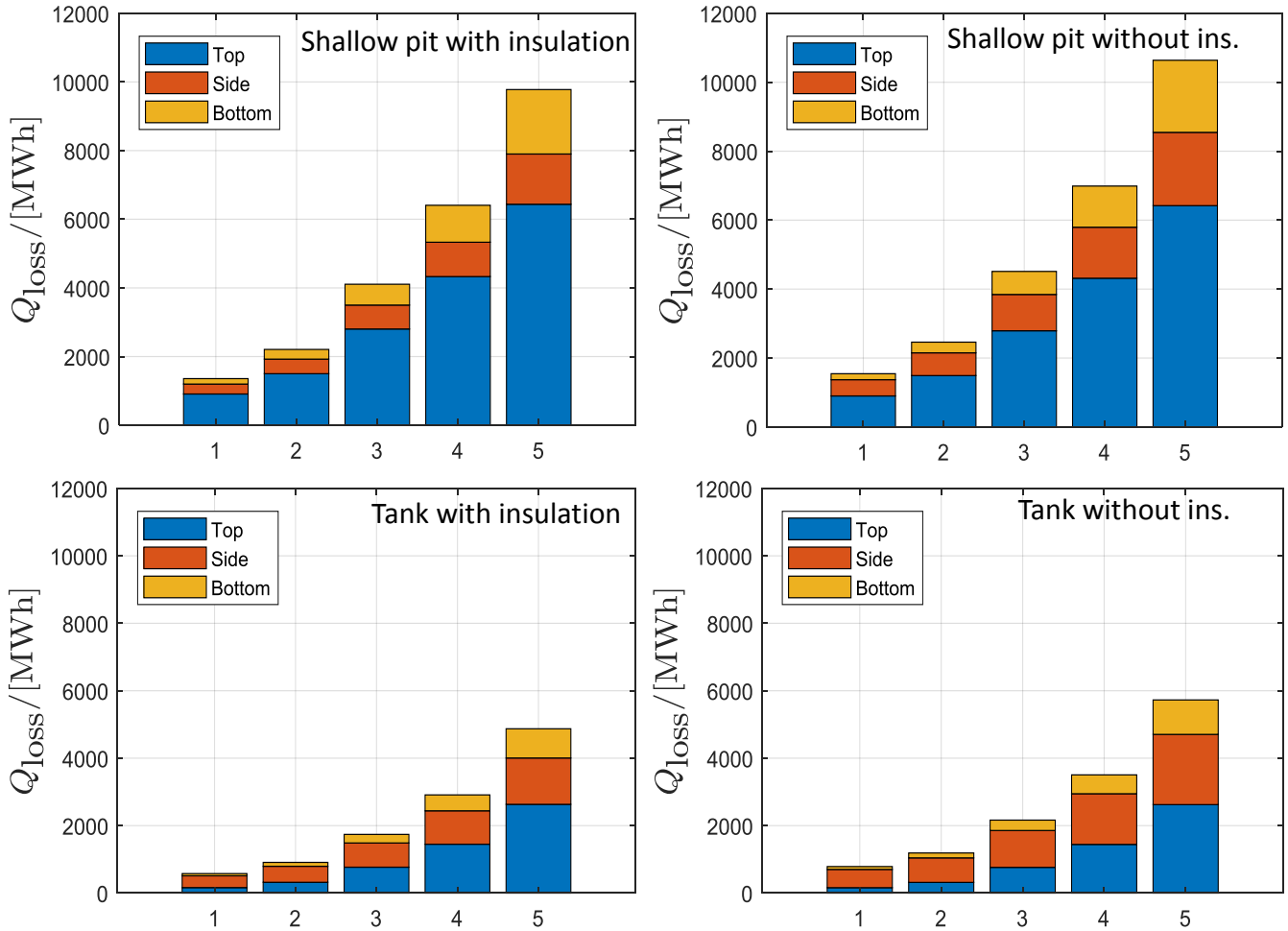
TES efficiency (year 10, λ_{ground} = 1.5 W/(m K))





The larger the TES the smaller the difference in TES efficiency

Storage losses for different volumes

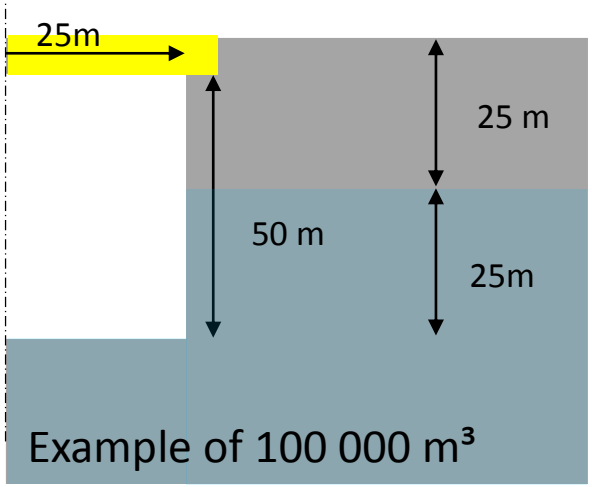


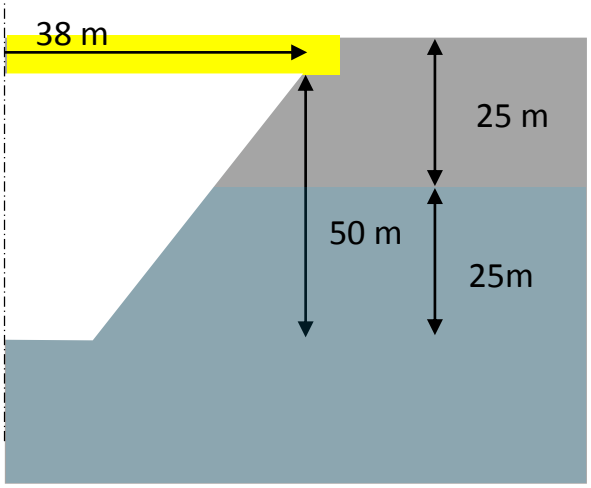
1: 100 000 m³
2: 200 000 m³
3: 500 000 m³
4: 1 000 000 m³
5: 2 000 000 m³

Economic analysis - TES construction

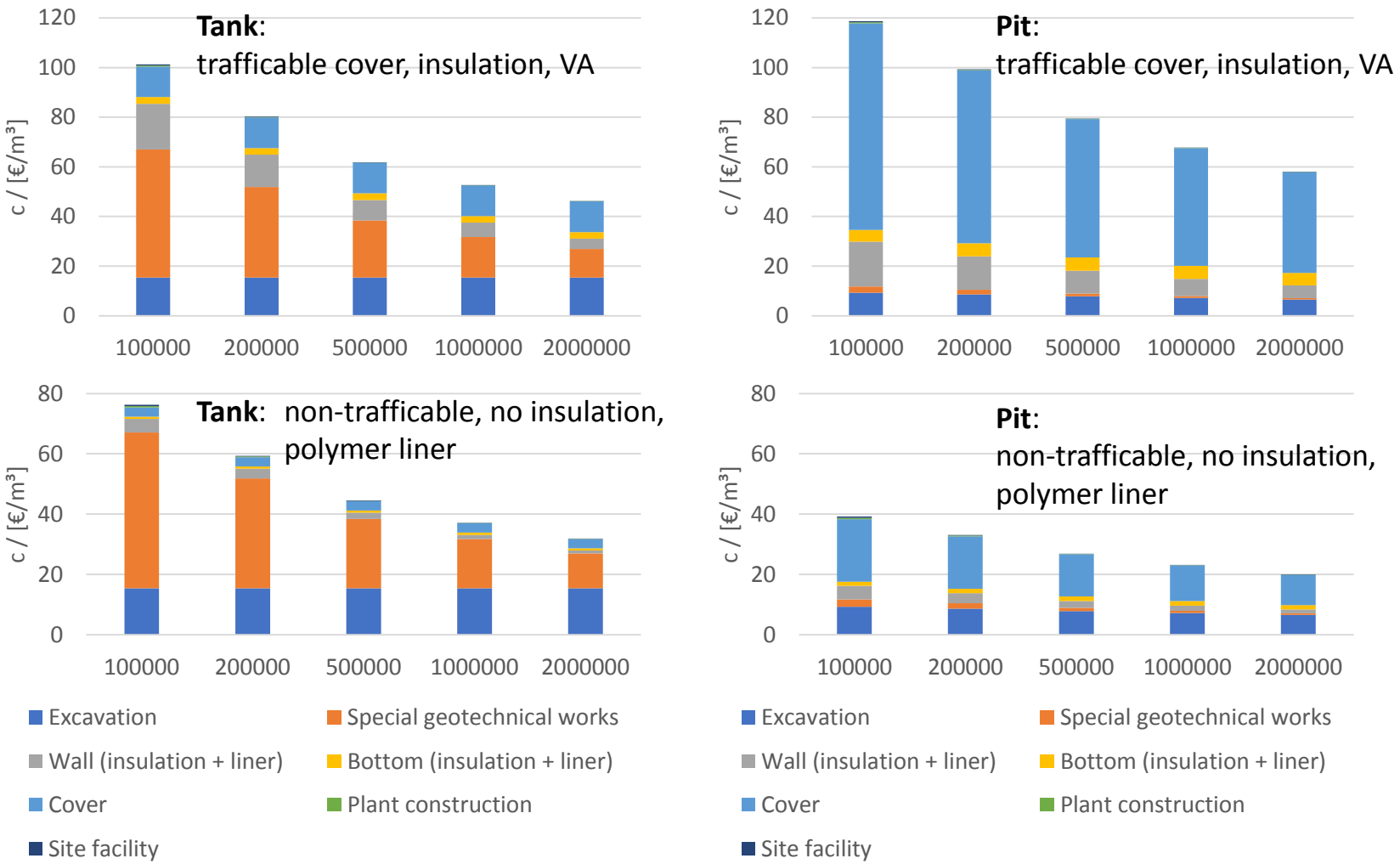
	(specific) costs	remark
excavation	20 €/m³	partly wet excavation
diaphragm wall	550 €/m²	50 m deep
Cut-off wall	50 €/m²	In case of ground water in 5 m distance
insulation	100 €/m³ *) 200 €/m³	Bottom (pressure resistant) Wall (including installation)
liner	150 €/m² 50 €/m²	stainless steel (HT) polymer liner (LT)
cover	**200 €/m²** **800 €/m²**	**floating cover (50 cm ins.)** **trafficable floating cover**
plant construction	40 000 €	Independent of size and construction
Site facilities	50 000 €	fix

*) optimistic assumption

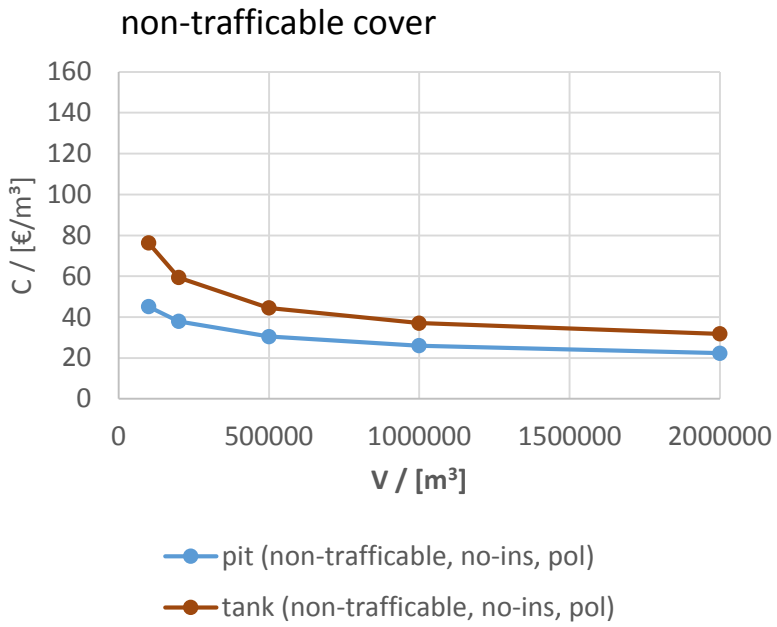


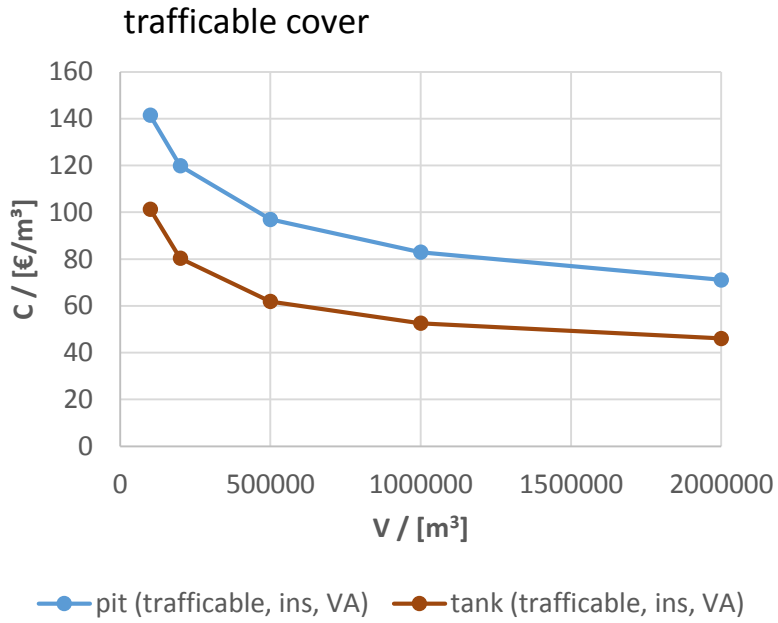


Breakdown of total specific costs for tank and pit TES



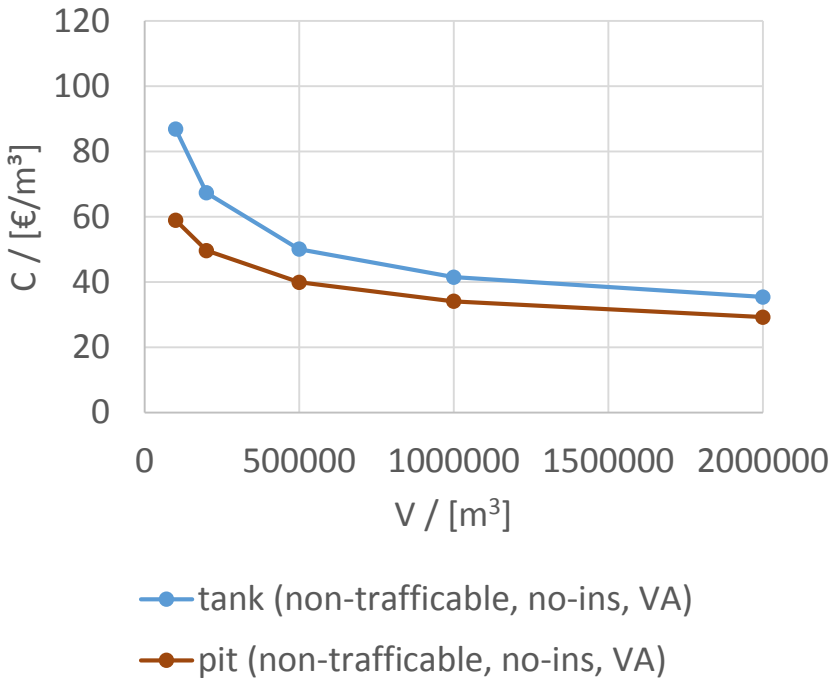
Trafficable cover, tank vs. pit

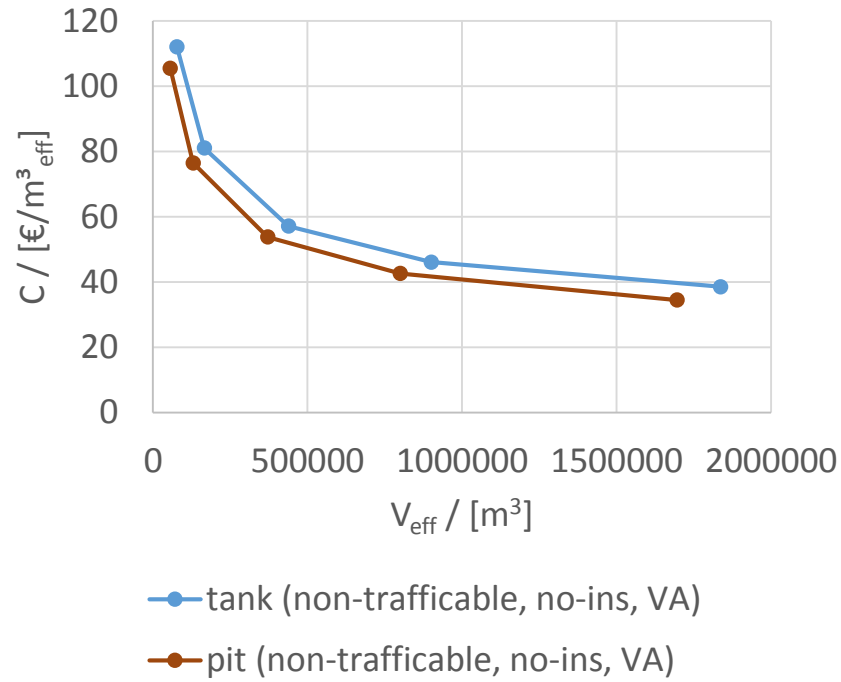




If trafficable cover is a must ⇒ tank TES
If space is limited ⇒ tank TES
If there is need for insulation for ground water over-temperature protection ⇒ tank TES
Otherwise pit TES

Specific costs and specific costs related to effective volume $V_{eff} = \eta_{TES} \cdot V$





Conclusions and Outlook

- TES in DH is key to reduce fossil fuel use
- Costs and performance of TES is very sensitive on construction type and geometry as well as on site BC
    - tank or pit
    - insulation
    - Trafficable cover
    - Groundwater
- Evaluation of energetic performance by means of numerical simulations
- Economic calculation by means of (simplified) cost calculation
- Comparison of different TES types with specific costs related to effective volume
- Ongoing work will concentrate on
    - Improvement of construction of TES
    - System simulation

Project Consortium

Industry

- PORR
- AGRU
- VAM
- SOLID
- Ste.p
- GVT
- METAWELL
- Geologie und Grundwasser
- Gabriel Chemie
- Lenzing Chemie
- Wien Energie
- Salzburg AG

Research

- **AEE INTEC (Lead)**
- UIBK, Innsbruck
- Johannes Kepler Universität Linz, IPMT
- Smart Minerals

Foreign expertise:

- PlanEnergi, Denmark
- SOLITES, Germany

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