Background and Project Overview

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Grant Agreement 737054
Contents

- Global perspective and state of the art
- Ultra-High Temperature Energy Storage and Conversion
- AMADEUS Project overview
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Global Perspective

95% is pumped hydroelectric
(3 % or world power capacity)

http://www.energystorageexchange.org/
Global Perspective

Publications on “energy storage”

Publications on “thermal energy storage”

https://wcs.webofknowledge.com
Thermal Energy Storage (TES)

Concentrated Solar Power (CSP) represents 75% of global TES

- Others (ice, heat, chiller water)
- Tower
- Parabolic-trough
- Fresnel

Central Tower, Gemasolar (Sevilla, Spain)

Parabolic-trough Andasol 3 (Granada, Spain)

http://www.energystorageexchange.org/
Two-tanks Storage CSP (e.g. direct systems)

Plant peak efficiency: 23-35%

Two-tanks Storage CSP systems

- 100 kWh/m³
- 565 °C
- 290 °C
CSP cost reduction targets (e.g. U.S. Sunshot Initiative)
R&D directions (1): “Single tank” options

**Thermocline**
- High-temp Medium
  - Temperature Gradient (Thermocline)
- Low-temp Medium

**Packed Bed**
- High T
  - High-temp Fluid
- Low T
  - Low-temp Fluid

**Solids**

**Latent heat**
- solid
- liquid
  - isothermal
R&D directions (2): Increase the temperature

**Carnot efficiency**

- **Liquid Hydrogen**
  - 72%
- **Pressurized Hydrogen**
  - 64%
- **High temperature**
  - 54%
- **State of the art**
  - 46%
  - Solar salts (5-20 $/kWh)
- **Li-ion batteries**
  - 30%

**Energy density (kWh/m³)**

**Temperature (deg C)**
Single tank + ultra-high temperature?

- Liquid Hydrogen
- Pressurized Hydrogen (700 bar)
- Solar salts (5-20 $/kWh)
- Ultra-high temperature latent heat storage
- Silicon (3.5 $/kWh)
- Boron

- State of the art
- High temperature
- Carnot efficiency

- 54% Sensible Heat (comercial molten salts, 2 tanks)
- 64% Sensible Heat (other liquids, 2 tanks)
- 72% Sensible Heat (solids)
- 82% Latent heat (salts)
- 87% Latent heat (metals)

Carnot efficiency:
- 64%
- 72%
- 82%
- 87%

Energy density (kWh/m^3):
- 0
- 500
- 1000
- 1500
- 2000
- 2500

Temperature (deg C):
- 0
- 500
- 1000
- 1500
- 2000
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Temperature limits of current technologies

Molten salt decomposition (~ 565 °C)

\[
\begin{align*}
2\text{MNO}_3 &= \text{M}_2\text{O} + 2\text{NO}_2(g) + \frac{1}{2}\text{O}_2(g) \\
\text{M}: \text{alkali metal cation} \\
\text{M(NO}_3)_2 &= \text{MO} + 2\text{NO}_2(g) + \frac{1}{2}\text{O}_2(g) \\
\text{M}: \text{alkaline earth metal cation}
\end{align*}
\]

Turbomachinery, heat exchanger, pipes ...
Corrosion and mechanical strength (~600°C)

Steam turbines

~ 600 °C

F. Klocke et al. Turbomachinery component manufacture by application of electrochemical, electro-physical and photonic processes, CIRP Annals - Manufacturing Technology, Volume 63, Issue 2, 2014, Pages 703-726, ISSN 0007-8506,
Temperature limits of current technologies

Thermionics (electron flux)

- Power density > 10 W/cm² (>500 times solar PV’s)
- Efficiency ~ 5-12 %

Thermophotovoltaics (photon flux)

- Power density $\sim 2$-10 W/cm$^2$ (100-500 times solar PV’s)
- Efficiency $\sim 25\%$ (@ 1100 °C)
- Efficiency potential (> 40%)

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AMADEUS project


- Project call: FET-Open
- 7 partners
  - 3 Universities
  - 3 R&D Centers
  - 1 SME
- Budget: 3,270,496.25 €
- Duration: Jan 2017 – Dec 2019
- Coordinator: UPM (Spain)
AMADEUS project

Primary Energy
Any kind of input energy (solar, electrical, waste heat, ...)

Energy Storage
Ultra high temperature latent heat storage in molten metals
- Isolation cover
- Vessel

Energy conversion
Solid-state devices (hybrid thermionic & thermophotovoltaic)
- Collector
- PV cell
- Photons
- Electrons

Examples of possible practical implementation


Application example: Concentrated Solar Power (CSP)

Storage + Power generation
Total unit volume: 8 m³
Capacity ~ 4 MWh (12 h)
Power ~ 80 kW

Heliotstat area: 750 m² (65% opt eff.)

Dispatchable AC Power
Application example: Domestic

Storage + co-generation
Total unit volume: 8 m³
Capacity ~ 4 MWh (12 h)
Electric power ~ 80 kW
Thermal power ~ 250 kWₜʰ
AMADEUS project: Work Plan

WP1
Management

WP 2
Energy storage module

WP 3
Energy conversion module

WP4
Final PoC experiment
WP2: Energy Storage Module

- SiB-X alloys for PCM (Task 2.1)
- PCM - vessel interaction: wettability, reactivity, solubility (Task 2.2)
- PCM - vessel interaction: heat transfer and thermo-mechanical (Task 2.3)
- Thermal insulation (Task 2.4)
- Fabrication of final block and cycling experiments (Task 2.5)
WP3: Power Conversion Module

- Emitter development (Task 3.1)
- TPV cell development (Task 3.2)
- Collector and micro-spacers (Task 3.3)
- Device cooling (Task 3.4)
- Device characterization (Task 3.5)
- Final PoC (Task 3.6)
WP4: Final Proof of Concept Experiment

- Definition of components and system configuration (Task 4.1)
- Experimental setup preparation (Task 4.2)
- Realization of PoC experiment (Task 4.3)

Participants

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<th>Institution</th>
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Thermal insulation

Phase Change Material (PCM)

Micro-spacers

vessel

emitter

TPV cell

collector

Thermionic Photovoltaic

photonselectrons

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Impact in CSP cost reduction

- HTF-free
- Same unit of small size
- Increase efficiency