EERA JPNM European Energy Research Alliance

JOINT PROGRAMME ON NUCLEAR MATERIALS

MATISSE Materials' Innovations for Safe and Sustainable nuclear

Possible applications of SiC-based technology for durable design in Concentrated Solar Power (CSP)

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http://setis.ec.europa.eu/

MATISSE
Materials' Innovations for Safe and Sustainable nuclear

EERA
European Energy Research Alliance
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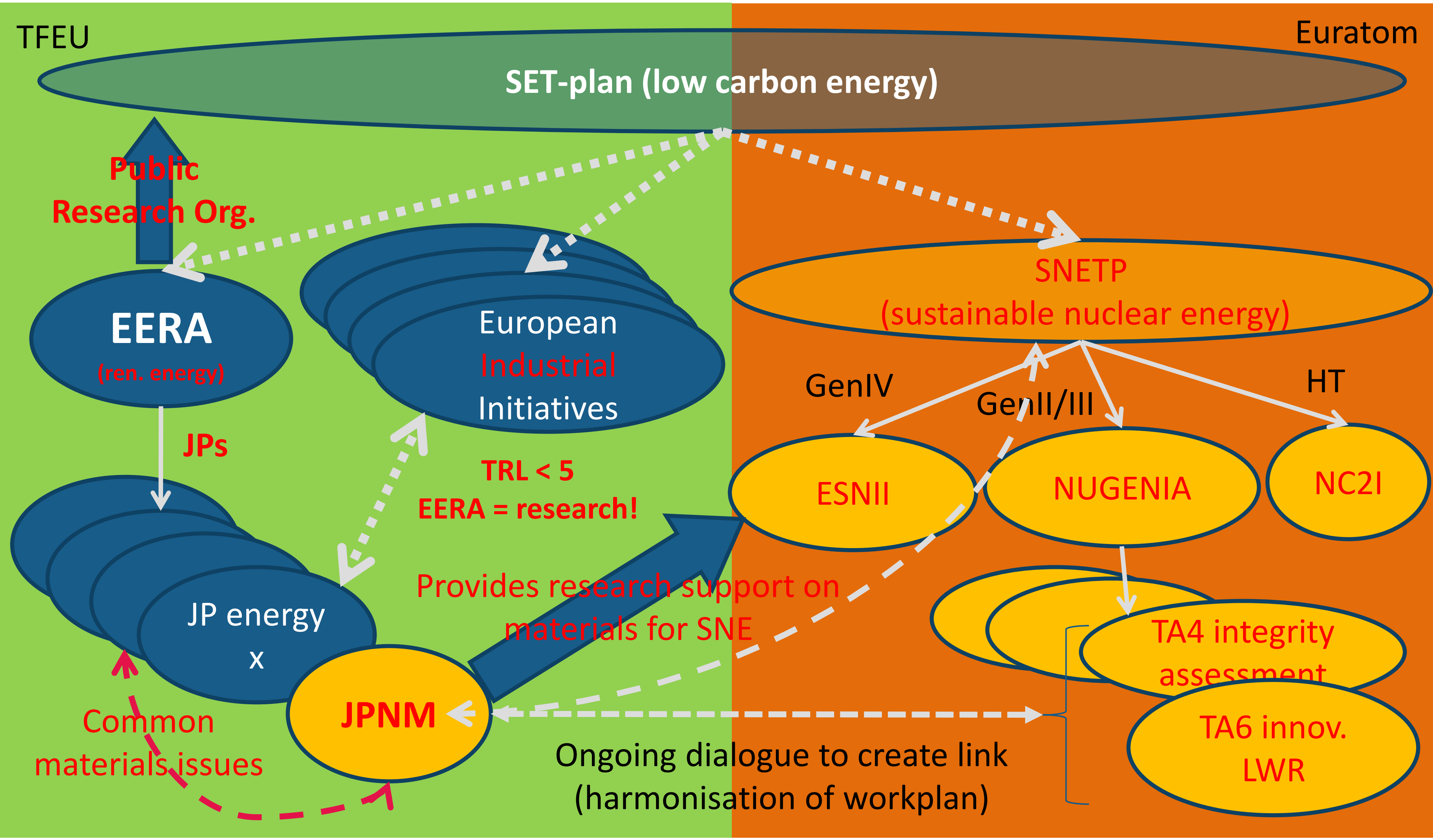
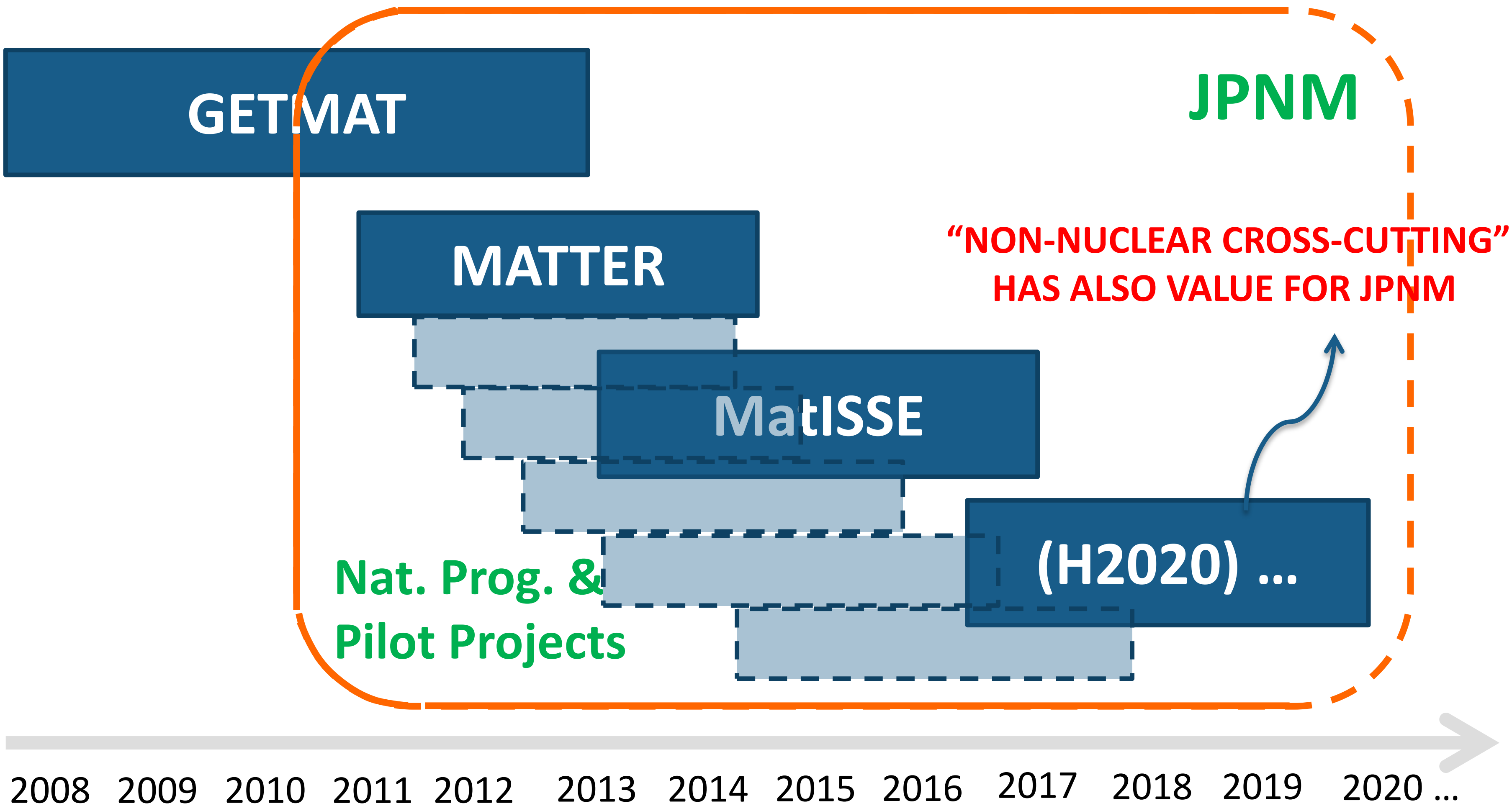
About strategy and cross-cutting opportunities called by the SET-PLAN

The JPNM role in the landscape of energy initiatives: at a glance



The JPNM is the unifying framework for several projects

EU projects on GenIV materials …



The JPNM role in the landscape of energy initiatives: exerpts from the strategic roadmap

The implementation of:

- *relevant parts of the Materials Roadmap Enabling Low Carbon Energy Technologies (SEC(2011)1609);*
- *relevant objectives of the SET-Plan (COM(2009)519);*

→ Offer cross-cutting opportunities for JPNM (SP3 in the specific case, but not limited to)

For CSP: :

- The Materials Roadmap invokes a comprehensive research and development programme on **low-cost**, **high mechanically stable absorber materials** suited also for higher temperature.
- The objectives include **scale-up material development** to industrial scales by technology pilots to test /validate material performances under real market conditions in the areas of [..], porous ceramic or metal structures for **central receivers**

→ **ADVANCED SiC-based** materials are good candidates, along with coatings, and an important opportunity to JPNM-SP3.

Materials' Innovations for Safe and Sustainable nuclear

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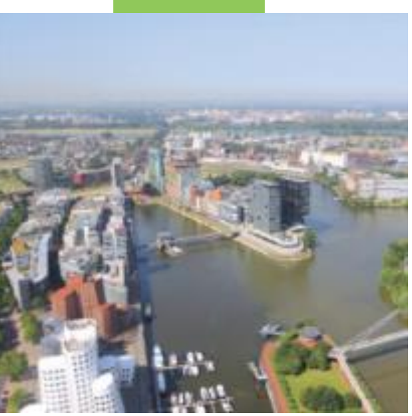
Part II DESIGN PROBLEMS WITH CERAMICS AND COATINGS IN CSP



Reference CSP Architectures

\+ Maturity -

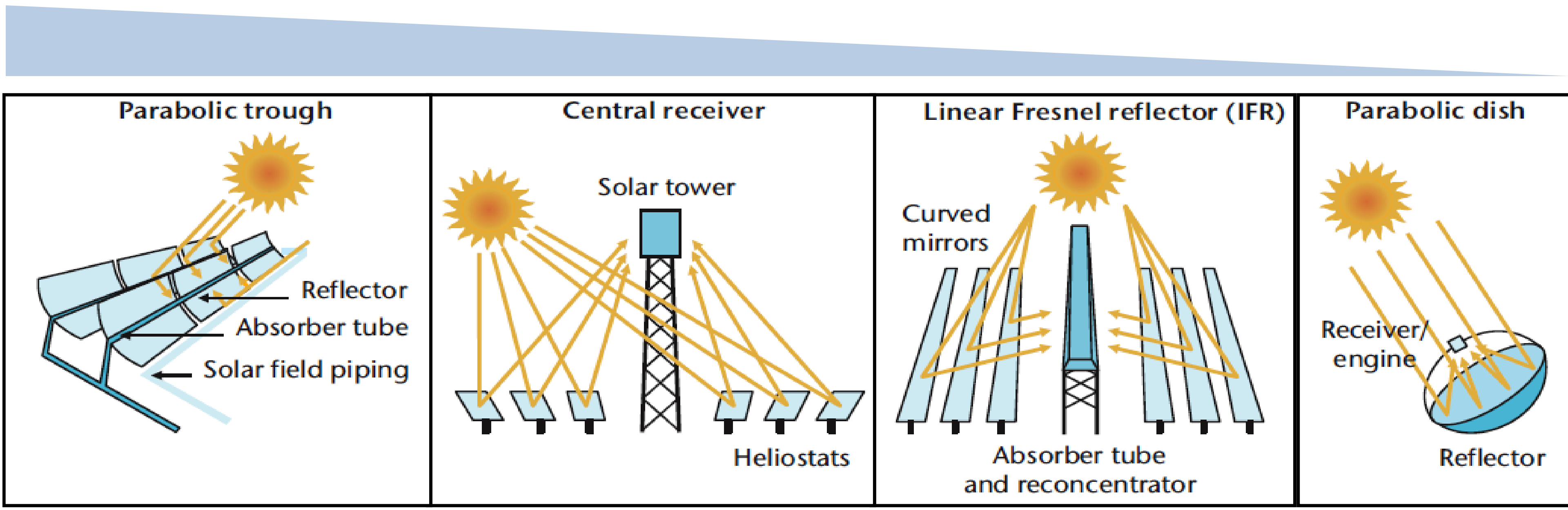
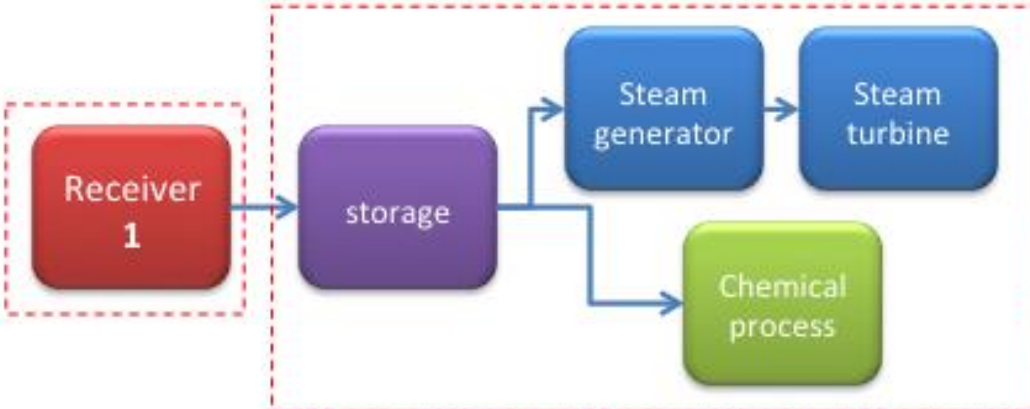


Figure 1. Main STE technologies and maturity levels

Credit IEA – 'New Policies Scenario for STE'

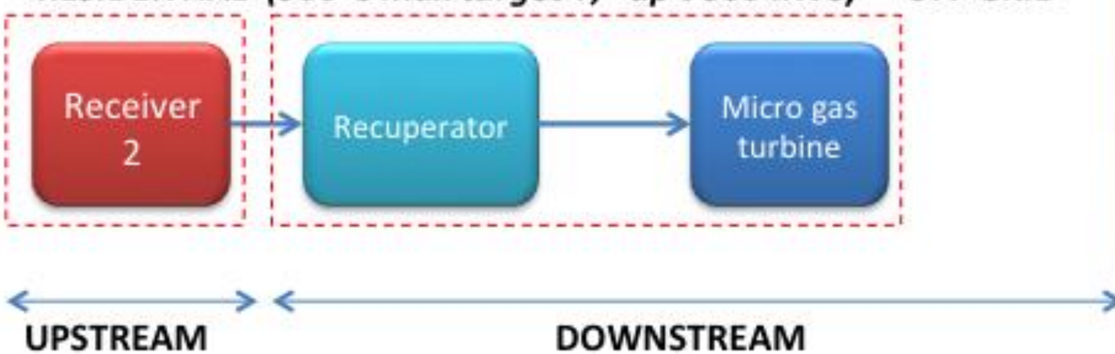
Reference CSP Architectures

SOLAR TOWER (900°C max target T; 10-15 MWe) - ON GRID



Credit CIEMAT

RESIDENTIAL (900°C max target T; up t 500 kWe) - OFF GRID

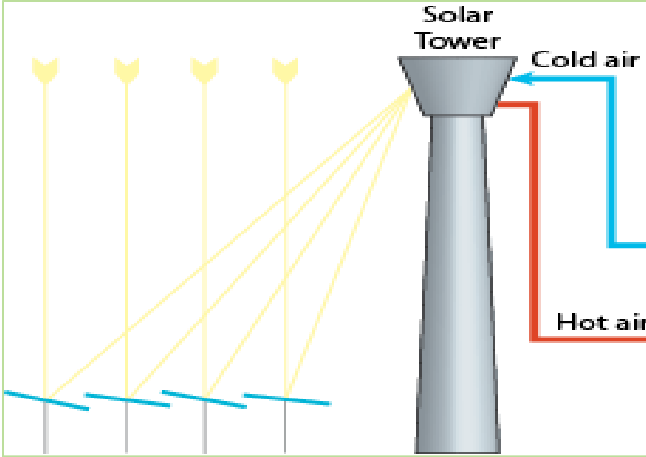


Credit ENEA

Indications from SET-PLAN for CSP

HORIZON CALLS FOR REDUCTION IN :

- *LOWER LEVELIZED COST OF ELECTRICITY (**LCOE**)*
- *TARGET **LCOE BELOW*** **10-12 c€/kWhe** (credit ESTELA)

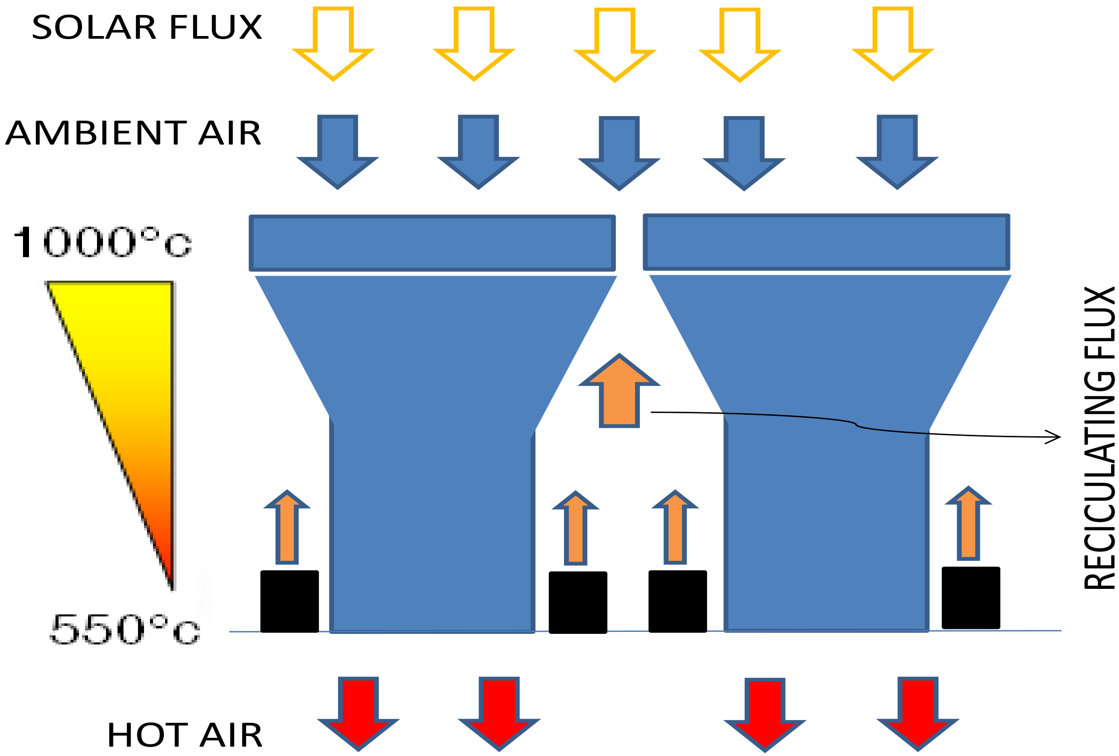


IMPLICATIONS FOR POSSIBLE SOLUTIONS :

- *Lifetimes of the order of 20 to 25 years, with minimal down and service time*
- *Large investment may be acceptable but is a potential downside for smaller systems … CAPEX reduced by achieving economy of scale*
- Condition the choice of the ADVANCED MATERIALS we can select/design for this application
- Efficiency can be improved by a T raise only to a certain extent (e.g. emissivity losses, convection, etc.)

ENPHASIS IS ON RELIABILITY AND LOW COSTS (rather than a radical increase in T…)

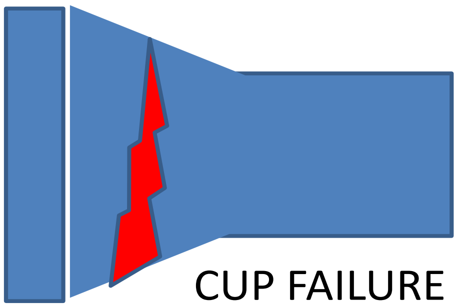
Issues in SOLAR TOWER CSP RECEIVER

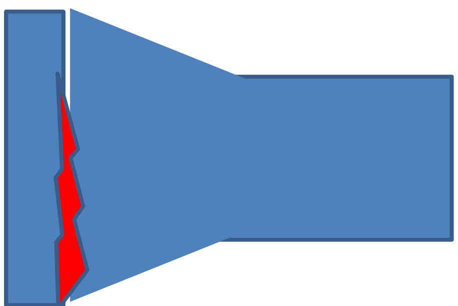


Credit PSA -CIEMAT

THERE ARE THERMAL GRADIENTS & THERMAL SHOCK ON MATERIALS

Issues in SOLAR TOWER CSP RECEIVER





1st generation CUPS made of Si-SiC and suffer from early failure:

- Fail in "intragranular" mode
- Fail at the interface between CUPS and TILES

(results from the SOLAIR FP7 PROJECT and* EU FP5 HitRec *from our sister program JP-CSP)*

1. We need materials with 99% survival probability at thermal gradient > 80°C/cm
2. **Both BULK & JOINING ARE KEY !!!!**

Part III SOME POSSIBLE SOLUTIONS

Solutions

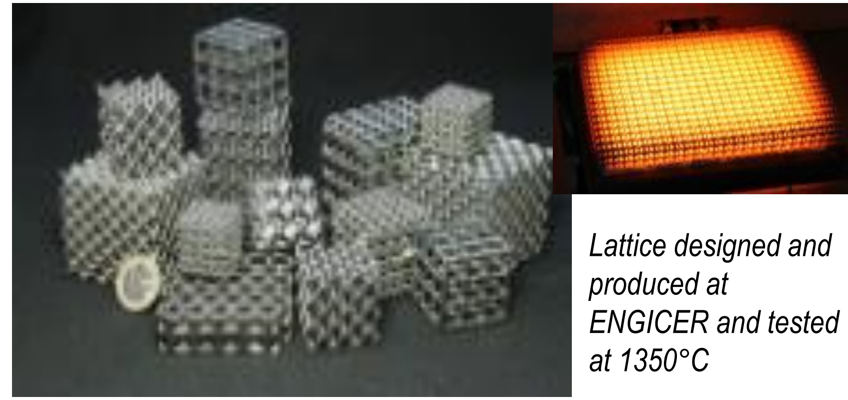
POSSIBLE REQUIREMENT

1. *Meet given thermal gradient strength*
2. *High conductivity*
3. *Manufacturing: low cost, high-throughput & high control (low defects)*
1. *Oxidation resistant*
2. *Reliable joining*
3. *Modeling and inspection/NDE*

2 solutions based on monolitic SiC-based, e.g. Si-SIC or All-SIC

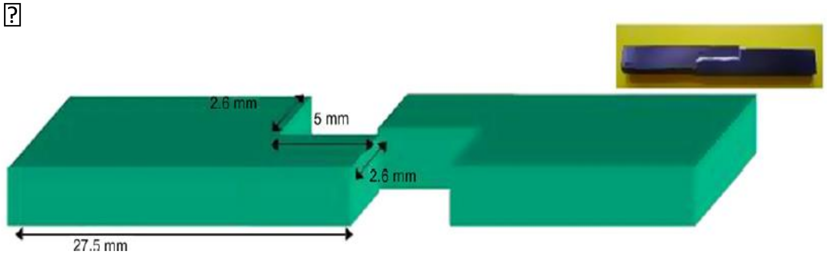
POSSIBILITY #1: (Si)SIC + hetero-joining

1. *High thermal conductivity due to Si phase*
2. *High toughness due to Si phase*
3. *Cheap*
4. *Could be produced from powders using additive manufacturing*
5. *Joining by many oxides*



Lattice designed and produced at ENGICER and tested at 1350°C

Method	Process Condition	Material/Phase in Joint	Typical Strength
Glass-ceramic joining	1375ºC, pressureless	Mullite, cristobalite, keivyite	~100 MPa
Metallic braze-based joining	~1400ºC, pressureless	Si, MSi_2 (M=Ti, Cr)	~100 MPa 4PB[2] or shear
Si-C reaction bonding	~1425ºC, pressureless	SiC, Si	Up to ~250 MPa 4PB
Preceramic polymer joining	1000 – 1400ºC, pressureless	Si-O-C (-N)	Up to tens MPa, SLO[3] shear

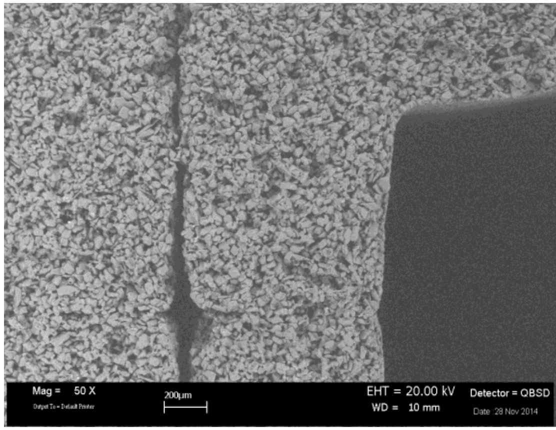


Credit POLITO

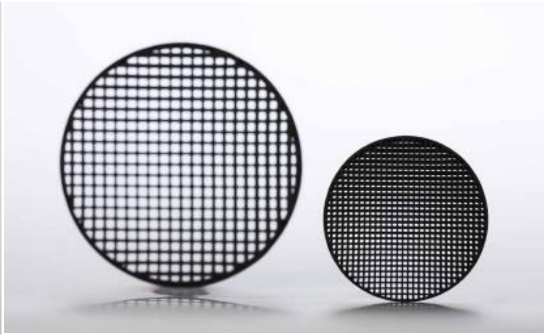
Solutions

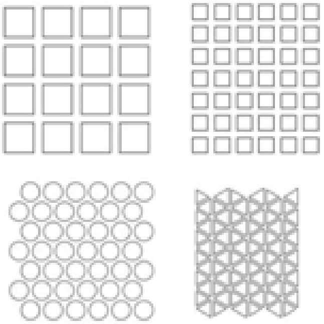
POSSIBILITY #2: All SIC

1. *High thermal conductivity*
2. *High oxidation resistance*
3. *Cheap Enough*
4. *Could be produced from powders in large Q.*
5. *Joining by crystalline SiC*



LIQTECH: Vapor Phase Sintering (VPS) of SiC at 2600-2800° C, in a controlled atmosphere

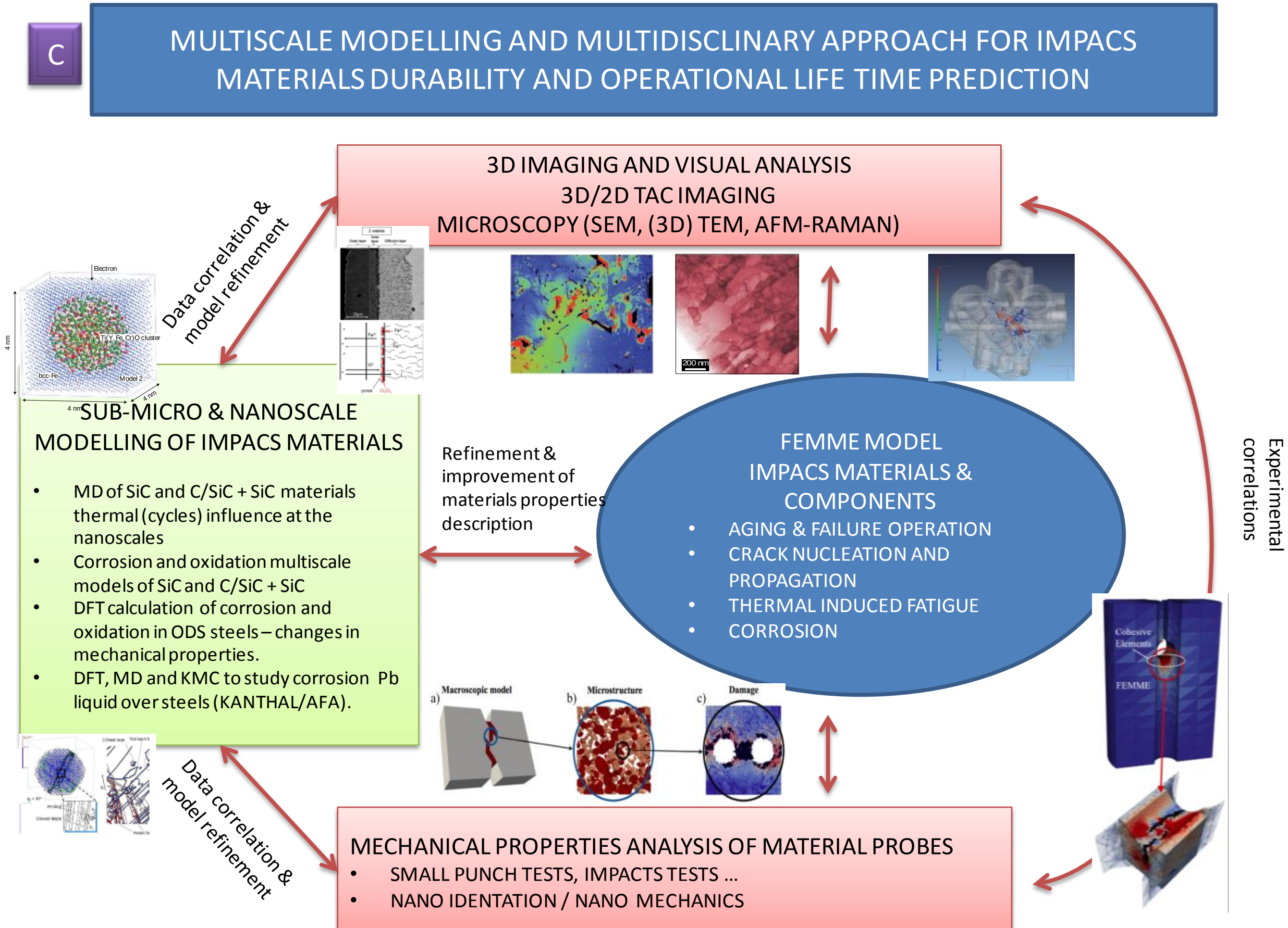




Credit LIQTECH

Controls and optimization/NDE (from JPNM SP3)

1. *Multiscale modeling & characterization*
2. *X-ray tomography and ultrasounds*



Credit UOXF, ICCRAM

Solutions

ECONOMIC COMPARISON

Monolithic options (from powders):

SiSiC: <50€/Kg (conductivity/ductility) Vs. All-SiC: 50-100€/Kg (better oxidation)

Both are technically valid and economically viable

CMC options (from fibers+CVI):

SiC/SiC: 5000€/Kg Tolerated thermal gradient > 120°C/cm

leap engine effects? economy of scales and increased T operations may make it worthy the extra performance offered by the CMC

ENPHASIS IS ON RELIABILITY AND LOW COSTS RATHER THAN A RADICAL INCREASE IN T !!!

Conclusions

CONCLUSIONS: we have a trajectory for SiC-based materials

- ✓ *High thermal conductivity → TH. GRADIENT STRENGTH*
- ✓ *High oxidation resistance*
- ✓ *Cheap and scalable , yet flexible & reliable*
- ✓ *Reliable Joining (even by crystalline SiC)*
- ✓ *Additive manufacturing can be used*
- ✓ *Multiscale modeling/testing and NDE to support design*
- ✓ *More performing solutions offered by CMC may be at reach soon through economy of scale "leap forward" + introduction of LM storage options*

Thermostructural SiC based materials and composites are unfolding nicely and gaining momentum, offering opportunity for technological deployment and transfer for the nuclear community (where the market will never reach the scale of aerospace of wide spread CSP).

THANKS

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