# Raising the Lifetime of Functional Materials for Concentrated Solar Power Technology

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Dear Reader,

The overall aim of the RAISELIFE project is to decrease CAPEX and OPEX of components to reduce the cost of renewable electricity from CSP by understanding and improving the in-service durability of functional coatings and materials on one hand, and by minimizing the O&M cost on the other hand. O&M impacts the durability and performance of materials and coatings, e.g. due to cleaning cycles in harsh CSP environments. This interdependency and the economic effects have been investigated. On the other side, a key goal is to evaluate the environmental impact on the materials studied in the frame of the project (coatings and molten salts mixtures). In this last edition of the RAISELIFE newsletter we look in more detail the approach of the RAISELIFE project on the economic impact and effect on the levelized cost of electricity (LCOE) of each degradation mechanism and coating development/improvement assessed in this project in the *Special Topic "Impact of degradation on performance of components and systems"*.

We address this newsletter to stakeholders who are active in the field of Concentrated Solar Power Plants, from power plant developers / operators and technology suppliers to the scientific community as well as governmental bodies. Members from the general public who are interested in topics related to the RAISELIFE project, such as concentrated solar power and material durability will also gain from our newsletter.

We wish you an inspiring read!

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# Special topic: Impact of degradation on performance of components and systems

*Partners involved*

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*Importance of topic*

To increase the power output of solar thermal power plants over the full life time, it is essential to focus on the improvement of functional materials such as mirror coatings, selective and non-selective receiver coatings, as well as corrosion resistant steel and coatings to use with molten salt. The EU-funded project RAISELIFE focuses on raising the lifetime of these key functional materials. The impact of these new materials on the LCOE was assessed by performing dynamic system simulations.

*Current state of art*

The variation of solar irradiation and sun position throughout the year requires simulation methods in order to assess the electricity yield of solar thermal power plants. Usually annual simulations are performed, using typical weather data for the evaluated location. However, degradation effects are often neglected or considered by using mean values for key functional material parameters. The RAISELIFE approach ensures the consideration of degradation in multi-year simulations throughout the whole lifetime of the plant, also enabling the optimization of operation and maintenance strategies.

*The RAISELIFE approach*

The techno-economic assessment was conducted for different material developments showing the impact of degradation on the LCOE of CSP plants. Therefore, degradation models were derived from accelerated aging and on-site tests. These models were implemented in a dynamic system simulation environment. The resulting energy yield is used to calculate the LCOE and to compare the different materials.

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A simulation tool chain was developed to quantify the impact of the new material developments of the RAISELIFE project in plant operation. This tool chain consists of the Fraunhofer ISE raytracing software Raytrace 3D, the DLR thermal efficiency FEM model ASTRID and the Fraunhofer ISE dynamic system simulation tool ColSim CSP.

The ray tracing software Raytrace3D developed by Fraunhofer ISE calculates the flux distribution on absorber surfaces with high spatial resolution. Reflections from the receiver tubes towards the environment or to other tubes are considered. All relevant optical effects like cosine losses, shading, absorption on heliostats, blocking, spillage, atmospheric attenuation and reflection on the receiver surfaces are considered. With the help of a sky discretization approach [1], the transient distribution of concentrated radiation on the receiver surfaces is calculated in the form of flux maps depending on sun position and receiver load. These act as an input to the thermal receiver model and system simulation.

With the ASTRID© approach by DLR [2], the thermal efficiency of the receiver is simulated. The previously described flux maps are input to this FEM model, defining the radiation boundary conditions. One dimensional fluid flow elements are used to model the heat transfer to the fluid. Local heat transfer coefficients are implemented as a function of the local fluid temperature, the Reynolds number is calculated based on the Gnielinksi correlation and the radiosity method [3] is used to describe the thermal radiation exchange between absorber tubes, insulation and ambient. For absorber tubes, insulation and heat transfer fluid, the local temperatures are obtained. Based on these temperatures, the thermal receiver efficiency is calculated with the thermal losses by long-wave radiation, convection and conduction. The thermal efficiency depending on different load cases is input to the system simulation in ColSim CSP.

The Fraunhofer ISE simulation software ColSim CSP[4] performs fast dynamic system simulations with an adjustable level of detail. For the RAISELIFE project, one minute time steps are being used. The tool is optimized for solar thermal power plants and solar thermal process heat applications. All relevant components of the reference system like heliostat field and receiver, HTF pump, thermal energy storage and power block are part of an extensive library of detailed component models. Transient effects and operational constraints like mass flow and temperature limitations are considered. This enables the simulation of solar field and power block start-up and shut-down. For the project RAISELIFE, the simulation environment ColSim CSP was adapted to the material development models mentioned above. For the evaluation of heliostat coatings, the reflectance loss over time was considered for different material developments, but also for different corrosion classes. Also anti-soiling coatings were evaluated by taking into account varying soiling factors and always considering a cleaning frequency of 14 days.

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To evaluate the system behaviour including degradation over the full life time of a plant, multi-year simulations are performed. The operation and storage dispatch strategy aims at producing electricity at design load as often as possible. The energy output of annual as well as multi-year simulations can be used to perform feasibility studies and assess the system design and performance.

The reference CRS power plant located in Ouarzazate, Morocco has a gross electricity output of 150 MW, thermal power of 600 MW and about 4.5 hours of storage. The heliostat field consists of 72,000 heliostats of 20.8 $m^2$.

The economic impact of each material development is assessed. For each simulation scenario, the energy yield in each year of the plants lifetime is obtained. This energy yield is input to the calculation of economic key performance indicators like Levelized Cost of Electricity (LCOE).

*Possible impact*

Each material development was evaluated based on the derived degradation models and material parameters. One work package addressed heliostat coatings. The most interesting developments were two-layer protective coatings that were contrasted against the state-of-the-art three-layer coating. Compared with the state-of the art three-layer coating, slight performance improvements could be reached with the new two-layer coatings in certain corrosion classes. Additionally, the mirror costs were slightly reduced. The evaluation showed that particularly the effect of better coating performance is relevant for the reduction of LCOE. Further assessments of anti-soiling coatings and cost-saving composite mirrors were evaluated in the project and showed significant improvements of the LCOE.

Another work package had the aim of developing suitable materials for secondary mirrors used in central receiver systems. Even though the new material showed significant improvements to the reference case, the results showed that the plant could only be operated few years due to heavy degradation. Therefore the material could not be applied in a system that operates 30 years. The evaluation of the secondary mirror therefore focused on the theoretic performance of a secondary mirror without considering degradation, showing the impact of energy yield as well as additional and saved costs on the plants LCOE. The simulations showed that the electricity yield could be increased by 1.57%, given that the secondary mirror resists the high heat load. Due to a reduction in panel height also cost savings of the receiver can be expected, leading to a reduction of the LCOE of about 1.9%, if a suitable material is found.

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For the evaluation of receiver coatings, the absorptance and emmitance loss/increase over time was considered for different material developments. Also recoating processes of these receivers were considered. While receiver recoating leads to improved system performance, the additional costs and downtime during application have a negative effect on the LCOE. Therefore an optimization was conducted, to find the ideal recoating interval to reach the minimum LCOE. An exemplary case of one material development is shown in 1. While the mean annual yield is the highest for three reapplications in a lifetime of 30 years (recoating interval of eight years), the LCOE is the lowest for one reapplication (recoating interval of fifteen years). From an economic point of view the optimal recoating interval is therefore fifteen years in this case. Compared to the case with no reapplication at all, the LCOE can be reduced by 0.1%.

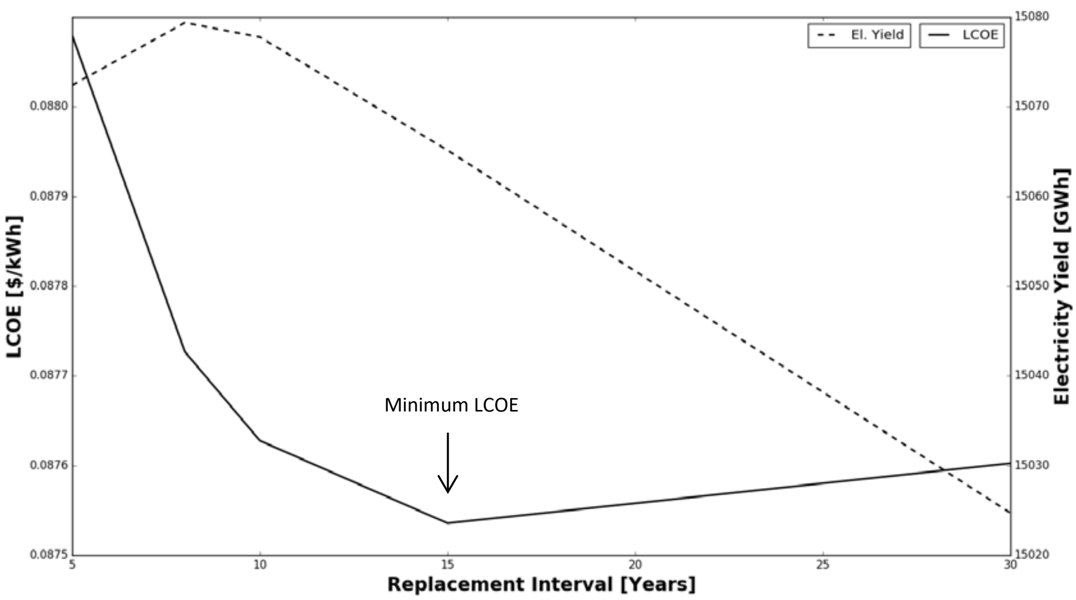


*Figure 1: Influence of number of replacements in 30-year life time on LCOE and mean annual yield*

For all receiver coating material developments, the lowest LCOE (resulting from the ideal recoating interval) was compared and showed that the LCOE can be reduced.

Additionally the usage of steel coatings to be able to use less costly steel in the storage system was assessed economically. Also an improved new salt mixture consisting of a new

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composition of potassium and sodium nitrate was evaluated and found to have a positive effect on the LCOE.

Finally, a "best case" analysis was done, showing the impact of all best performing developments in the project RAISELIFE. Table 1 shows the summary of the case comparison. The electricity yield in 30 years could be increased by 1.5% to 15,099 GWh. The LCOE could be reduced by 9.8% to 7.99 $Ct/kWh.

*Table 1: Comparison of reference case and best-case scenario*

| | **Reference Case** | **Best Case** | **LCOE reduction** |
|---|---|---|---|
| **Protective Heliostat Coating** | State-of-the-art coating | RAISELIFE coating | -0.2 %* |
| **Composite Mirrors** | No | Yes | -9.3 %* |
| **Anti-Soiling Coating** | Uncoated | RAISELIFE coating | -1.5 %* |
| **Absorber Coating** | State-of-the-art coating | RAISELIFE Coating | -1.1 %* |
| **Cheaper storage + steel coating** | No | Yes | -0.7 %* |
| **Electricity Yield** | 14,880 GWh | 15,099 GWh | |
| **LCOE** | 8.86 Ct/kWh | 7.99 Ct/kWh | **-9.8 %** |
| | | | |
| ***Additional option: Secondary Mirror*** | *No* | *Yes* | ***-1.9 %*** |
| ***Additional option: New salt mixture*** | *No* | *Yes* | ***-2.0 %*** |

**The individual reduction values do not necessarily add up to the total LCOE reduction because they refer to different reference values*

The evaluation of the RAISELIFE best case scenario shows that the LCOE can be reduced by almost 10% compared to the reference scenario. The highest impact has the use of composite mirrors. Nevertheless, not all questions regarding the technical implementation have yet been clarified, for example how the different thermal expansion coefficients of the various materials affect the accuracy and durability. Also anti-soiling coatings that increase the average reflectivity have a high impact. The improved RAISELIFE absorber coatings show smaller degradation rates and therefore require less recoatings during the lifetime of the plant and therefore also have a positive impact on the

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electricity yield and cost calculation. Corrosion resistant steel coating and the less expensive 2-layer protective mirror coating also reduce the costs. Additional savings can be reached by applying a secondary mirror as the yield is increased and costs can be reduced. This LCOE reduction of 1.9%, however, refers to another reference system design and therefore cannot be added to the list of total savings. The number gives a clear indication that a LCOE reduction can be reached based on the current assumptions, if a secondary mirror material is found that withstands the harsh temperature conditions. The same way, also the usage of a new salt mixture can reduce the LCOE further by 2.0%, especially because the operation temperature can be increased.

The RAISLIFE evaluation shows that very significant cost reduction can be reached by technical improvements of key functional materials. By conducting dynamic system simulation for the full lifetime of a solar thermal power plant, not only detailed yield analysis can be performed, also maintenance strategies, like the selection of the ideal recoating interval, can be optimized.

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