6° Seminario
Acercamiento Tecnológico
Codelco Digital: Construyendo la Minería del Futuro

Organiza:
CODELCO
Orgullo de Todos

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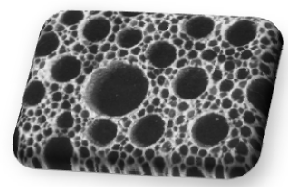
CENTRO DE INNOVACIÓN EN ENERGÍA

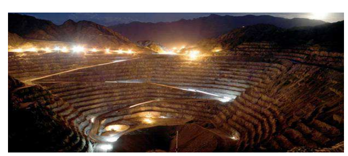
# Thermal Energy Storage for Industrial Process Using New Copper Composite Materials

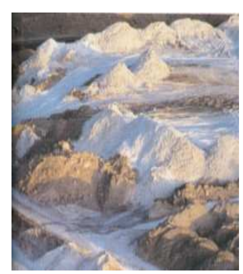



Gustavo Cáceres


July 6th 2012


**Fondecyt Project Nº 1120490**



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# Energy storage

- Energy storage (ES) is the storing of some form of energy that can be drawn upon at a later time to perform some useful operation.
- Forms of energy storage:

**Chemical Energy Storage**

- Electrochemical batteries
- Organic molecular storage

**Mechanical Energy Storage**

Hydro-storage
Compressed air storage
Flywheels

**Thermal Energy Storage**

- Sensible heat storage
- Latent heat storage
- Chemical heat storage

**Biological Energy Storage**

**Magnetic Energy Storage**

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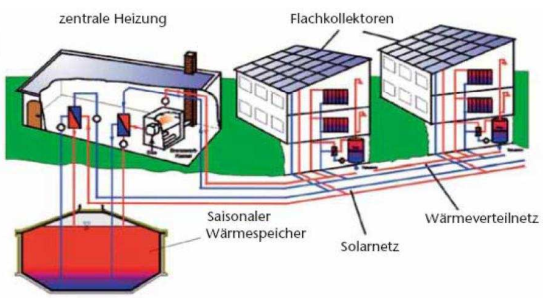
# Thermal Energy Storage




Solar Cooling & Heating

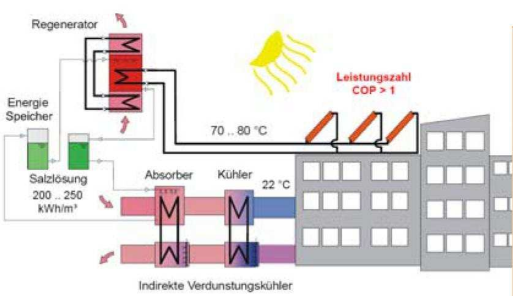
Industrial Process Heat

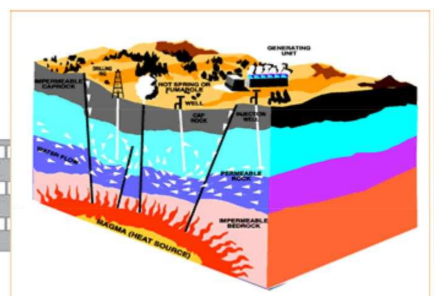
**0 – 100 °C** | **100-300 °C** | **300 -1000 °C**

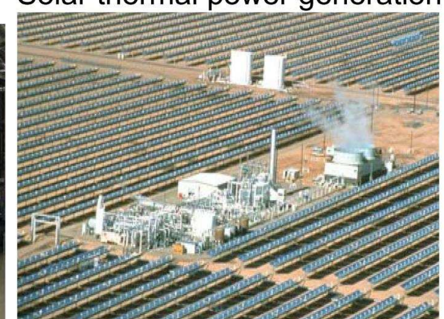
Geothermal power

Decentral CHP

Solar thermal power generation



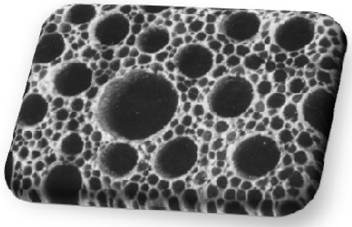


Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

**CONTEXT**

- Thermal energy storage for industries
- Porous copper foam impregnated with nitrates
- These materials are already a feasible storage material for low temperature applications.
- Research for High Temperature: Heat losses in industrial processes (mining, metallurgy and solar thermal energy)

To capture and store heat, a HTTES Material has to be included in the system



## INDUSTRY

- Those with more market penetration or projection in Chile

**MINING**

**METALLURGY**

**SOLAR THERMAL ENERGY**

**OBJECTIVES**

1) Material Modelling (physic model) and Numerical solutions.

2) Assess the viability of using metal foams and salt to storage thermal energy from industrial processes and be use whenever it’s profitable for the industry.

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# Objective 1)

•Find a macroscopic equation, by using the volume averaging method, capable of modelling the heat transfer phenomena in a different configuration.

- Using, first, the basic heat transfer equation.
- Not phase change included
- Not convection flow included

•Test, through simulations, the convenience of using a mixture of salts and copper as the essentials materials of the prototipe.

# HTTES Material

**Materials**

- **Single material**
  - **Cooper?**
  - **Salts?**
- **Mixture**
  - **Salts (60%KNO3+40%NANO3) + Copper**
    - **Copper: High thermal conductivity**
    - **Salts : High heat capacity**

| Materials/Properties | Density (kg/m3) | Specific Heat (J/kg.K) | Thermal Conductivity (W/m.K) |
|---|---|---|---|
| **Copper** | 8960 | 385 | 400 |
| **(60%)KNO3+(40%)NANO3** | 1899 | 1423,5 | 0.536 |

# Average Heat Transfer Equation

The average equation can be written as

$$\rho_{eff} C_{p_{eff}} \frac{\partial \hat{T}}{\partial t} - k_{eff} \nabla^2 \hat{T} = 0$$

✓**One equation**

✓**Assumes homogenous material**

***Mixture theory***

$$(\gamma\rho_C + \delta\rho_S)\left(\varepsilon c_{p_C} + \theta c_{p_S}\right)\frac{\partial}{\partial t}\left(\frac{1}{A}\int_{\varphi} T \cdot d\vec{s}\right) - (\alpha k_C + \beta k_S)\nabla^2\left(\frac{1}{A}\int_{\varphi} T \cdot d\vec{s}\right) = 0$$

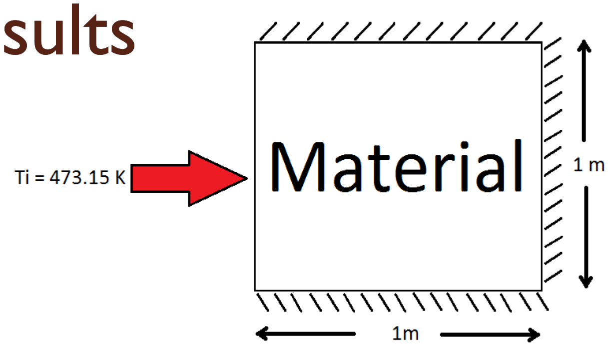
$K_{eff} = \alpha k_1 + \beta k_2$, *where* $\alpha$ *and* $\beta$ *are volume fractions*, $\alpha + \beta = 1$

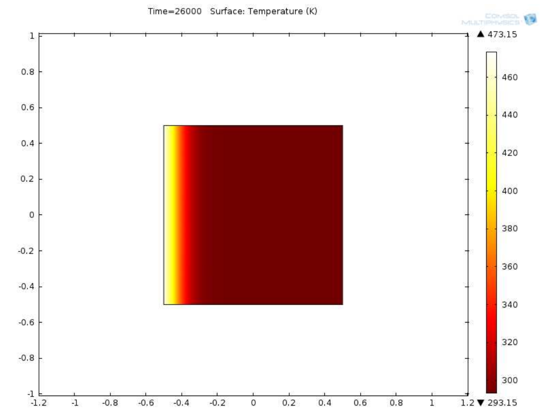
$\rho_{eff} = \gamma\rho_1 + \delta\rho_2$, *where* $\gamma$ *and* $\delta$ *are volume fractions*, $\gamma + \delta = 1$

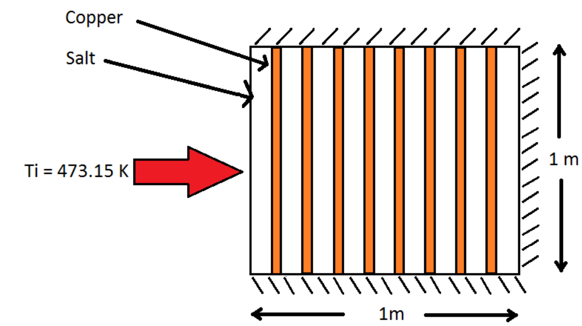
$C_{p_{eff}} = \varepsilon c_{p_1} + \theta c_{p_2}$, *where* $\varepsilon$ *and* $\theta$ *are volume fractions*, $\varepsilon + \theta = 1$

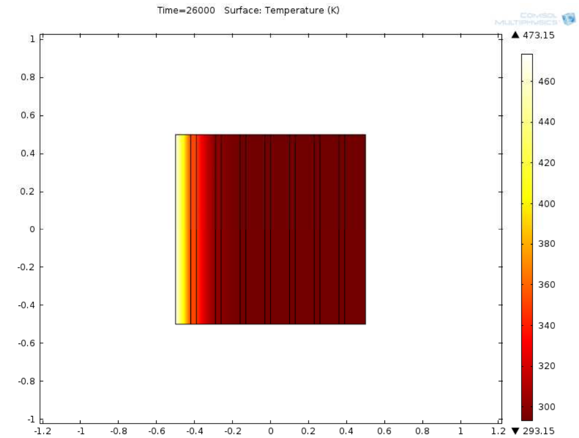
# Preliminary Results

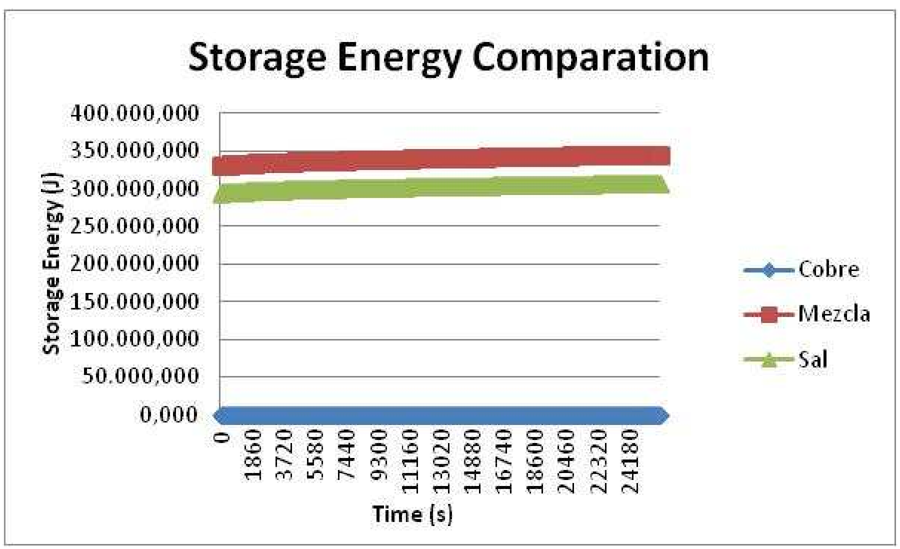
Temperature : 473.15 K
Time: 26000 s



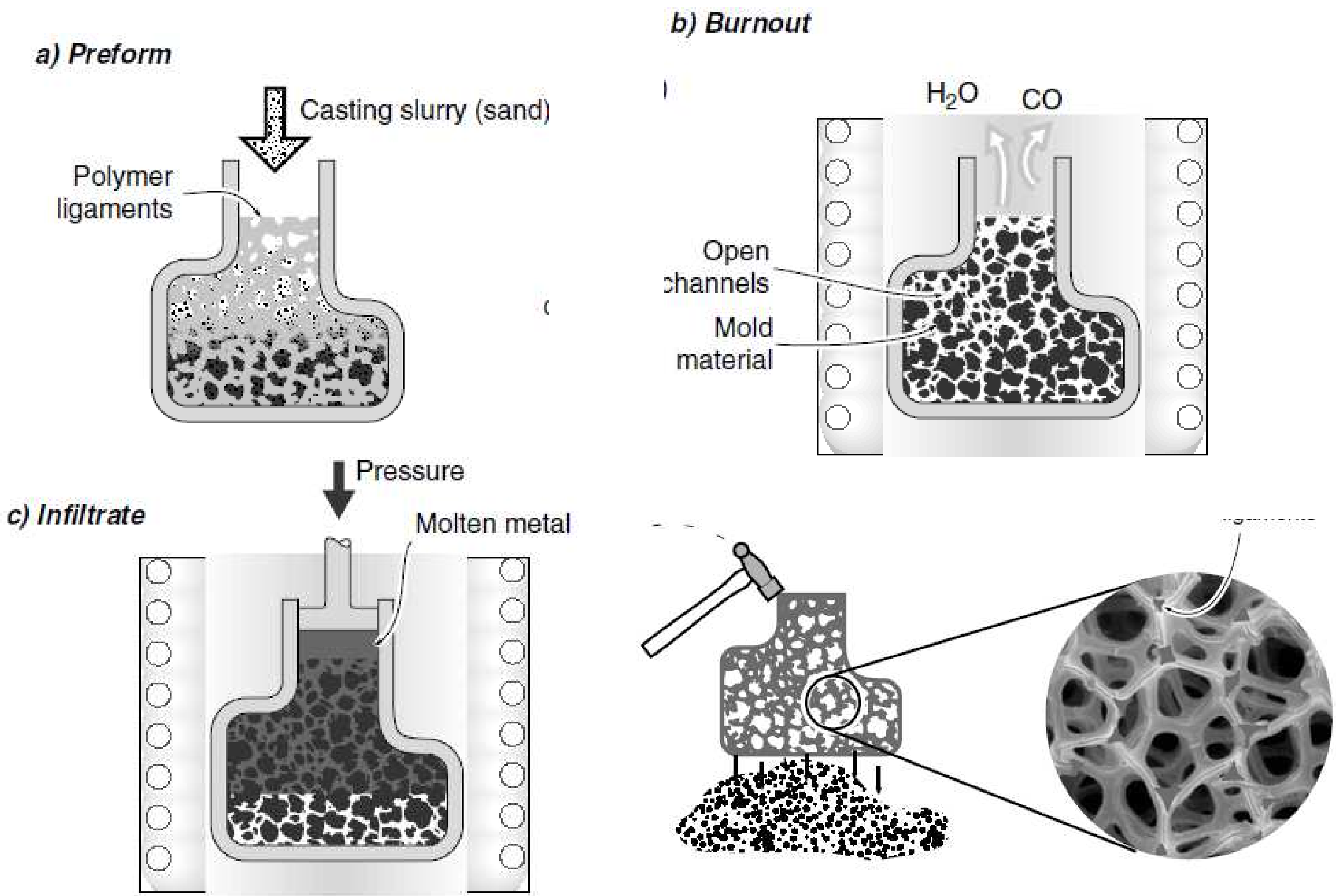
# Objective II)

Assess the viability of using metal foams and salt to storage thermal energy from industrial processes and be use whenever it's profitable for the industry.

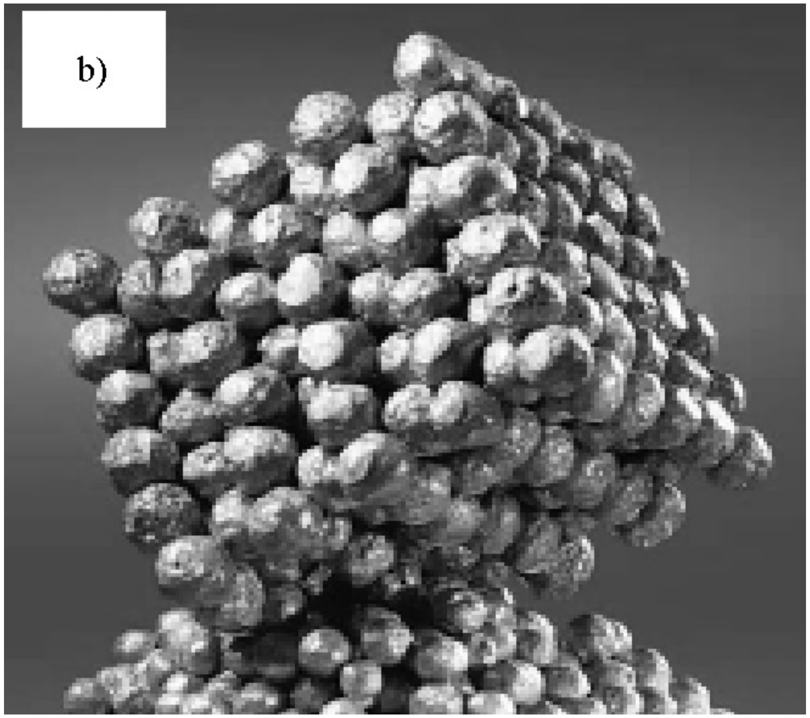
**METAL FOAM**


- Highly conductive foams based on copper can be used as heat exchangers.
- Thermal conductivity: 400 W/Km
- There are two main ways to create metal foams with the characteristics we look for: 1)Casting Method and 2) Metallic Hollow Spheres Structures

# INVESTMENT CASTING WITH POLYMER FOAMS



# METALLIC HOLLOW SPHERES STRUCTURES




- Bonding by sintering

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## INVESTMENT CASTING WITH POLYMER FOAMS

- Manufacture cost is approximately 80% labeled by the material cost.

- Cost of copper 7.46 USD/kg in June, 2012.

## METHODOLOGY for TES in CSP Plants

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Input Data

- Cost of copper and foam manufacture
- Cost of salts
- Cost per volume for the storage module
- Cost of heat exchangers
- Efficiency of the heat exchangers
- Thermal energy generated by the industrial process
- Thermal demand by the industrial process.

Variables

- Relative density of the foam
- Volume of foam
- Volume of salts
- Volume of the storage module

| | | |
|---|---|---|
| Foam [3-5] | 9325 | USD/ton |
| Potassium nitrate [7] | 1080 | USD/ton |
| Sodium nitrate [8] | 515 | USD/ton |
| Salts mixture | 741 | USD/ton |
| Copper density | 8960 | kg/m3 |
| Salts density [6] | 1899 | kg/m3 |
| Salts heat capacity [6] | 2703 | kJ/m3K |
| Salt demand [6,9] | 269.78 | m3/MW |
| Storage Tank [10] | 129746.20 | USD/MW |

## PRELIMINARY RESULTS

Solar power plant is considered calculating the LEC including and not a thermal energy storage system

Inclusion of TES systems in solar thermal plants have impact in  the levelized energy cost. Around 10% in current technologies.

First approach  to validate the inclusion of TES system in potentials Chilean solar energy power plants.

# Conclusions

1. Volume averaging method to study the heat behavior in different configuration geometries because of its simplicity in numerical solution.

2. The materials as HTTES to be used will be the mixture between cooper and salts, because of its heat storage efficiency, given by copper´s high thermal conductivity and salt´s high heat capacity.

3. It will be very important improve de efficiency of materials in order to increase their positive impact on the LEC in solar plants.

# Upcoming work

Developer physical modelling, using the volume averaging method, of heat transfer in a system that includes salt´s phase-change. new equation will be developed to determine the thermo-mechanic behavior of the materials

For technical-economy viability, in the next scenarios, we pretend to have a full model ready with the data (shown in table).

Establish techno-economical relation between the inclusion of TES and profits of each industrial application