# Durability of CSP Materials

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LNEG (Lisboa, Portugal)

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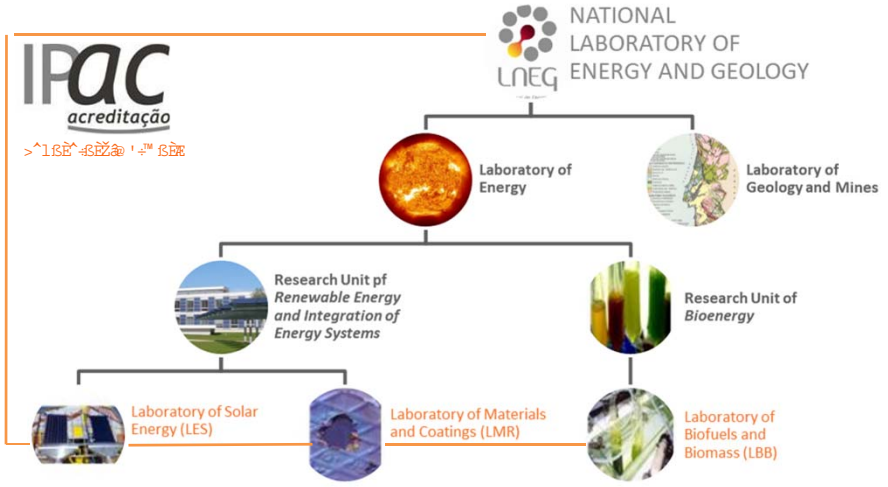
## Outline

- LNEG short presentation
- CSP and Corrosion costs
- Atmospheric corrosion and durability of reflectors
- Steels and Corrosion
- Corrosion with molten salts




LNEG

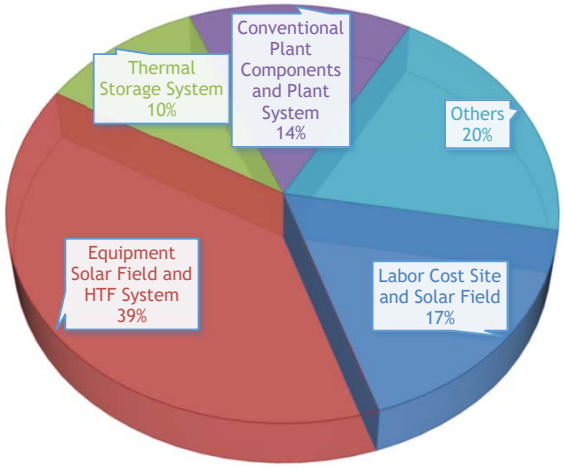
LNEG is an R&D institution oriented to meet the needs of society and business. We aim at a sustainable research in a sustainability frame through the generation of knowledge of our territory.



## Costs of CSP

| | |
|---|---|
| **Labor Cost Site and Solar Field** | Solar Field<br>Site preparation and Infrastructure<br>Steel Construction<br>Piping<br>Electric Installations and others |
| **Equipment Solar Field and HTF System** | *Mirrors*<br>Receivers<br>*Steel Construction*<br>Foundations<br>Trackers<br>Swivel joints<br>HTF System (Piping, Insulation, Heat Exchangers, Pumps)<br>Heat Transfer Fluid<br>Electronics, Controls, Electrical and Solar Equipment |
| **Thermal Storage System** | Salt<br>*Storage Tanks*<br>Insulation Materials<br>Foundations<br>Heat Exchangers<br>Pumps<br>Balance of System |
| **Conventional Plant Components and Plant System** | Power Block<br>Balance of Plant<br>Grid Connection |

## HIGH EFFICIENCY WITH LOW COST




Adatpted from https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/ESMAP_MENA_Local_Manufacturing_Ex_Summary.pdf

## CSP Materials

Material and Land Requirements for CSP Reference Plant

| | Parabolic Trough Plant 50 MW with 7 hours storage |
|---|---|
| Steel | 10,000–15,000 tons |
| Glass | 6,000 tons |
| Storage Medium (Salt) | 25,000–30,000 tons |
| Concrete | 10,000 tons |
| Insulation Material | 1000 tons |
| Copper* | 300 tons |
| Land | 2 km² |

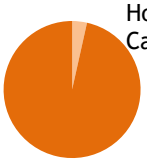
https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/ESMAP_MENA_Local_Manufacturing_Ex_Summary.pdf






## Corrosion Costs

How Much Can Be Saved?

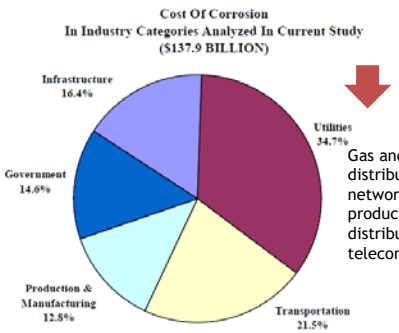


Direct costs
3.1% GDP
Gross Domestic Product

25-30%

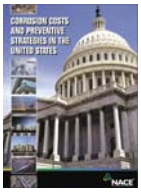
Appropriate anticorrosive protection measures

1000-1400 million €




Gas and water distribution, sewerage network, electriciy production and distribution, telecommunication

**High impacts:**
Economic
Environmental
Social



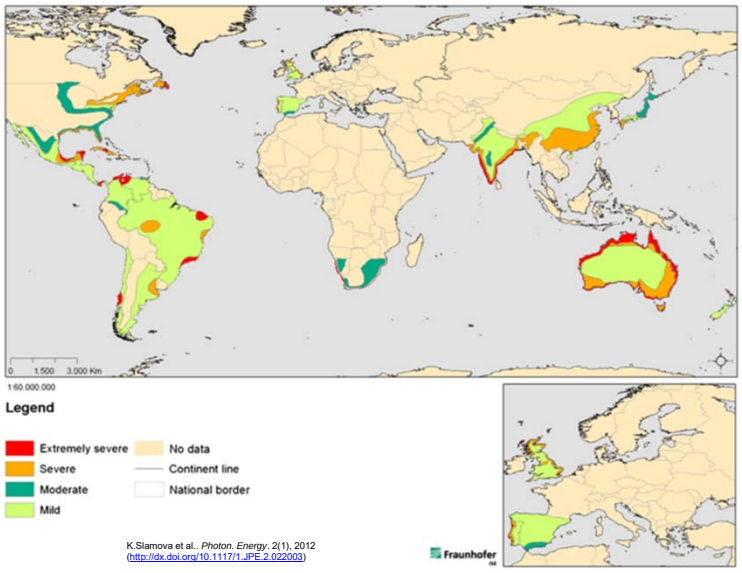

https://www.nace.org/uploadedFiles/Publications/ccsupp.pdf

### The Global Impact of Corrosion

The global cost of corrosion is estimated to be US$2.5 trillion, which is equivalent to 3.4% of the global Gross Domestic Product (GDP) (2013). By using available corrosion control practices, it is estimated that savings of between 15 and 35% of the cost of corrosion could be realized; i.e., between US$375 and $875 billion annually on a global basis, an astronomical savings. In addition, these costs typically do not include individual safety or environmental consequences. The high cost of corrosion has been known for years; Uhlig performed a comprehensive study in 1949 that revealed a cost of corrosion equivalent to 2.5% of the U.S. GDP.

(NACE Report 2016)

## ATMOSPHERIC CORROSIVITY DATA IN THE WORLD




K.Slamova et al., *Photon. Energy*. 2(1), 2012 (http://dx.doi.org/10.1117/1.JPE.2.022003)

Fraunhofer

http://geoportal.lneg.pt/geoportal/mapas/ajuda/MapaCorrosao_Ajuda.html

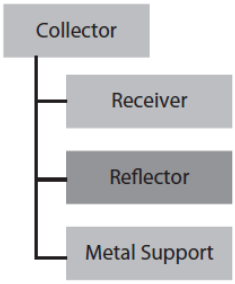
| | |
|---|---|
| C1 | very low corrosivity |
| C2 | low corrosivity |
| C3 | medium corrosivity |
| C4 | high corrosivity |
| C5 | very high corrosivity |
| CX | extreme corrosivity |

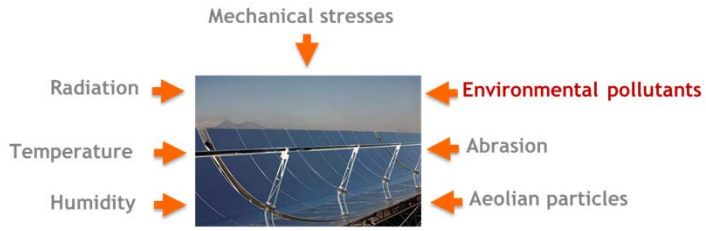


## Support structures

- ELECTRODEPOSITION
- SHERARDIZING
- HOT DIP GALVANIZING
- METALIZATION

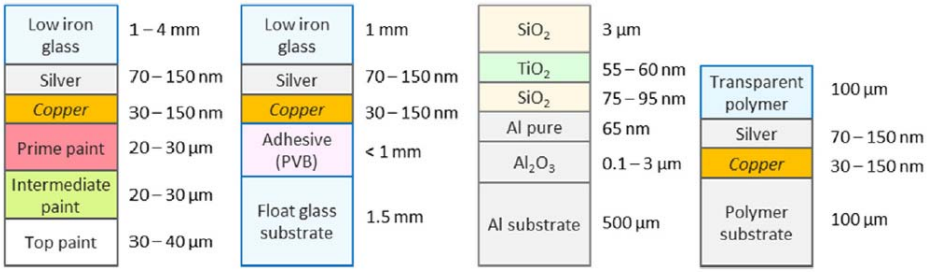
## Durability of Reflectors




**Goals for solar reflector materials**

- 30 years lifetime
- >95% specular reflectance (φ = 7.5 mrad)
- specular reflectance loss <1% over lifetime
- low manufacturing cost < 10 €/m²

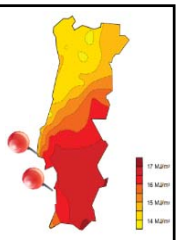



Coralie Avenel et al. Solar Energy Materials and Solar Cells 186 (2018) 29-41
https://doi.org/10.1016/j.solmat.2018.06.024

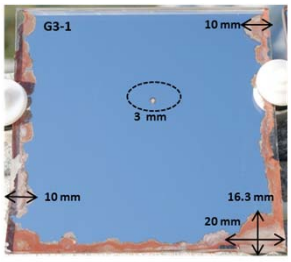


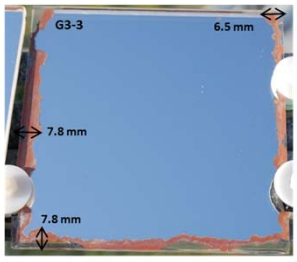
## Durability of Reflectors

### 2 years of outdoor exposure

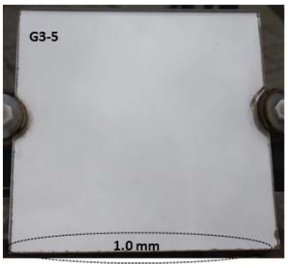


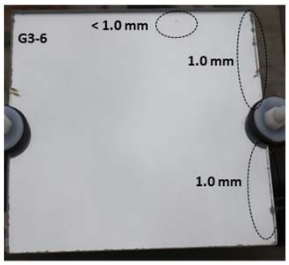
**VERY HIGH – EXTREME CORROSIVITY**
**SINES TEST SITE**




**LOW – MEDIUM CORROSIVITY**
**LUMIAR_LISBON TEST SITE**



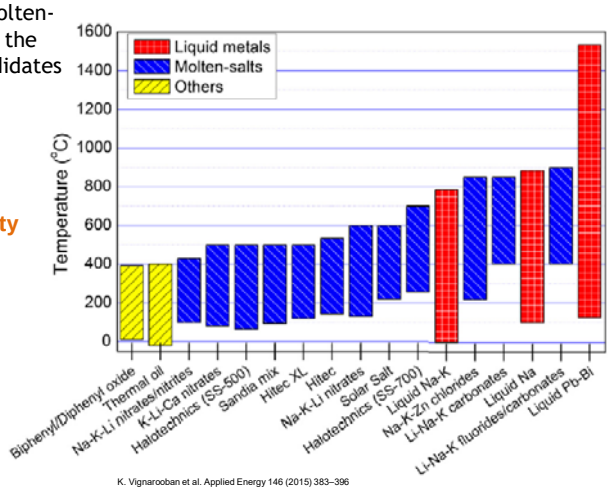



## Corrosion and Molten Salts

High operating temperature is necessary to improve efficiency in the CSP system and molten-salts have been revealed the most promising HTF candidates at high temperatures.

**Low melting point**
**High specific heat**
**High thermal conductivity**
**High boiling point**
**Low pressure value**
**Low viscosity**
**Low reactivity**
**Low cost**
**Economic availability**
*Low corrosivity*

**OPERATING TEMPERATURE RANGE FOR VARIOUS HTFs**




K. Vignarooban et al. Applied Energy 146 (2015) 383–396

Corrosion issues are more significant in CSP plants operated with molten-salts compared to other HTFs, mainly because of the high operating temperatures.

For reliable long-term application and in particular high temperatures (e.g. ≥500ºC) there is still a lack of knowledge about corrosion mechanisms and results and methodologies are inconsistent about steel corrosion rates in molten salts

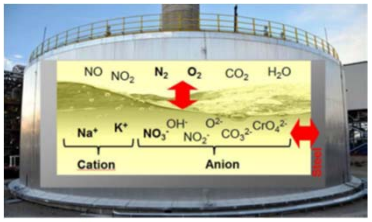


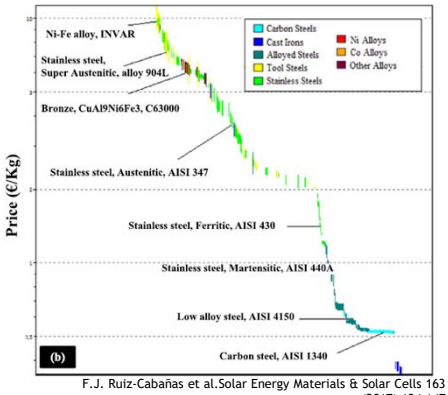
## Corrosion and Molten Salts (Inside corrosion)

| Alloy type | Advantage | Disadvantage |
|---|---|---|
| Carbon and low alloy steel | - Sufficient mechanical properties<br>- May be tolerant to low concentration of chloride impurities<br>- Low relative cost | - May require protective nitrogen atmosphere during exposure to molten salt to control corrosion rate<br>- Corrosion rate increases when operating temperatures increases<br>- May be intolerant to chloride impurities |
| Stainless steel | - Good mechanical properties tend to be maintained at the higher temperatures<br>- Better corrosion performance than carbon steel<br>- Little effect of chloride impurities on corrosion rate<br>- Low cost relative to Ni-base alloys | - Corrosion rate increases with operating temperature<br>- Risk of localized corrosion |
| Ni base alloys | - Resistance to localized corrosion and SCC superior to SS | - Similar corrosion rate to SS<br>- High relative cost |

Stability of metallic materials in contact with HTF is a crucial parameter for the longevity of CSP systems.

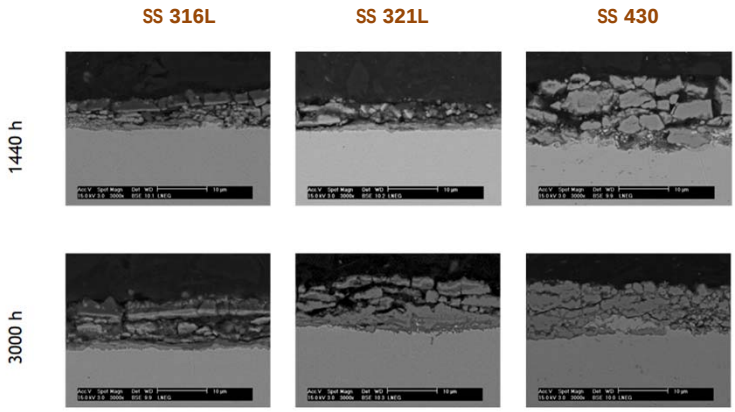
**what steel and what is their life time**




F.J. Ruiz-Cabañas et al.Solar Energy Materials & Solar Cells 163 (2017) 134-147

## Materials Corrosion for TES




Corrosion behaviour in contact with Ternary Nitrate Salt (500ºC)

**15% $NaNO_3$, 43% $KNO_3$ and 42% $Ca(NO_3)_2$**

Few data is available of structural materials degradation based on failure analyses in commercial plants.
Other corrosion tests are necessary to gain insight the material degradation by new molten salts for its use in CSP plants like:
- Dynamic corrosion tests
- Electrochemical techniques
- Mechanical testing (fatigue and stress corrosion cracking)

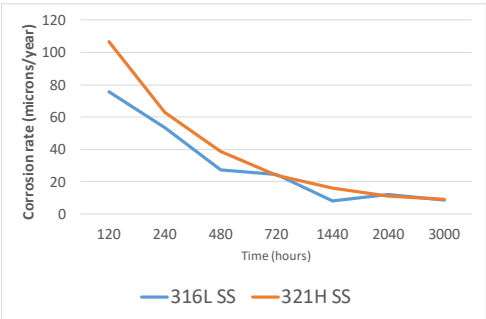


## Corrosion and Molten Salts

Corrosion rate in contact with Solar Salt (550ºC)

**40% $NaNO_3$, 60% $KNO_3$**

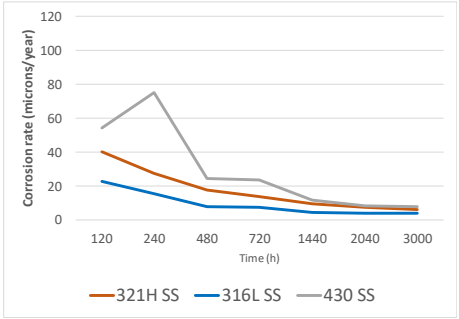
Austenitic SS




Corrosion rate in contact with Ternary Nitrate Salt (500ºC)

**15% $NaNO_3$, 43% $KNO_3$ and 42% $Ca(NO_3)_2$**

Austenitic and Ferritic SS

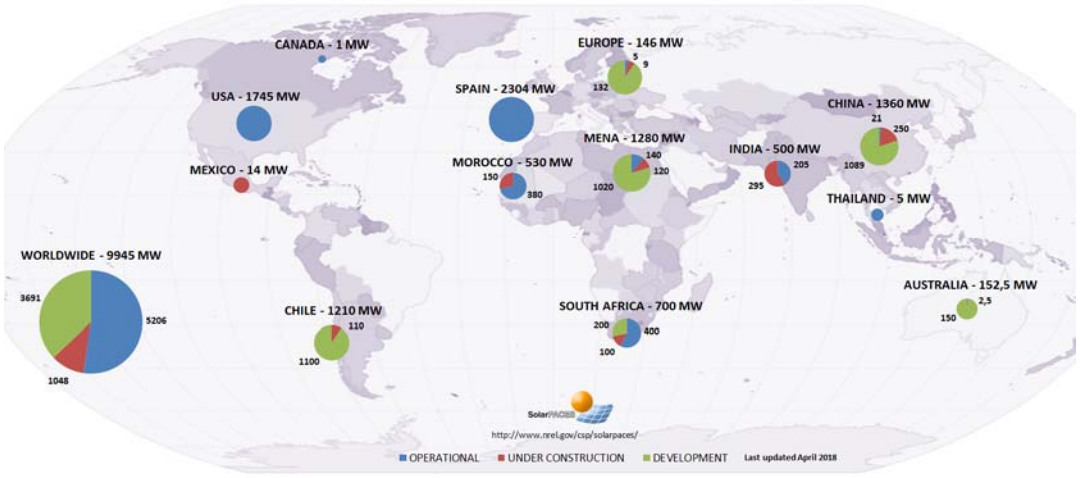



These salts are compatible with austenitic stainless steel with corrosion rate between 4-10μm/year.

Low alloy steels often reveal insufficient corrosion behavior.

A. Gomes *et al.* 2018 *Solar Energy* (accepted)

# DURABILITY OF MATERIALS : AN INTERDISCIPLINARY RESEARCH






## Thank you for your attention

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New Storage Latent and Sensible Concept for High Efficient CSP Plants (GA nº720985)

Project STAGE-STE - Scientific and Technological Alliance for Guaranteeing the European excellence in Concentrating Solar Thermal energy (7FP) (2014-2018) GA 609837

**Funded by the European Union**