DiaC^{2}Lab

Diamond and Carbon Compounds Laboratory

Innovative Conversion Technologies for Solar Concentrating Systems & Development of an Outdoor Solar Concentration lab

Daniele M. Trucchi

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DiaC^2 Lab is inside Research Area of Roma 1
Via Salaria km. 29,300 - 00015 Monterotondo Scalo (RM), Italy

A. Bellucci – PhD Student – Thermal Energy Converters
P. Calvani – Post-Doc – Device Technology & Surface Devices
E. Cappelli – Senior Researcher – PLD Deposition
R. Flammini – Researcher – Surface Physicist
M. Girolami – Post-Doc – Ionizing Radiation Detectors
V. Valentini – Researcher – Chemical Characterization

In collaboration with CNR-IMIP Potenza Section

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EU Project – FP7-Energy **E2PHEST2US** - *Enhanced Energy Production of Heat and Electricity by a combined Solar Thermionic-Thermoelectric Unit System* - GA 241270

Innovative combined thermionic and termoelectric conversion technology for concentrating solar systems

Project budget: 2.67 M€

Duration: 2010-2013

EU Project – FP7-Energy **PROME³THE²US²** - *Production Method of Electrical Energy by Enhanced Thermal Electron Emission by the Use of Superior Semiconductors* - GA 308975

Innovative photon-enhanced thermionic conversion technology for concentrating solar systems

CNR Coordination

Total budget: 4.84 M€

Duration: 2013-2016

EU Project – FP7-Energy IRP **STAGE-STE** *Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy*

Development of materials and components for solar thermal energy

Total CNR budget: 363 k€ (on 18.1 M€ total)

Duration: 2014-2017

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EU Project E^2PHEST^2US

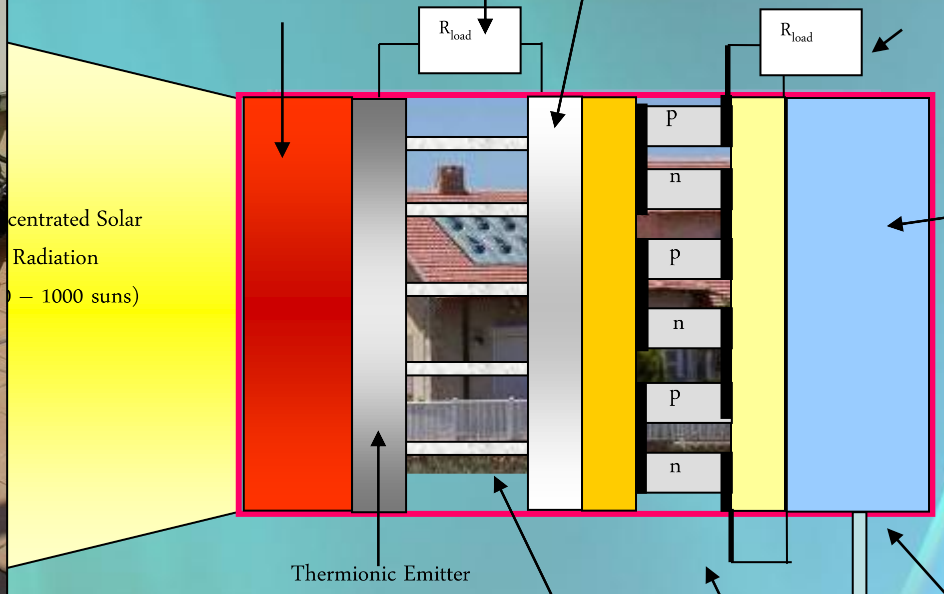
Partners:

- •CNR (Italy, Scientific Coordination)
- •CRR (Italy, Management Coordination)
- •SHAP (Italy)
- •Tel Aviv University (Israel)
- •Tubitak (Turkey)
- •Prysmian (Multinational Industry)
- •Maya (San Marino)

Duration: 3 years (Jan 2010 - Jun 2013)

•Total Project Cost: 2.68 M€

•Total EU Funding: 1.98 M€



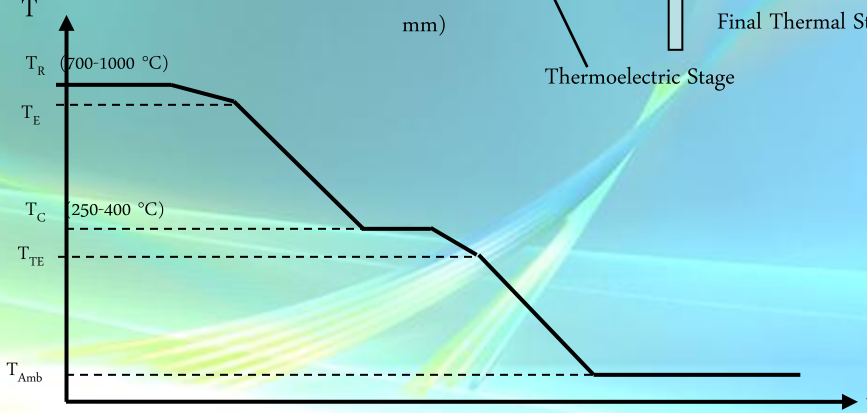
Development of:

•A radiation absorber made of ceramic materials able to work stably at high temperature (700 - 1000 °C)

•A thermionic conversion stage with CVD diamond as the active material

•A thermoelectric conversion stage constituted by high Seebeck coefficient materials

•Maximum theoretical efficiency >35%



*For details, http://www.ephestus.eu

PCT Patent n. ITRM2012A000427 "Thermionic Conversion Device"

Inventors: D.M. Trucchi, E. Cappelli, S. Orlando, D. Sciti

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Alternative Technology in Concentrating Systems

•Multi-junction Photovoltaic Cells

✓Nominal Conversion Efficiency of 40%

✓Compactness

✓No mechanical parts in movement

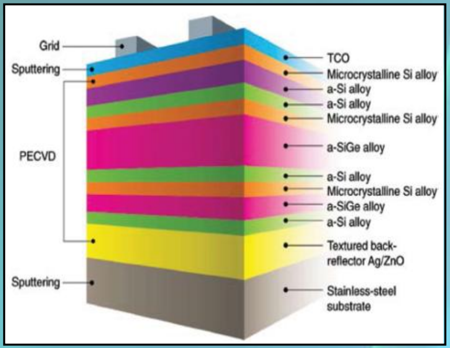
•Highly Expensive (MBE Fabrication)

•Mandatory Need of Cooling (Conversion Efficiency Exponentially Decreases with Temperature)

•Illumination Local Inhomogeneities Causes Output Bottlenecks

•Degradation with Hot-spots

•Production Dependent on Semiconductor Industry (Few Large-Scale World Suppliers)



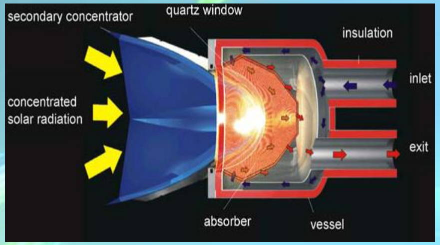
•Thermodynamic Conversion by Heat Engines (Stirling, Rankine)

✓Nominal Thermal-to-Electric Conversion Efficiency of 35% at High Temperatures (> 600 °C)

•Not Compact System

•Mechanical Parts in Movement (Degradation with Operative Time)

•Economically Reasonable for Large Plants (> 10 kWe)



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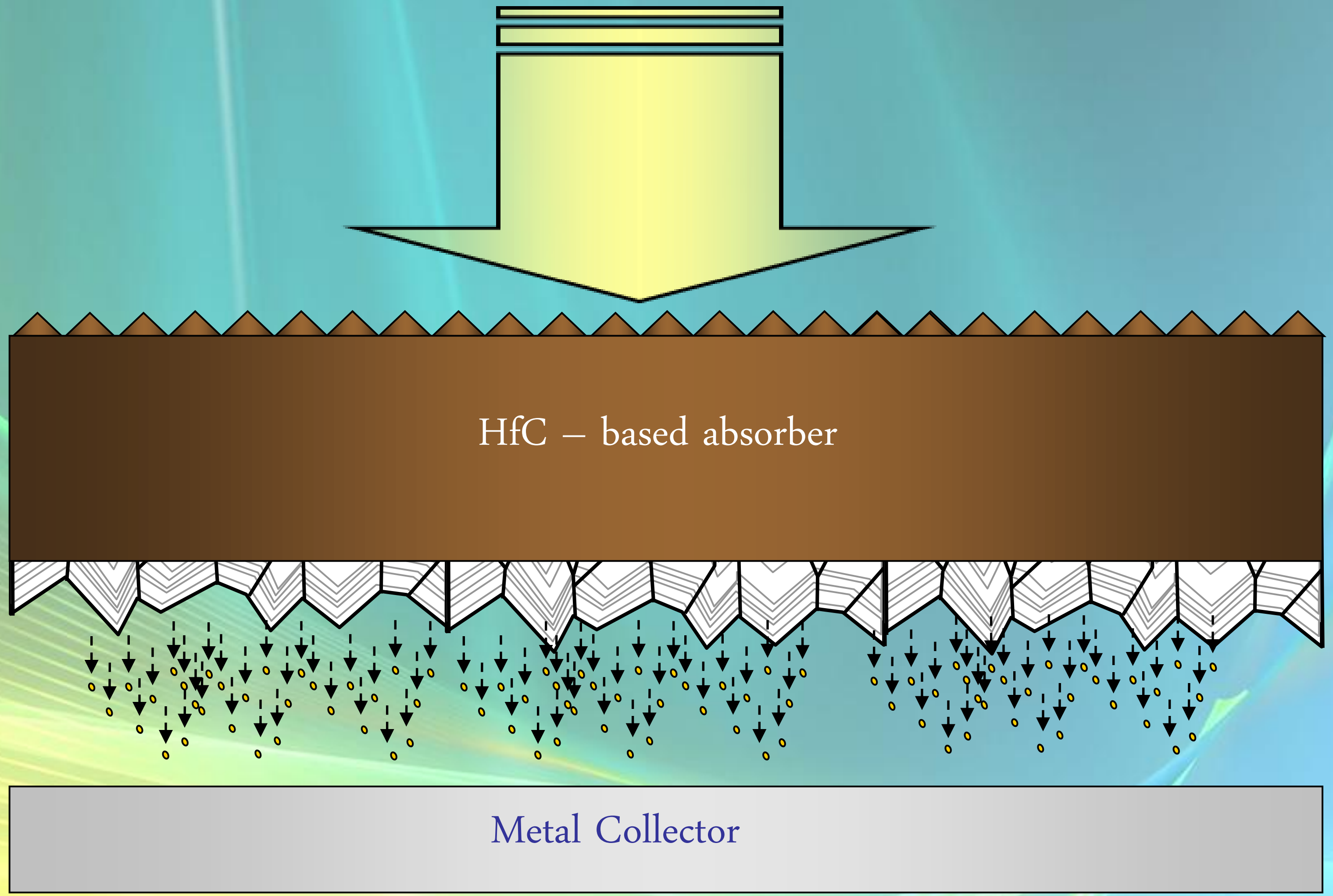

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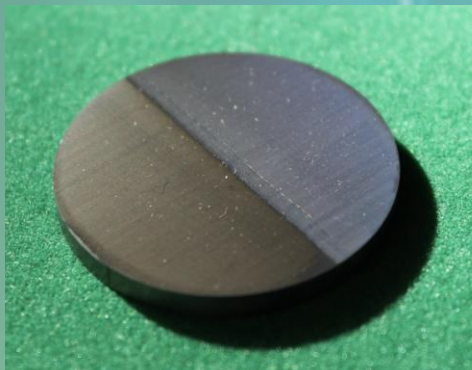
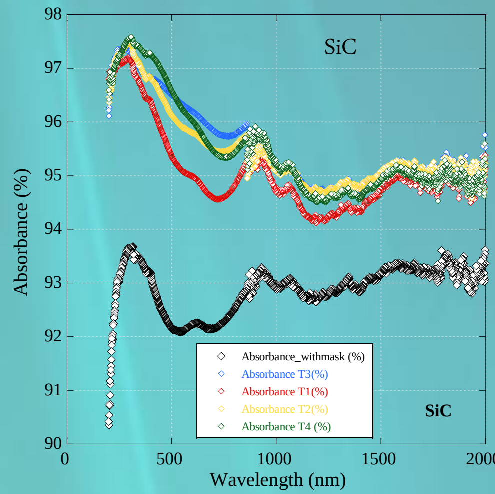
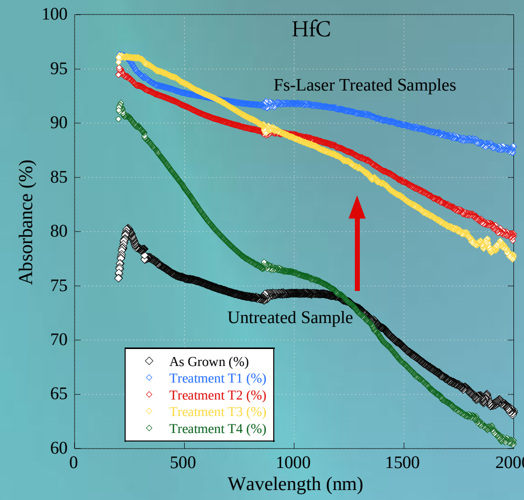
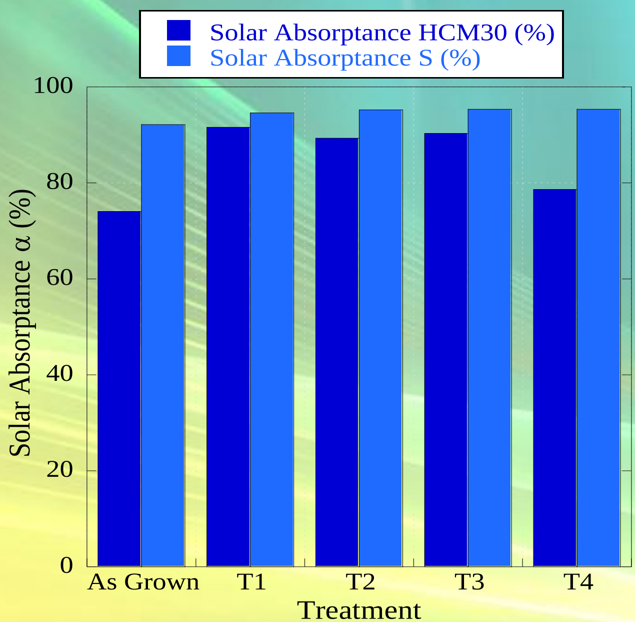
Absorbance Increase









Femto-second laser texturing induces:

- an excellent increase (>90%) in solar absorbance due to:
  - Increase of effective surface area
  - Diffractive effects owing to a structure with comparable periodicity with radiation (grating-like behavior)

- An increase of blackbody emittance.

⇩

Laser wavelength optimization (ongoing activity)

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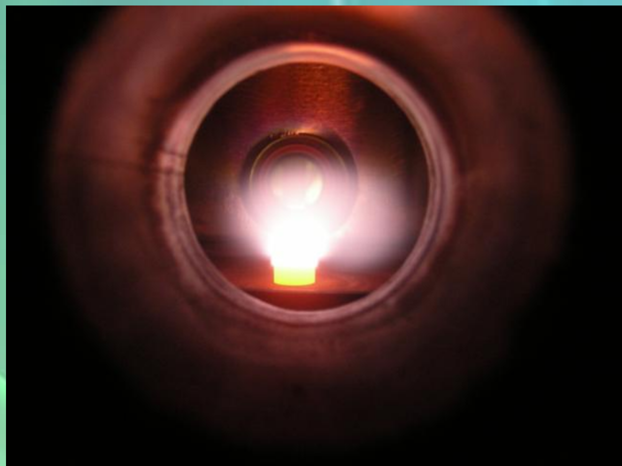
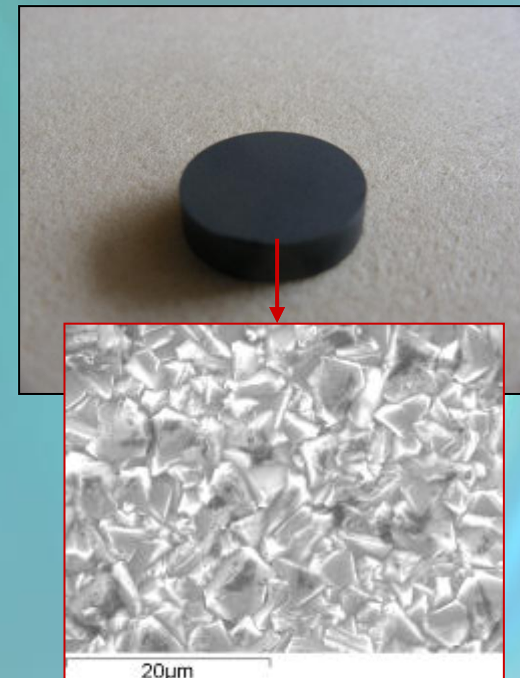
Thermionic Emitter – CVD Diamond

CVD (Chemical-Vapor-Deposition) Diamond deposited by MicroWave Assisted System



•Deposition @ $[CH_4]/[H_2]$ concentration of 1.5%



Surface hydrogenation process after deposition induces NEA condition (electron affinity < 0 eV)

If CVD diamond is n-doped by addiction of nitrogen during the deposition phase:

•The emission current increases from 10^{-5} A/cm^2 to about 3×10^{-2} A/cm^2 @ 780 °C

•The output voltage increases from about 1 to 2 V (Fermi level shift) @ 780 °C

Large improvements are possible by acting on deposition parameters:

•[CH4/H2] concentration -> crystal quality

•[N2] concentration -> doping level and profile

•Film thickness (< 1 um)

Collector is made of molybdenum that can be coated by Cesium (stability issues)

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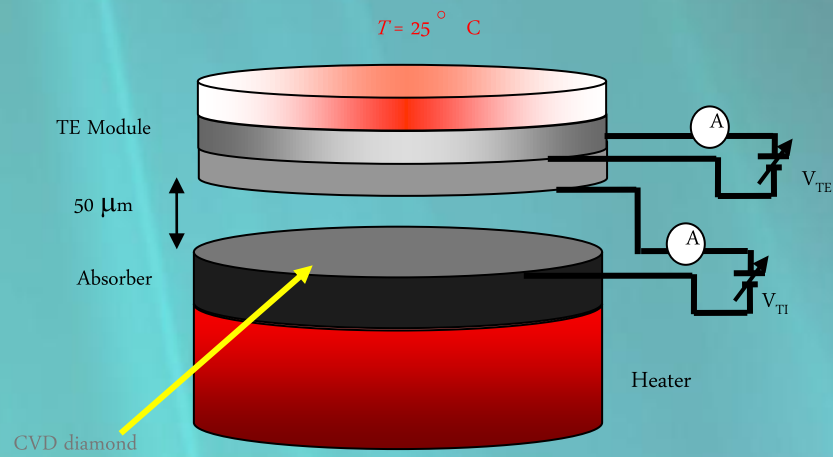
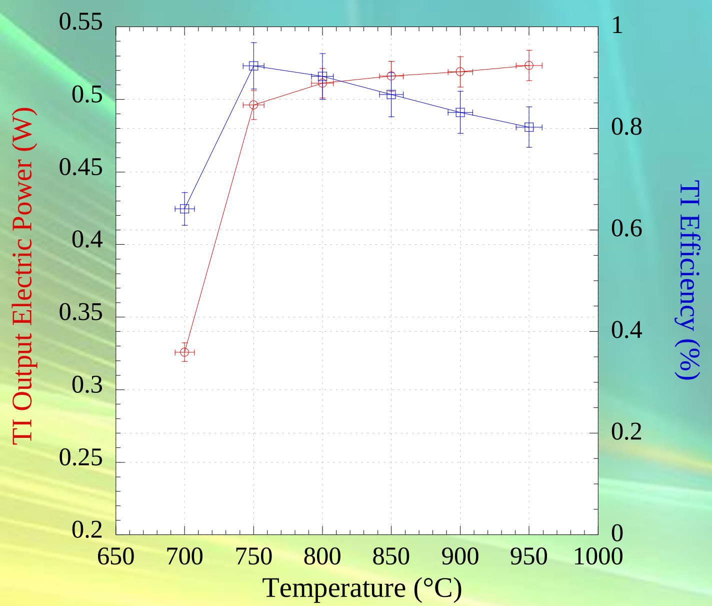
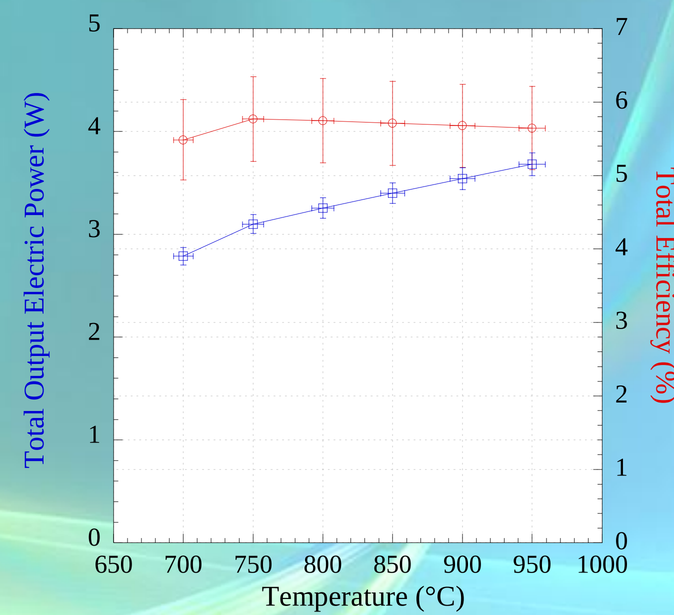
Thermionic Emitter – Lab Level Testing







Low TI conversion efficiency due to an incomplete development of thermionic emitter (control of material deposition)

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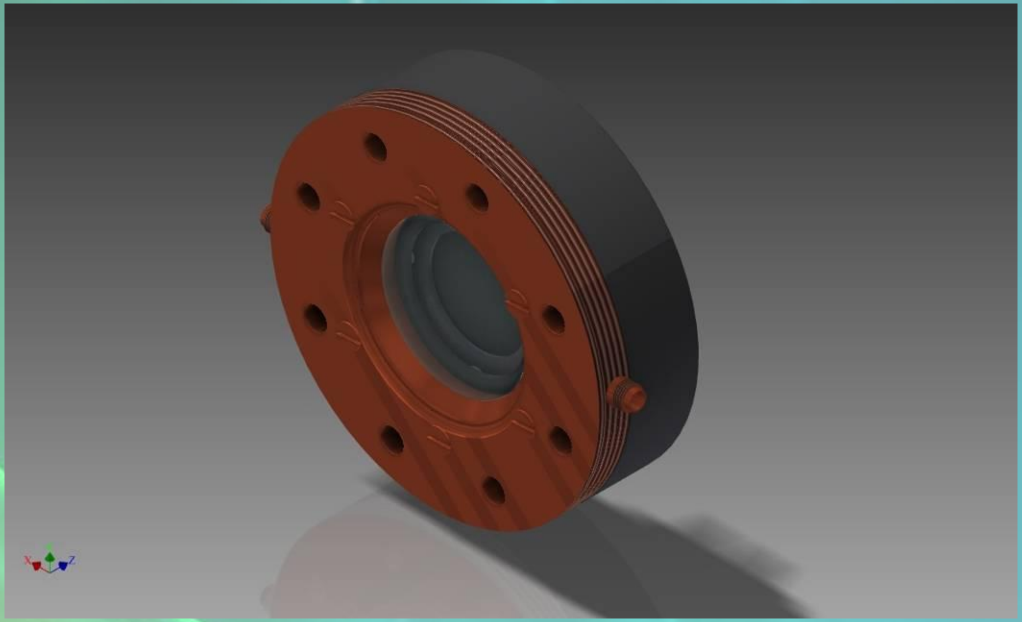

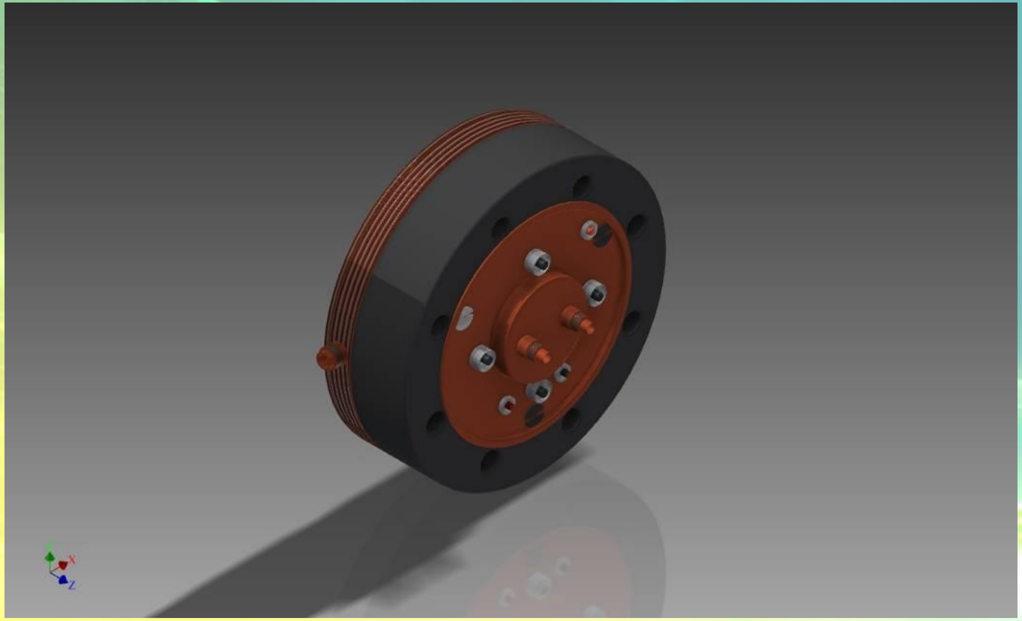

•**Compactness** (11.4 cm diameter × 4.0 cm thickness). The module has to be as compact as possible to reduce its volume for minimizing heat and optical losses and for reducing optical shadowing effects from non concentrated sun radiation;

•**Interchangeability of the components**. Each component can be mounted and dismounted thus favouring a strategy of continuous optimization of the CM performance;

•**Mounting easiness**. The enclosure has been selected to satisfy commercial standards and takes advantage of this for mounting the module on its support;

•**Scalability**. The design is completely scalable at larger dimensions;

•**Robustness**. It has been studied a proper method to fix the active elements on the supporting flange and favour the collection of exhaust thermal fluxes in the primary thermal circuit.

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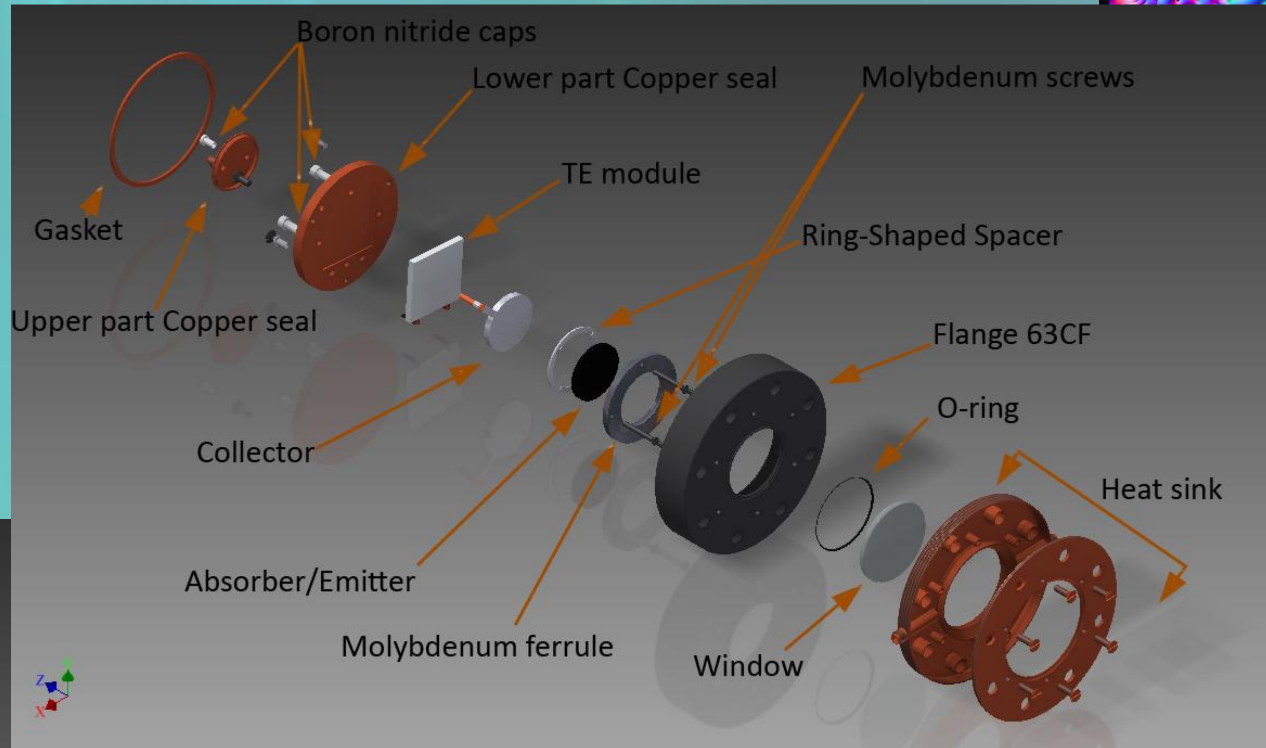
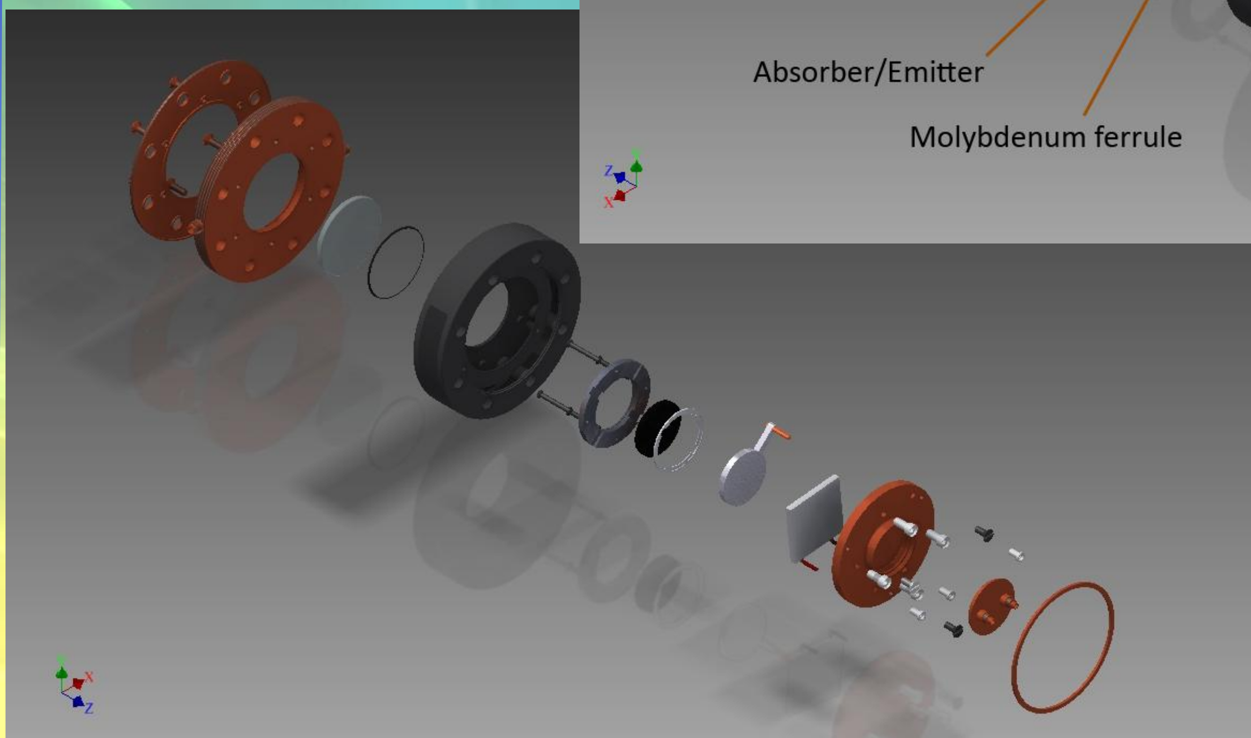
Conversion Module - Design





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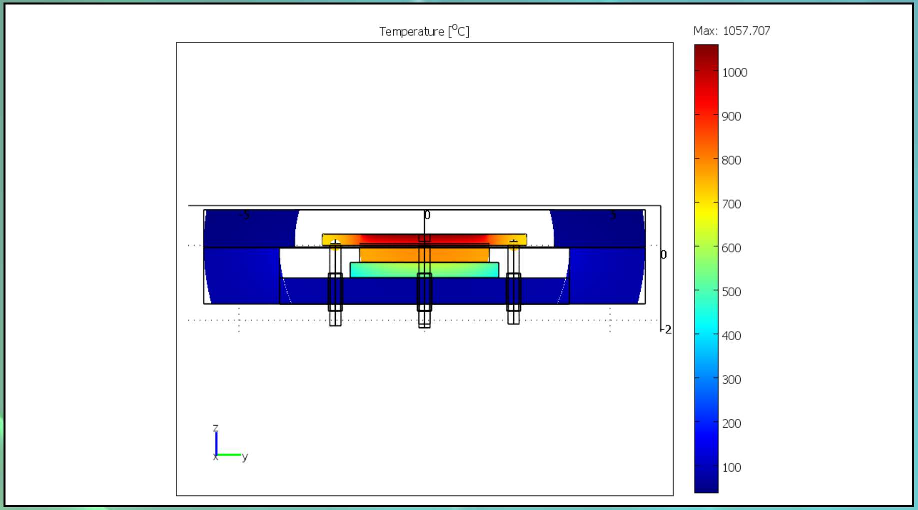
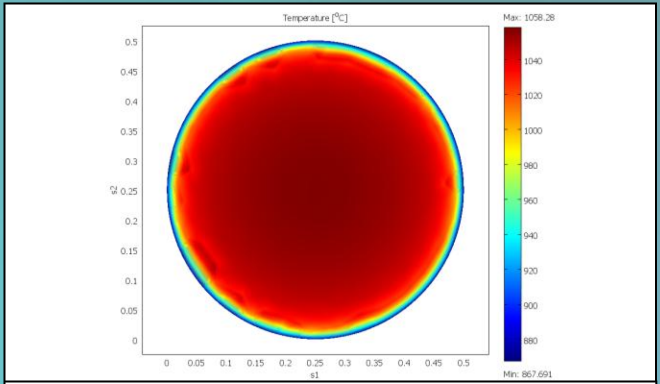
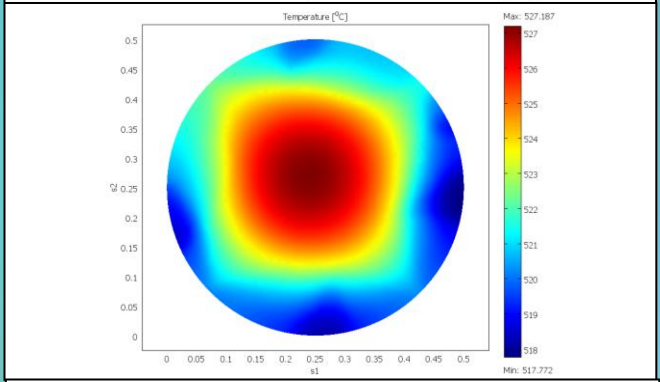
Conversion Module - Simulation

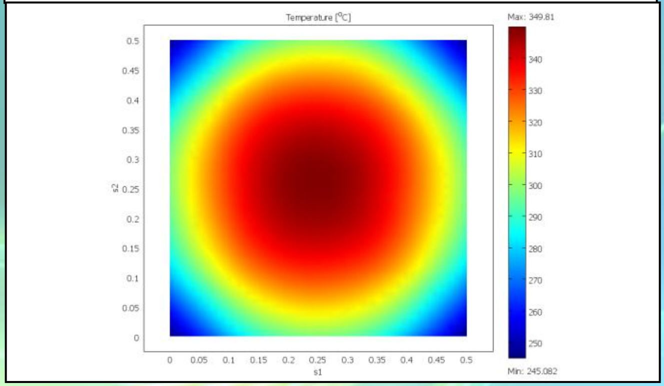




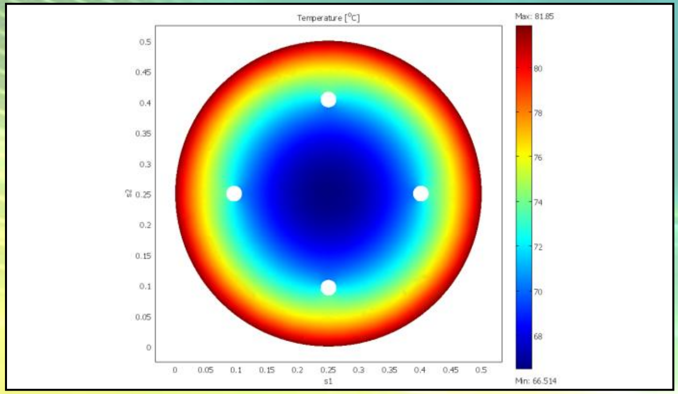
Absorber



TI Collector



TE “Hot” Side



Thermal Management Component

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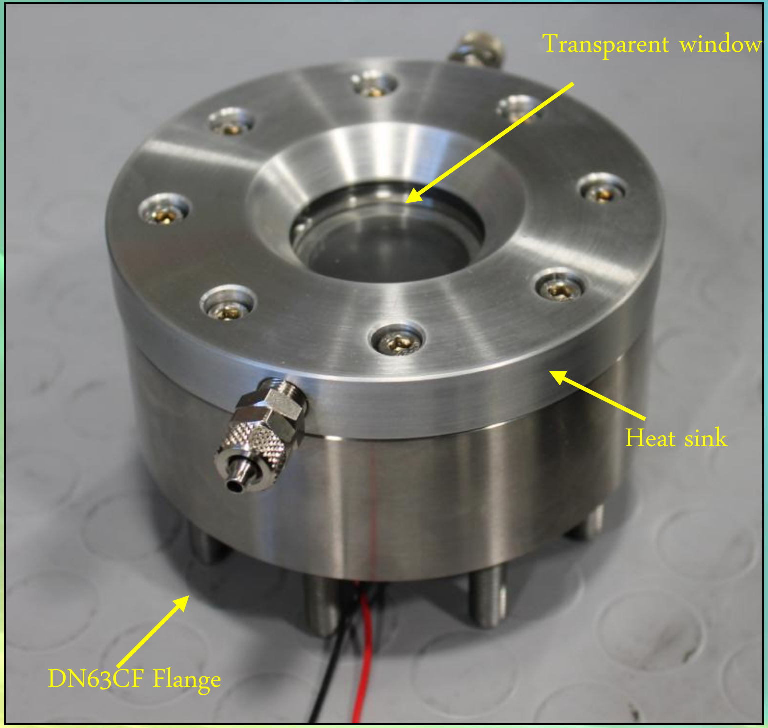
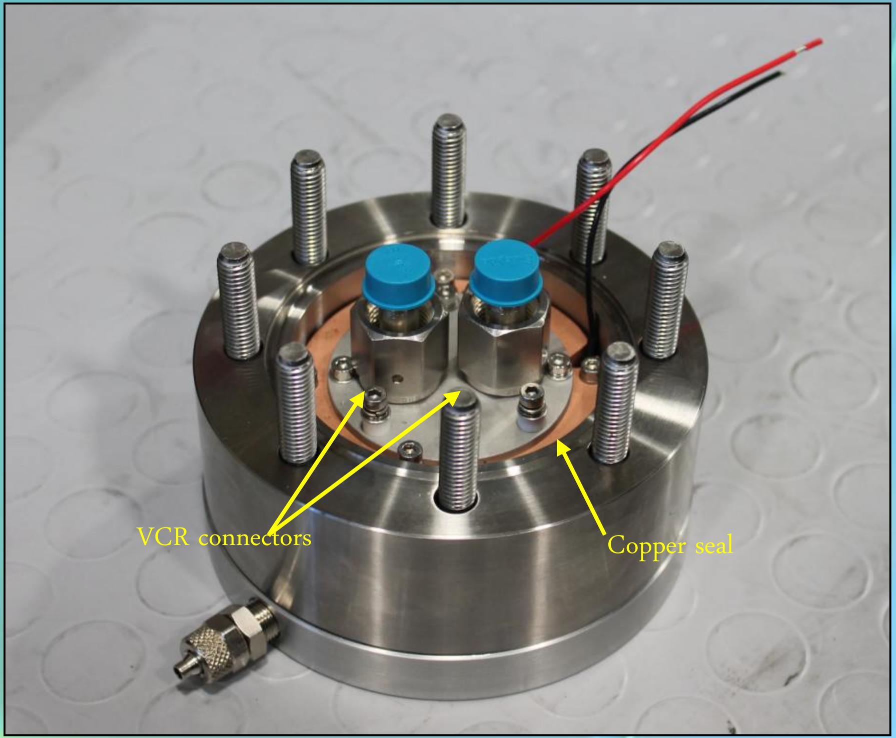
Conversion Module – Enclosure Fabrication





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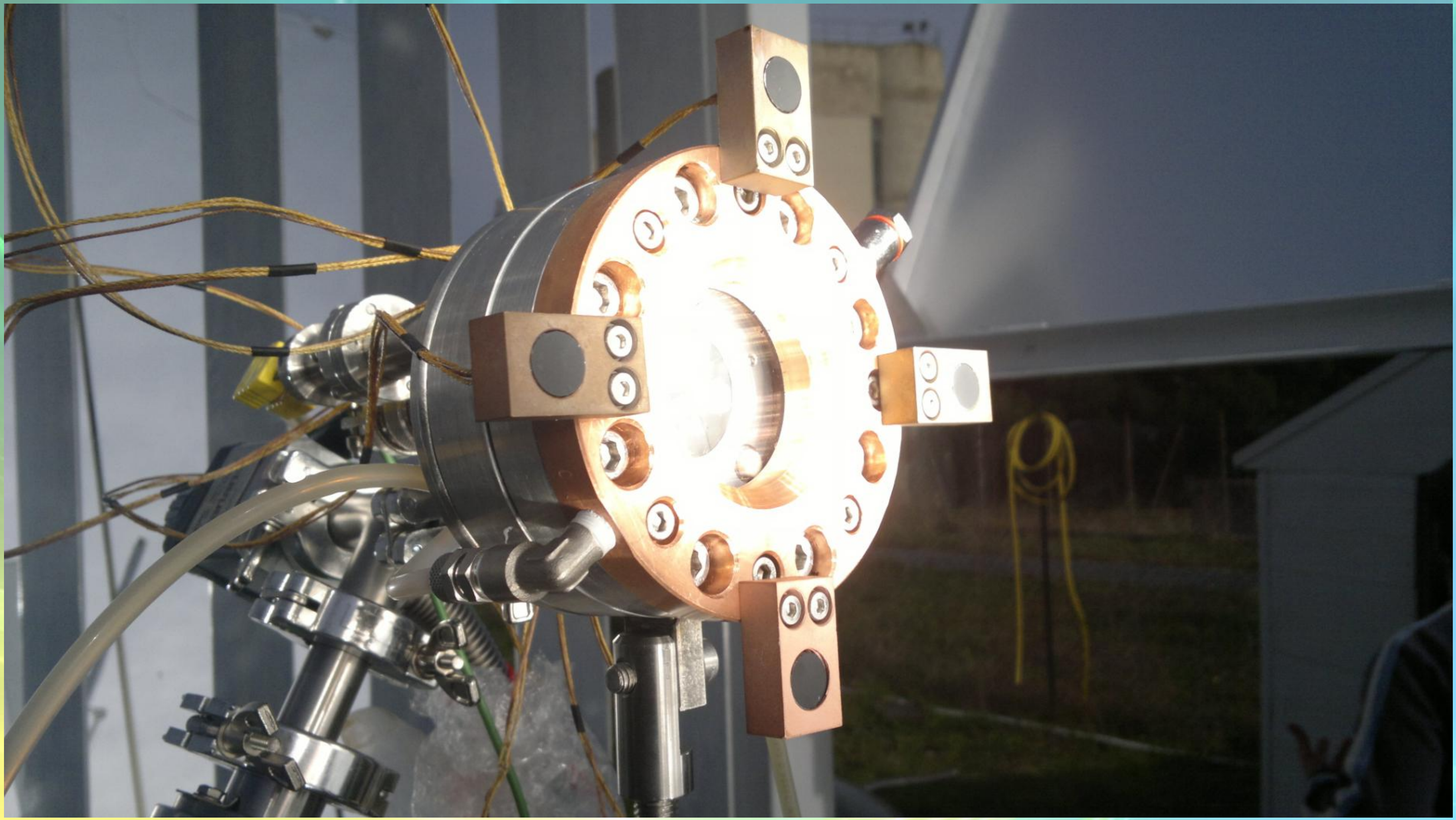

Experimental results are under elaboration!!!

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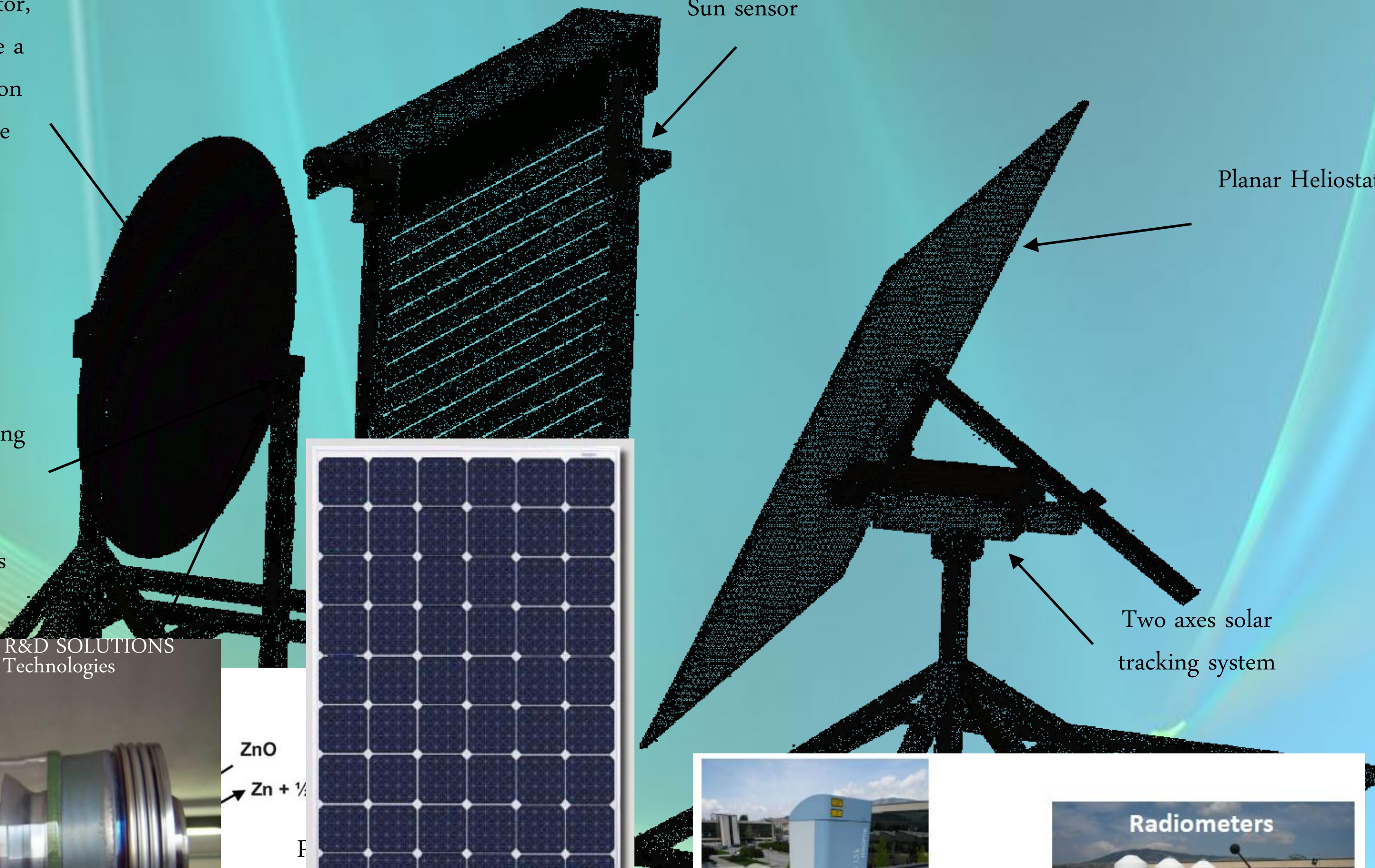
Oudoor Solar Concentration Lab



Parabolic reflector, able to produce a 800 suns spot on the focal plane

Sun sensor

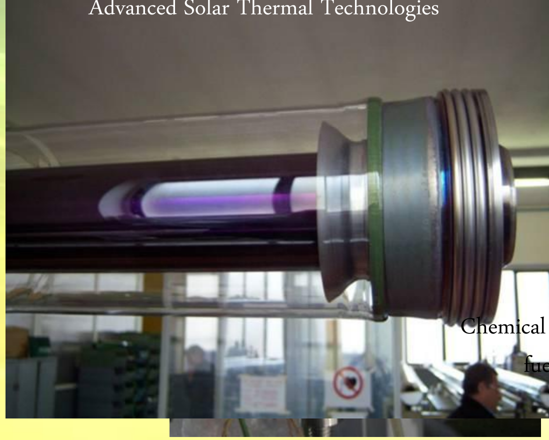
Planar Heliostat

Tecnology testing under concentrated radiation fous

Two axes solar tracking system

INNOVATIVE R&D SOLUTIONS

Advanced Solar Thermal Technologies



ZnO

Zn + ½

F

1

Chemical reactors for fuel production

ncy operations)

Enhanced Solar Tracking

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Thank you for the Attention!

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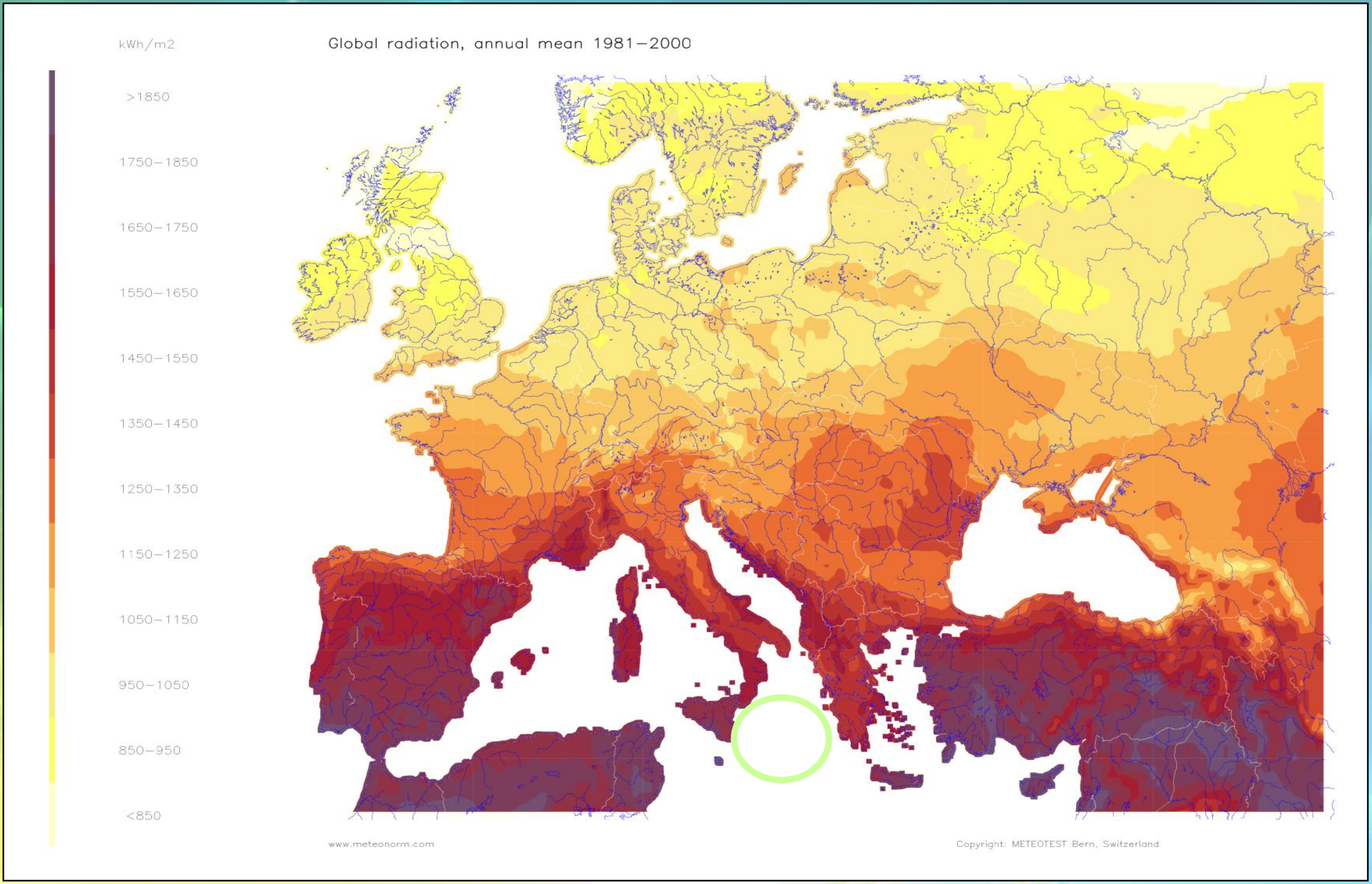

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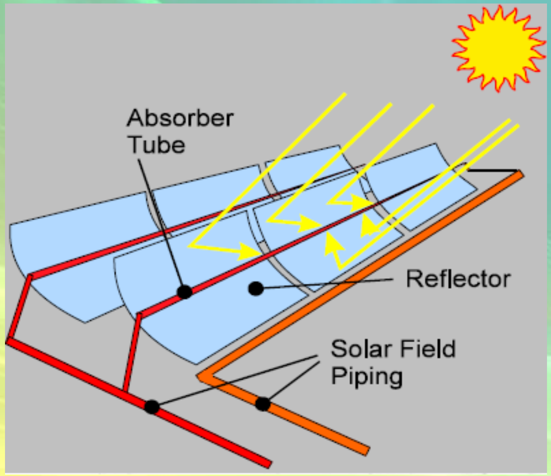
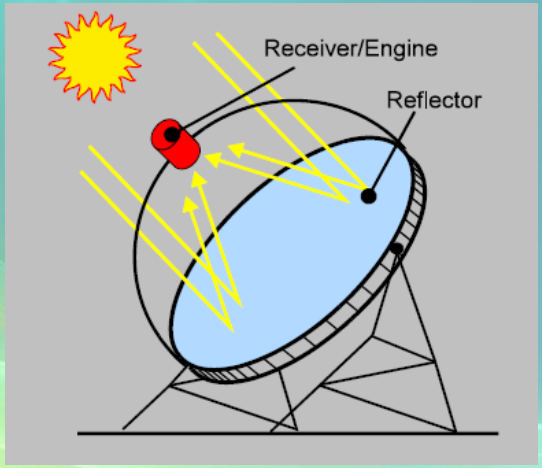
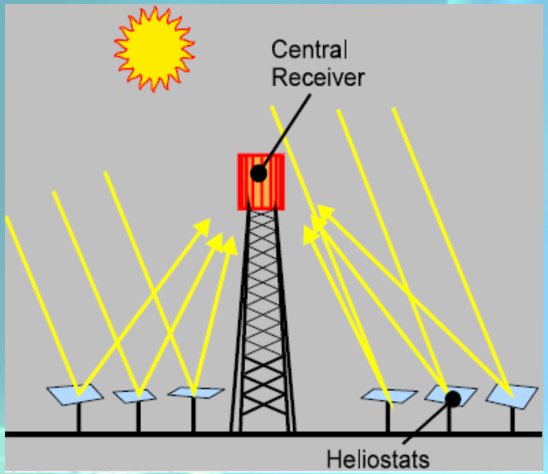
Tecnologie di concentrazione disponibili

- Collettori parabolici lineari (sistema 2D)
- Dischi parabolici (sistema 3D)
- Torre solare (sistema 3D)







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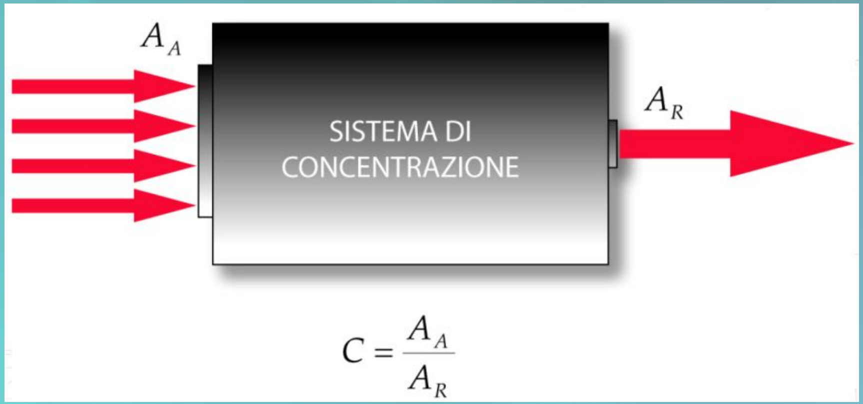
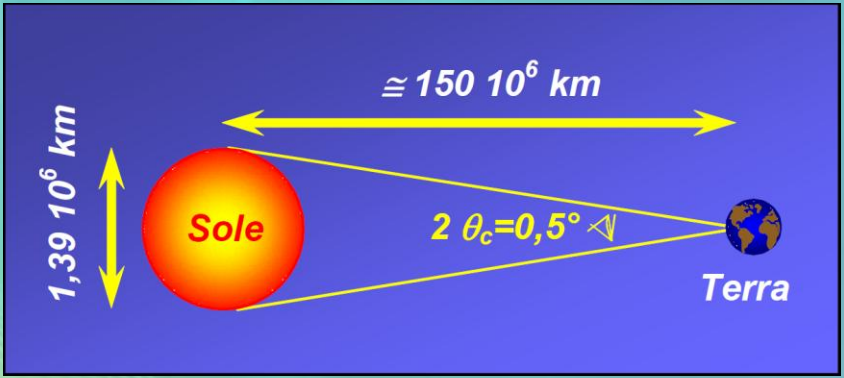
Sistemi a concentrazione

Il fattore di concentrazione è il rapporto tra le aree di ingresso (A_A) e di uscita (A_R) del sistema di concentrazione





Per i sistemi di concentrazione 2D (concentrazione lineare), il valore massimo teoricamente ottenibile è pari a:

$C_{2D,teorico} = 1/\sin(\theta c) \approx 200$

Per i sistemi di concentrazione 3D (concentrazione puntuale), il valore massimo teoricamente ottenibile è pari a:

$C_{3D,teorico} = 1/\sin^2(\theta c) \approx 40\ 000$

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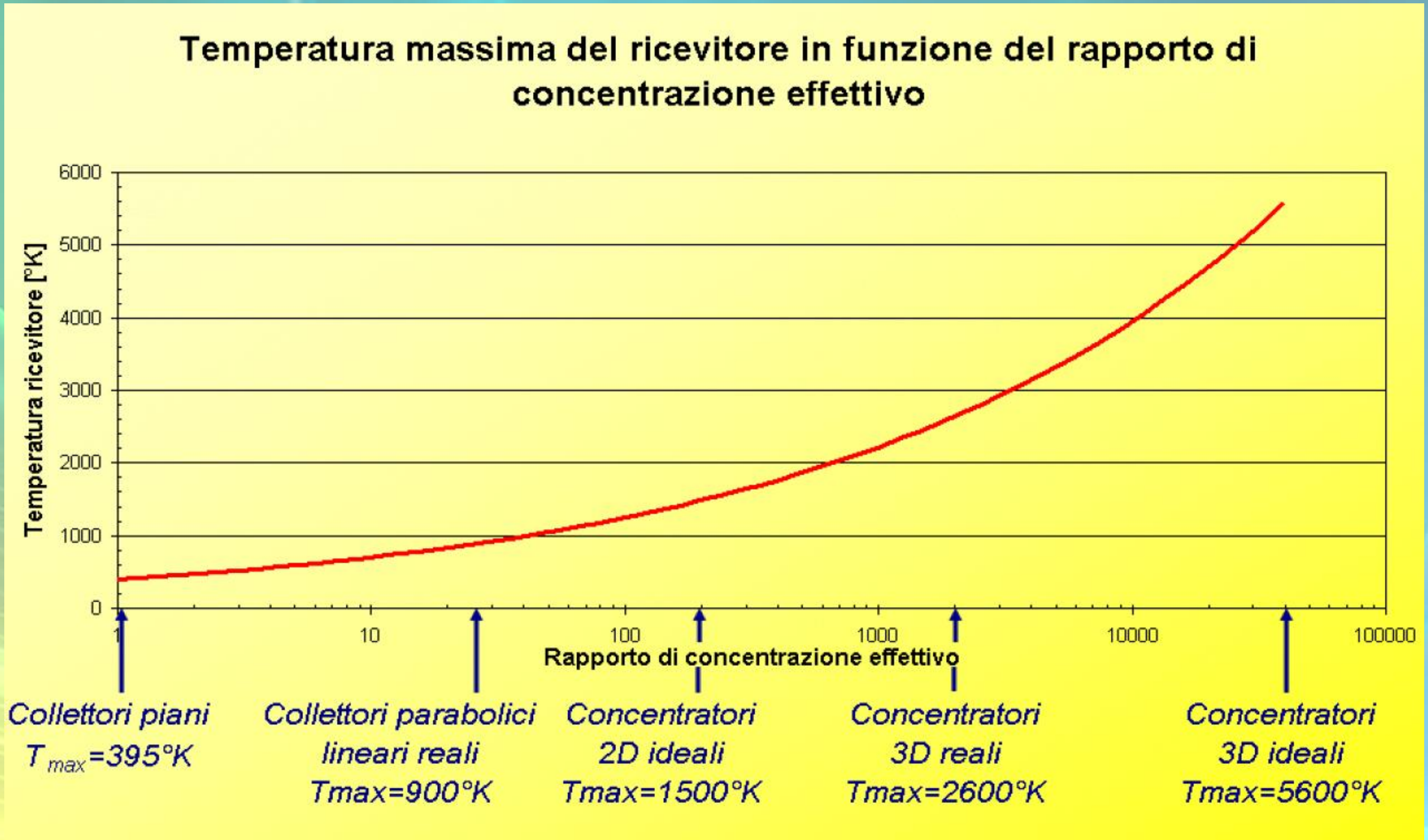
Temperature raggiungibili



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