UNDERGROUND THERMAL ENERGY STORAGE
IMPROVING EFFICIENCY THROUGH SEASONAL HEAT STORAGE

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MEETING THE FUTURE NEEDS OF ENERGY CONSUMPTION

“\textit{We should leave the oil before it leaves us}”
Nobuo Tanaka, Executive Director of IEA (International Energy Agency)

Sustainable energy sources:
- Wind: Electricity
- Solar: Electricity and heat
- Geothermal: Heat (and electricity)
- Biomass: Electricity and heat
- Waste Heat: Heat

Solar, biomass or waste heat are often insufficient to meet winter heat demand!

One of six future technologies in order to satisfy the worldwide energy consumption:
“\textit{Thermal Energy Storage}” (IEA/OECD-Energy Roadmap 2030)
INTRODUCTION

PRINCIPLE

HEAT GENERATION  \rightarrow  HEAT STORAGE  \rightarrow  HEAT DEMAND

SEASONAL THERMAL ENERGY STORAGE

Heat Amount in kBtu/month

Heat Demand  \hspace{1cm}  Available Solar Heat Energy
INTRODUCTION

REQUIREMENTS

System requirements:

- Heating dominated
- Housing areas / apartment buildings / industrial areas > 100kW (341 kBtu/hr)
- Long-term storages are ideal min. 35,000 ft³, preferably >350,000 ft³
- Sufficient excess heat (from solar energy, CHP, etc.)
SYSTEM COMPONENTS

- Heat source
- District heating network
- Seasonal thermal energy storage
- Heat consumption (consumer)
SYSTEM COMPONENTS
THERMAL ENERGY STORAGE – RELATIVE COSTS

Costs of seasonal stores (with planning, without VAT)

- Study
- Tank
- Pit
- Borehole
- Aquifer

Source: Forschungsbericht zum BMU-Vorhaben 0329607L, Solare Nahwärme und Langzeit-Wärmespeicher, SOLITES, 2007

*1 USD = 0.733 EUR
**SYSTEM COMPONENTS**

**BOREHOLE THERMAL ENERGY STORAGE**

**Ground Conditions:**
- No groundwater flow, or very slow moving (< 3 ft/yr)
- Ground with good thermal properties

**Borehole Field Characteristics:**
- Low surface/volume ratio
- Temperature level: ca. 50°F - 195°F
- Typical depth: 100-300 ft
- Probe distance: 5-15 ft
- Storage capacity: 1.5-3 kBtu/ft³
- Insulation on top

![Diagram of borehole field characteristics and system components](image)
SYSTEM COMPONENTS
BOREHOLE THERMAL ENERGY STORAGE

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Source: www.dlsc.ca
Due to the high temperature resistance of PEXa (up to 200°F), PEXa probes are ideal for use in underground thermal energy storage systems.

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>Durability (Safety Factor SF=1.25)</th>
<th>PE 100 (HDPE 4710)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Years / Maximum Pressure)</td>
<td></td>
</tr>
<tr>
<td>20°C (68°F)</td>
<td>100 year / 15 bar (218 psi)</td>
<td>20°C (68°F) / 100 year / 15.7 bar (228 psi)</td>
</tr>
<tr>
<td>30°C (86°F)</td>
<td>100 year / 13.3 bar (193 psi)</td>
<td>30°C (86°F) / 50 year / 13.5 bar (196 psi)</td>
</tr>
<tr>
<td>40°C (104°F)</td>
<td>100 year / 11.8 bar (171 psi)</td>
<td>40°C (104°F) / 50 year / 11.6 bar (168 psi)</td>
</tr>
<tr>
<td>50°C (122°F)</td>
<td>100 year / 10.5 bar (152 psi)</td>
<td>50°C (122°F) / 15 year / 10.4 bar (151 psi)</td>
</tr>
<tr>
<td>60°C (140°F)</td>
<td>50 year / 9.5 bar (138 psi)</td>
<td>60°C (140°F) / 5 year / 7.7 bar (112 psi)</td>
</tr>
<tr>
<td>70°C (158°F)</td>
<td>50 year / 8.5 bar (123 psi)</td>
<td>70°C (158°F) / 2 year / 6.2 bar (90 psi)</td>
</tr>
<tr>
<td>80°C (176°F)</td>
<td>25 year / 7.6 bar (110 psi)</td>
<td>80°C (176°F) / -</td>
</tr>
<tr>
<td>90°C (194°F)</td>
<td>15 year / 6.9 bar (100 psi)</td>
<td>90°C (194°F) / -</td>
</tr>
</tbody>
</table>
Heat generation can be accomplished by:

- Solar collectors
- Solar absorbers
- Combined Heat and Power plants (CHP)
- Industry waste heat
CONCEPT

A large array of solar thermal panels collect and concentrate heat in a central location for use in the winter.

EFFECT

The solar fraction of a conventional solar system is between 7% - 35%. Using seasonal storage, a solar fraction of up to 90% can be reached.
SYSTEM COMPONENTS
HEAT GENERATION OPTIONS – SOLAR ABSORBERS

CONCEPT
Solar heat of asphalt or concrete areas is extracted by integrated absorber pipes. The heat is stored in an underground geothermal energy storage (heating soil > 77°F). This seasonal stored heat can then be extracted in the winter by a heat pump and be used for space heating.
In **summer**, the traffic area acts as a solar thermal collector and the heat can be stored in the ground via PEXa probes.

- **Cools road surface**
- **Extends surface lifespan**

In **winter**, heat is extracted from the ground via probes and transferred to the road surface:

- **Free from ice** or **free from snow**
- **Sun up to 190 Btu/hr/ft²**
- **50 Btu/hr/ft²** up to **95 Btu/hr/ft²**
CONCEPT

- A combined heat and power (CHP) plant produces decentralized power and heat for a surrounding community
CONCEPT

- A combined heat and power (CHP) plant produces decentralized power and heat for a surrounding community

- Through the use of seasonal heat storage, this heat can be stored during the summer to meet higher demands in the winter

Number of CHP (International Energy Agency 2009):

Northern Europe: ~1,800 plants (mainly DK and GB)
Southern Europe: ~1,300 plants
Central Europe: ~3,000 plants
Western Europe: ~4,100 plants
North America: ~3,300 plants
Asia: ~2,600 China / 700 India
Current state: CHP with e.g. biogas as fuel

Electricity production: 500 kW\textsubscript{el}
Heat: \(~12\) billion Btu per year

Chiller: 2 million Btu/hr for summer operation
Disperses more than \textbf{5.5 billion Btu} each summer
CASE STUDIES
CASE STUDIES
SOLAR ABSORBER – SUFFOLK, UK

System description
- Sixth Form College – new construction
- 215,000 ft² usable area for 2,200 students

Heat sources:
- 16,800 ft² bus stop used as a solar absorber

Heat storage:
- 18 x 330 ft probes as underground geothermal energy storage
System description
- 260 houses, 1 school, and 1 sports hall
- 4,100 MWh/yr (14 billion Btu/yr) with network temperatures flow/return 150/95°F

Heat sources:
- 79,000 ft² solar collectors with 5.1MW (17.4 million Btu/hr) peak output
- 750 kW heat pump (2.6 million Btu/hr)
- Supplementary heating through district heating network

Heat storage:
- 3,500 ft³ high temperature peak load storage (hot water)
- 17,000 ft³ buffer storage (hot water)
- 1.5 million ft³ borehole thermal energy storage (80 PEXa probes)
System description
- 6MW system (3,800 MWh/yr) for 1400 homes (20.5 million Btu/hr, 13 billion Btu/yr)

Heat sources:
- 183,000 ft² solar collectors (~3 football fields)

Heat storage:
- 48 PEXa probes at 150 ft deep and 250,000 ft³ buffer tank
CASE STUDIES
SOLAR COLLECTORS – OKOTOKS, CANADA

System description
- 52 house community “Drakes Landing”

Heat sources:
- 800 solar thermal collectors (ca. 25,000 ft² area)

Heat storage:
- Borehole thermal energy storage of 144 PEXa probes at 115 ft depth
- Max. design temperature of borehole field: 175°F
INTEGRAL PLANNING
WORKING TOWARD THE OPTIMUM DESIGN

Solar energy system

Building construction

Optimization requires collaboration and communication!

Thermal storage

Controls

Ground heat exchanger

HVAC design

District heating system

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UNDERGROUND THERMAL ENERGY STORAGE
FURTHER MARKET DEVELOPMENT

Growing demand for large-scale thermal energy storage for combined heat and power plants from:

- District heating sector
- Industrial facilities

New storage projects around the world:

- Spain, Norway, Hungary, Canada, South Korea, Austria, Switzerland
- Denmark!
INTERNATIONAL ENERGY AGENCY (IEA) “TASK 45”

Main objective: “To assist in a strong and sustainable market development of large solar heating and cooling systems for district heating and cooling applications. The systems can include seasonal storages and/or heat pumps/chillers.”

Systems types:
- Solar preheating
- Solar in combination with other energy sources
- **Systems with storage**
  - Collector fields
  - Direct/indirect (i.e. with or without heat exchangers)

Focuses on “MW-size” systems, >0.5 MW (collector area >700 m²)
Subtask B: Storages

- Improving the economy of (Seasonal) storage technologies
- Increasing knowledge on durability, reliability and performance of (seasonal) storage technologies
- Demonstrating cost effective, reliable and efficient seasonal storage of thermal energy

Main results to be published in a book “Design Guidelines For Large Solar Systems”
THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?

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