E-ECO DOWNSTREAM

Development of Heating Technologies for the Efficient Renewable Energy Consumption of CO_2-Neutral Downstream-Processes

Shaping the Future of Burner Technology

As part of the **E-ECO Downstream** project, our team is officially launching a new initiative focused on revolutionizing industrial burner technology. In the transition to fossil-free steel production, the ability to adapt to new, sustainable fuel sources is paramount. Our work aims to bridge the gap between design flexibility and manufacturing precision turning current furnaces into future-ready systems.

The Challenge: Flexibility in a Changing Energy Landscape

Traditional burners are designed for specific fuel types and flow rates, making the transition to renewable fuels like Hydrogen (H_2), bio-methane or mixtures of both gases a significant hurdle. Currently, replacing entire burner systems to accommodate these fuels requires massive capital expenditure (CAPEX), costing thousands of Euros per burner. Our mission is to disrupt this cycle by enabling existing burners to utilize green fuels through the integration of custom-designed, 3D-printed burner components such as nozzles, flame stabilizers, and swirl plates for a retrofit rather than replacing the entire system.

This project has received funding from the European Union under grant agreement NUMBER — **101178210**

Our Roadmap: A Smarter Way to Design

We are embarking on an ambitious task to redesign burner parts by integrating advanced computational methods with cutting-edge manufacturing:

- **Intelligent Optimization:** We are developing a parametric numerical model to simulate combustion effects. To ensure efficiency, we are deploying **Bayesian optimization** to intelligently navigate the design space. This approach allows us to identify the most promising configurations while minimizing the number of iterations.
- **A Collaborative Workflow:** Our methodology relies on a tight-knit synergy between expert-led CFD (Computational Fluid Dynamics) modeling and active learning, ensuring our design criteria, specifically regarding temperature and flow fields, are met with high accuracy.
- **Advanced Prototyping:** Once the optimal geometries are identified, we plan to leverage additive manufacturing using corrosion- and temperature-resistant powder metals, enabling the creation of complex burner designs that were previously unattainable.

From Digital to Physical: Additive Manufacturing

Once our models confirm an optimal burner design and ensuring superior temperature and flow field performance, we don't stop at the computer screen. We are utilizing additive manufacturing (3D printing) with corrosion and at up to 1,200 °C temperature-resistant powder metals. This allows us to produce complex, highly efficient geometries that would be impossible to manufacture using traditional methods. Additionally, the high temperature resistance alloys allow us to overcome previous limitations in functionality in burner systems.

Building the Foundation

While we are currently in the foundational phase of this project, we are excited to establish a robust framework that will serve as a cornerstone for future burner efficiency. By refining our simulation and experimental strategies now, we are positioning ourselves to deliver real-world solutions for energy-intensive industries.

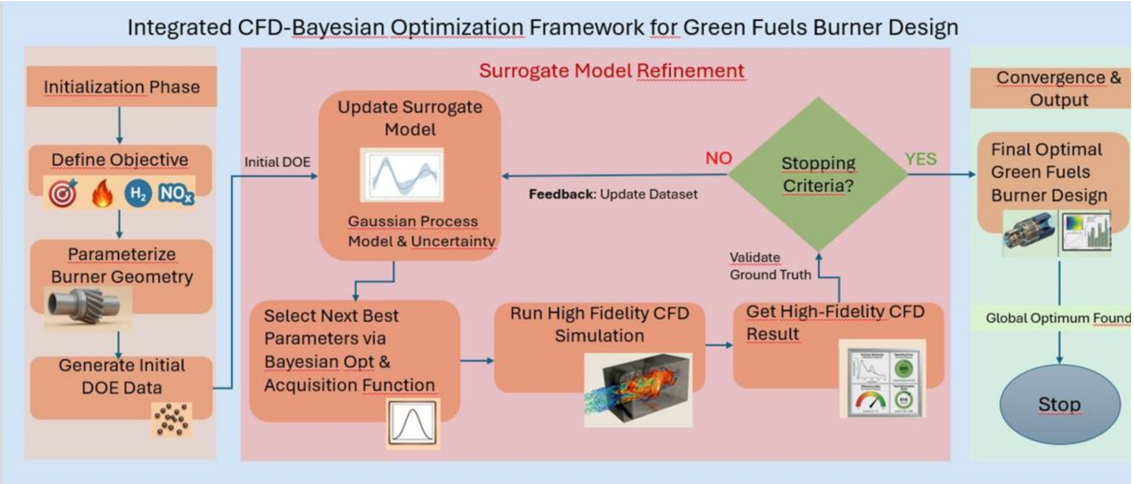

Figure 1: Integrated CFD- Bayesian Optimization Framework for Reducing Iterations in Green Fuels Burner Design

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This flowchart shows a step-by-step framework that uses CFD and machine learning to design a retrofitted burner that minimizes NO_x production while using mixtures of natural gas and hydrogen. It works in a continuous three-phase loop:

First, the process starts by setting goals (outputs)—i.e. minimizing NO_X emissions and combus-tion efficiency. The framework then defines the burner's design parameters as inputs, which include nozzle geometry and the swirl number. From there, it gathers a baseline dataset by running initial CFD simulations.

Second, the system enters a refinement loop where an AI-driven surrogate model (Gaussian Process) maps the design space and highlights uncertainties. An acquisition function chooses the best possible modifications, which are then tested using a high-fidelity CFD simulation. If the stopping criteria are not met, these simulation results are fed back into the loop to improve the model.

Finally, once the optimization criteria are satisfied, the loop stops, providing the final optimal burner design.

Next Steps

In the upcoming project activities, the focus is on completing the integration of the optimiza-tion framework with the CFD simulation environment to enable efficient design iterations. Ba-sed on the resulting optimized geometries, retrofit components will be manufactured using advanced 3D-printing technologies. These designs will then be evaluated in comprehensive experimental campaigns at the pilot test rig, where both the retrofitted burner concepts and state-of-the-art reference burners will be investigated. The experimental findings will be used to validate the com-putationally generated retrofit geometries and to assess their perfor-mance under realistic oper-ating conditions. The final design solutions and the corresponding experimental results will provide the basis for retrofit concepts that can be transferred and applied to other industrial plants across Europe, supporting improved efficiency and reduced emissions in existing combustion systems.