SOLAR

WP3 – Solar H2

H_2 microreactor design & DMR characterization

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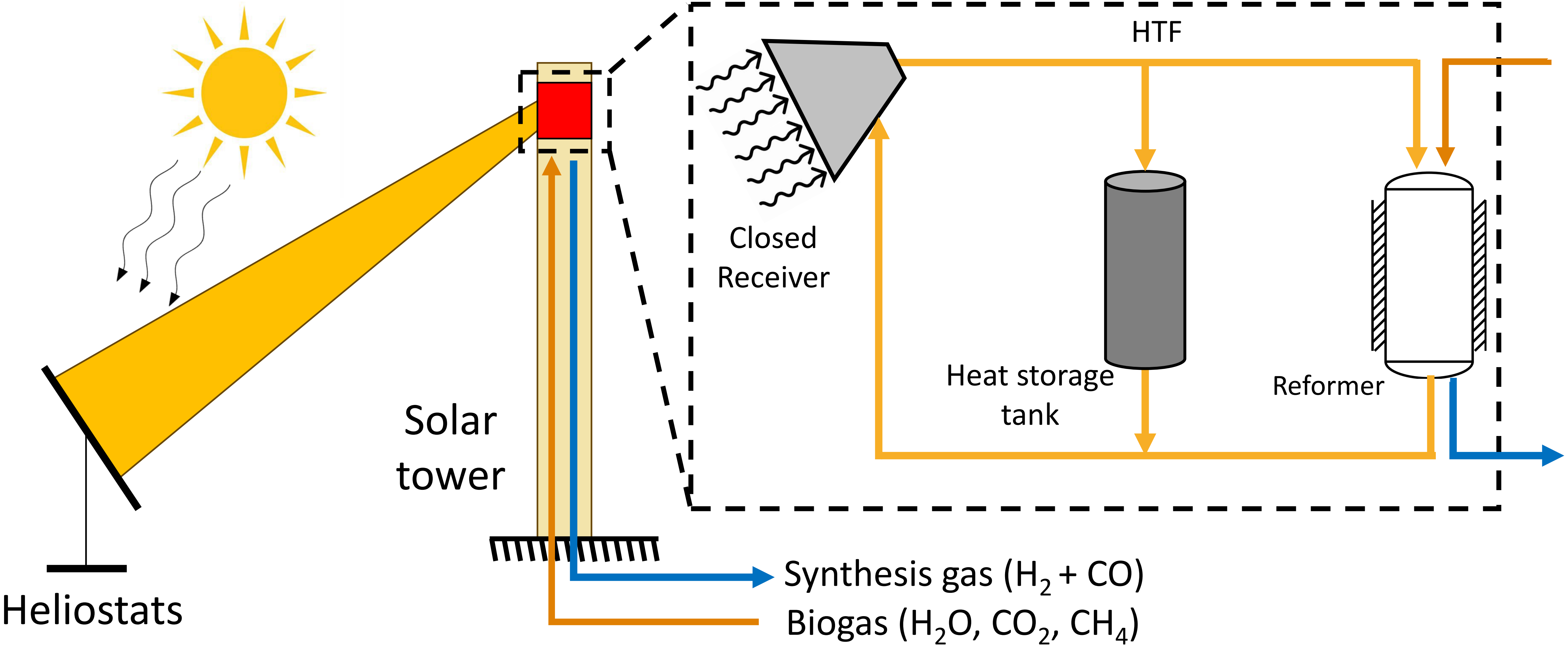
Standard Closed Receiver Solar Reforming



HTF

Closed Receiver

Heat storage tank

Reformer

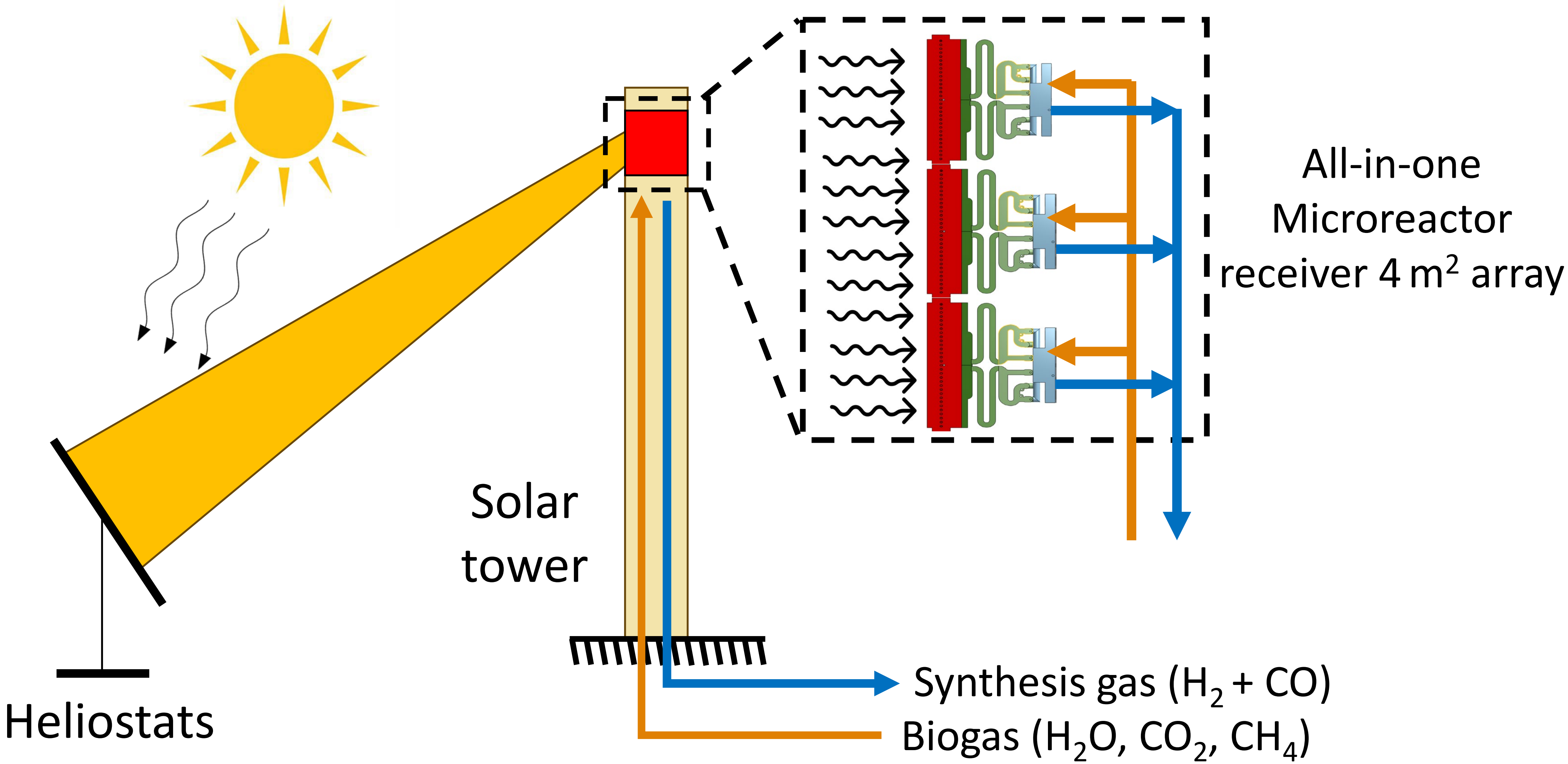
Solar tower

Heliostats

Synthesis gas (H_2 + CO)

Biogas (H_2O, CO_2, CH_4)

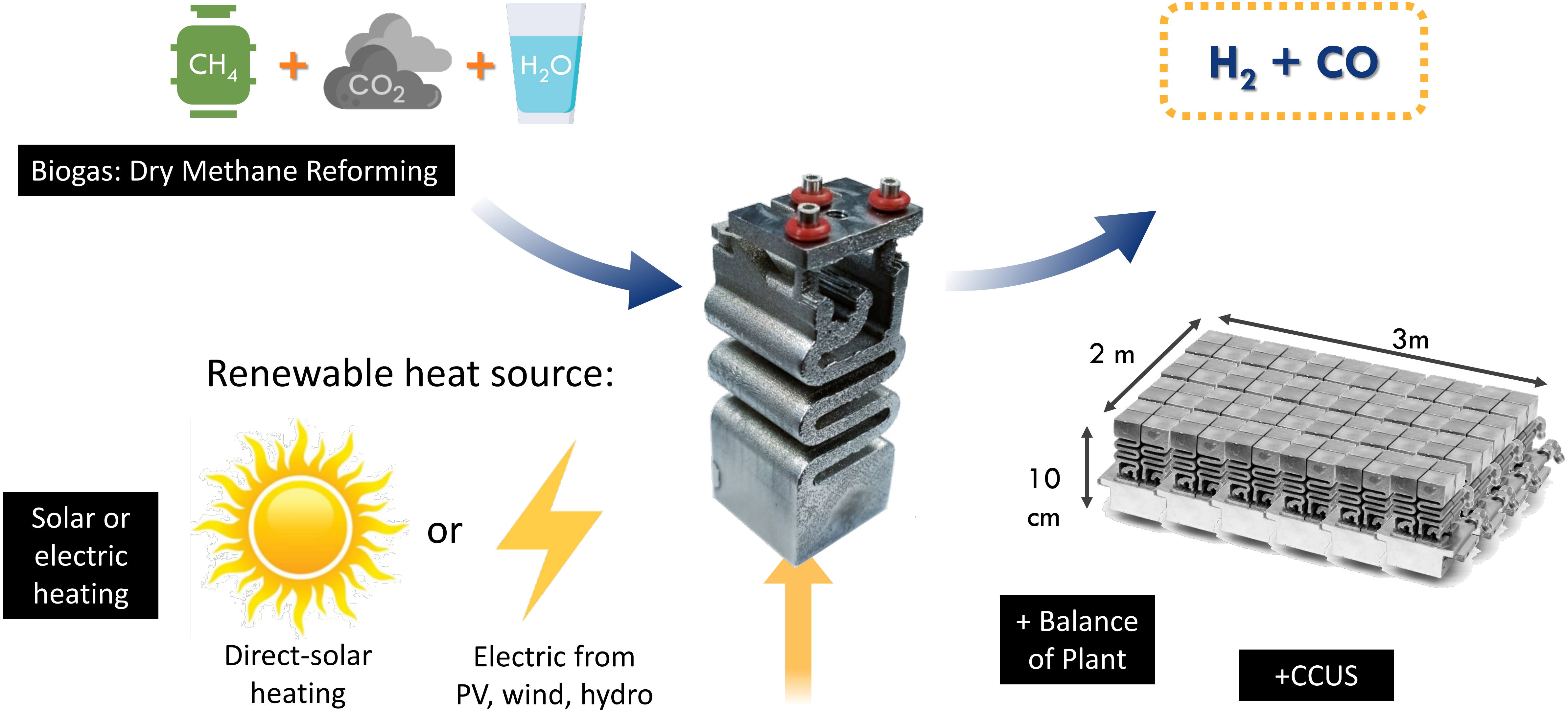
Reactor Matrix Solar Receiver microreactor concept from USherbrooke



Synthesis gas ($H_2 + CO$)

Biogas (H_2O, CO_2, CH_4)

Micro-reactor driven by renewable heat source



Biogas: Dry Methane Reforming

H_2 + CO

Renewable heat source:

Solar or electric heating

Direct-solar heating

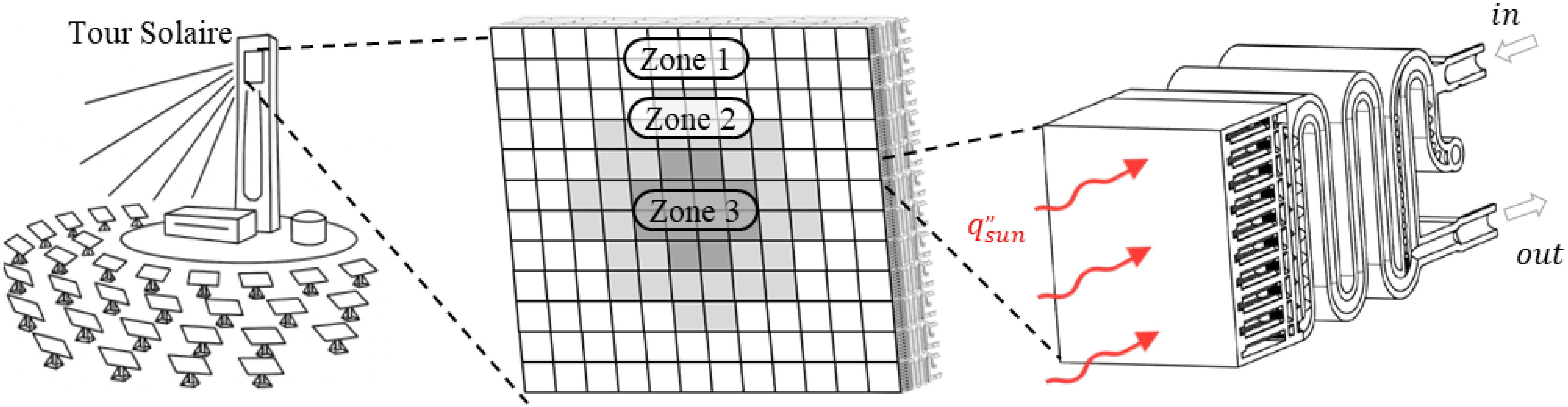
Electric from PV, wind, hydro

+ Balance of Plant

+CCUS

Matrix and reactor architecture

SOLARX



Solar tower

- What flux distribution can we get?

Reactor matrix

- How many zones do we need?
- What is the impact of the flux distribution?

Unitary reactor

- What is the best reactor architecture
- What is the reactor behaviour?

Advantages of the technology

High Performance:

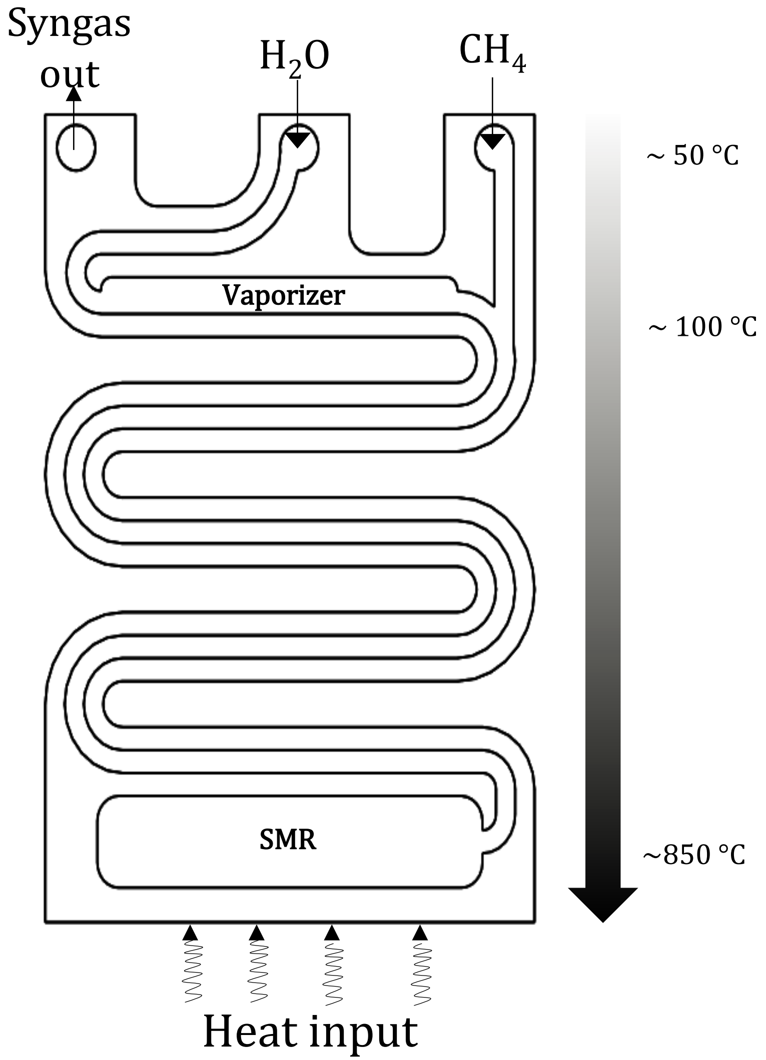
- Avoid combustion: no NOx, easy to seperate CO_2
- Can reach high process temperatures with minimal complexity and losses
- Process integration, allowing waste heat recovery for high efficiency

Practical Implementation:

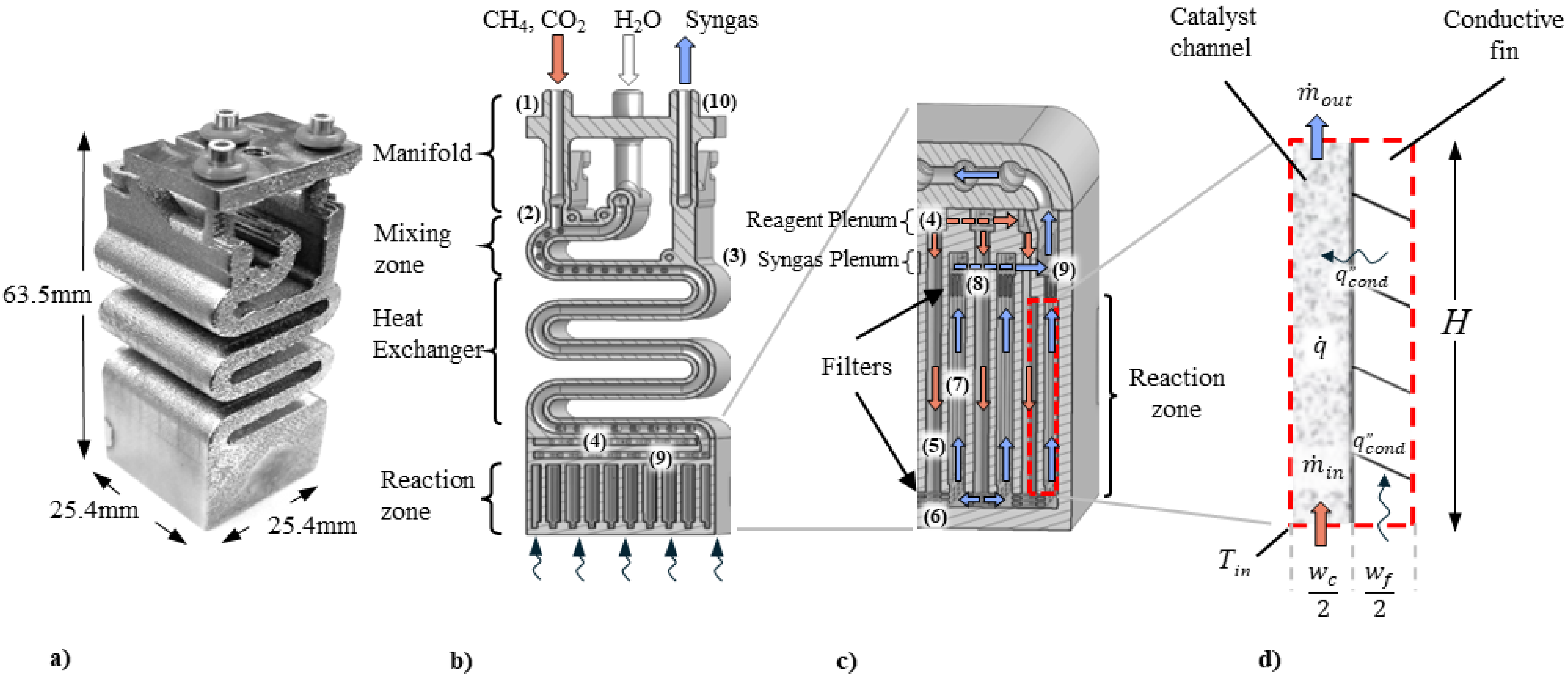
- Compact, with unprecedented power density
- Allow DMR, SMR and bireforming
- Scalable units from small to large scale (MW)
- Solar or electrical heat sources

Economical:

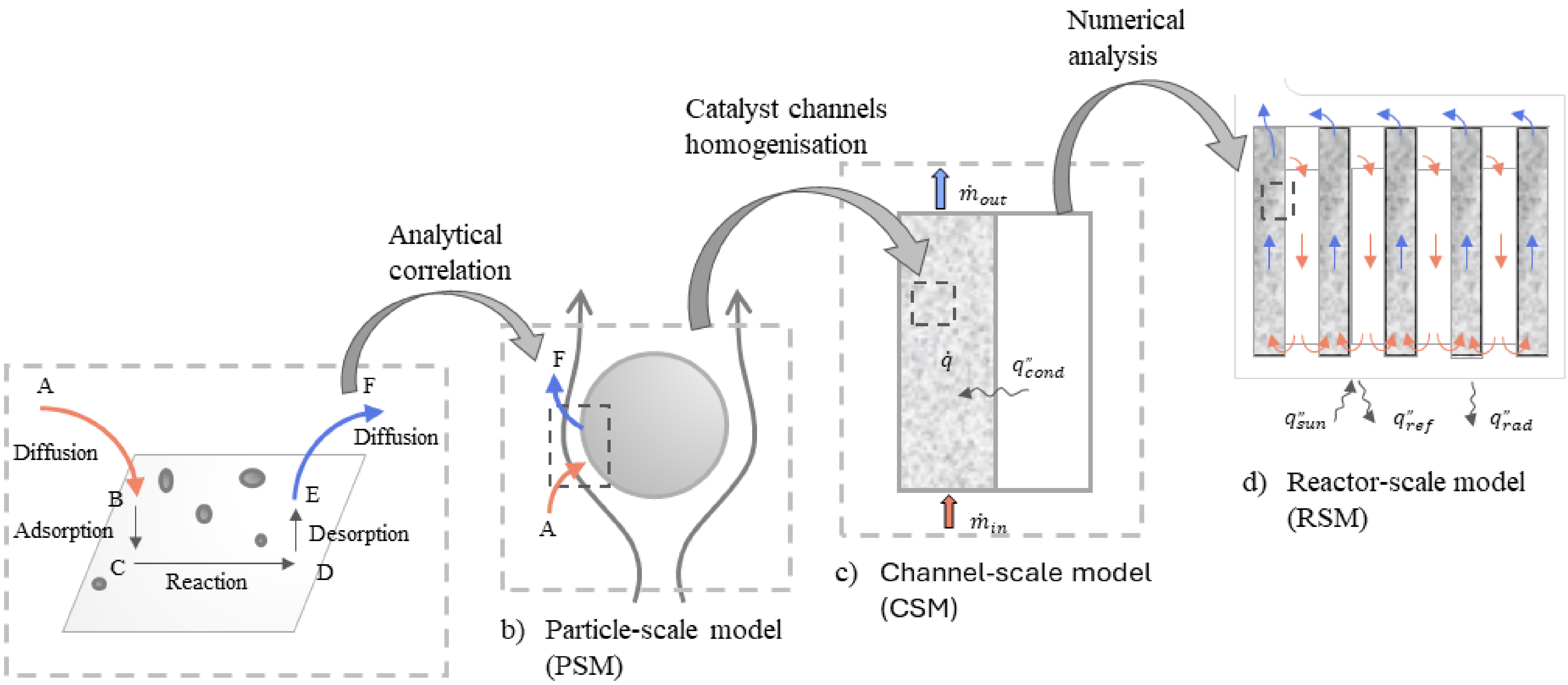
- Low cost, batch fabrication approach
- Maintenance without shutdown
- Low LCOE



Reactor architecture



Multi-Scale Modeling



a) Surface kinetics model (SKM)

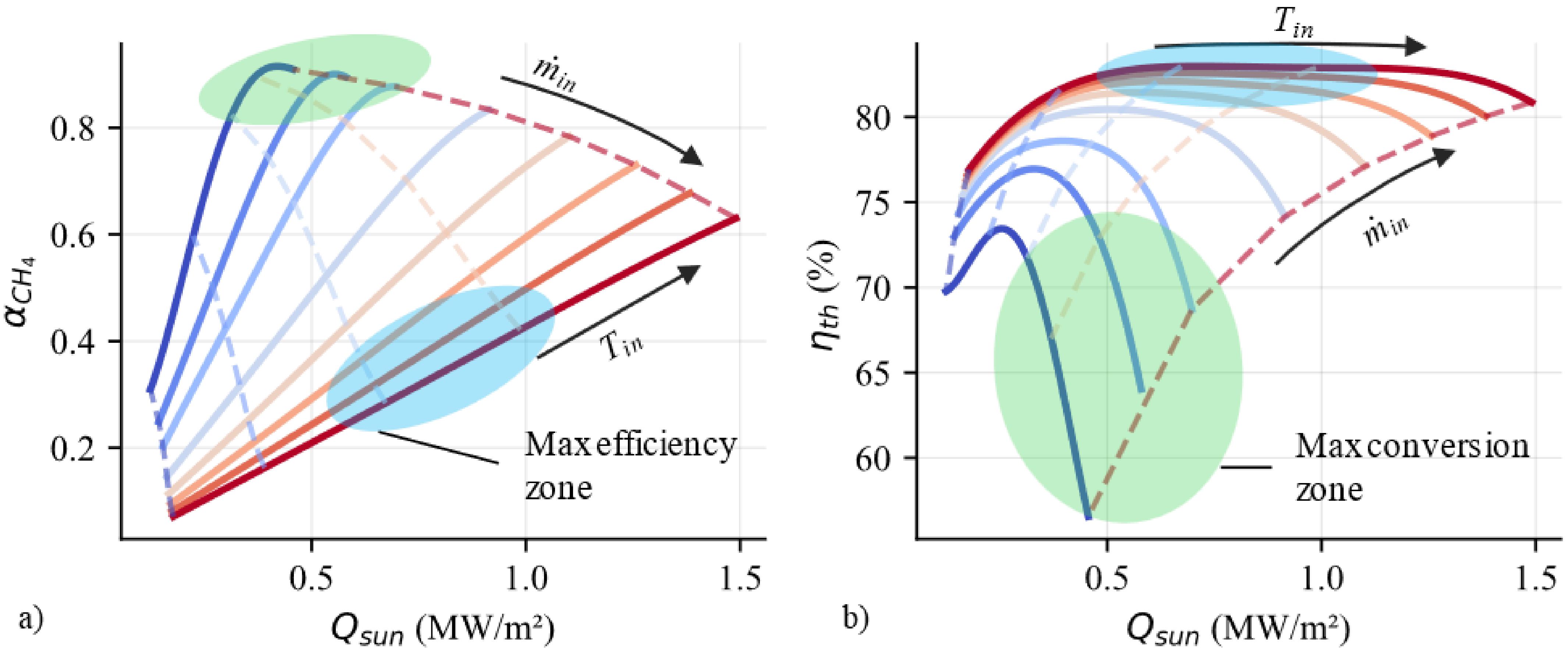
b) Particle-scale model (PSM)

c) Channel-scale model (CSM)

d) Reactor-scale model (RSM)

Best design behaviour

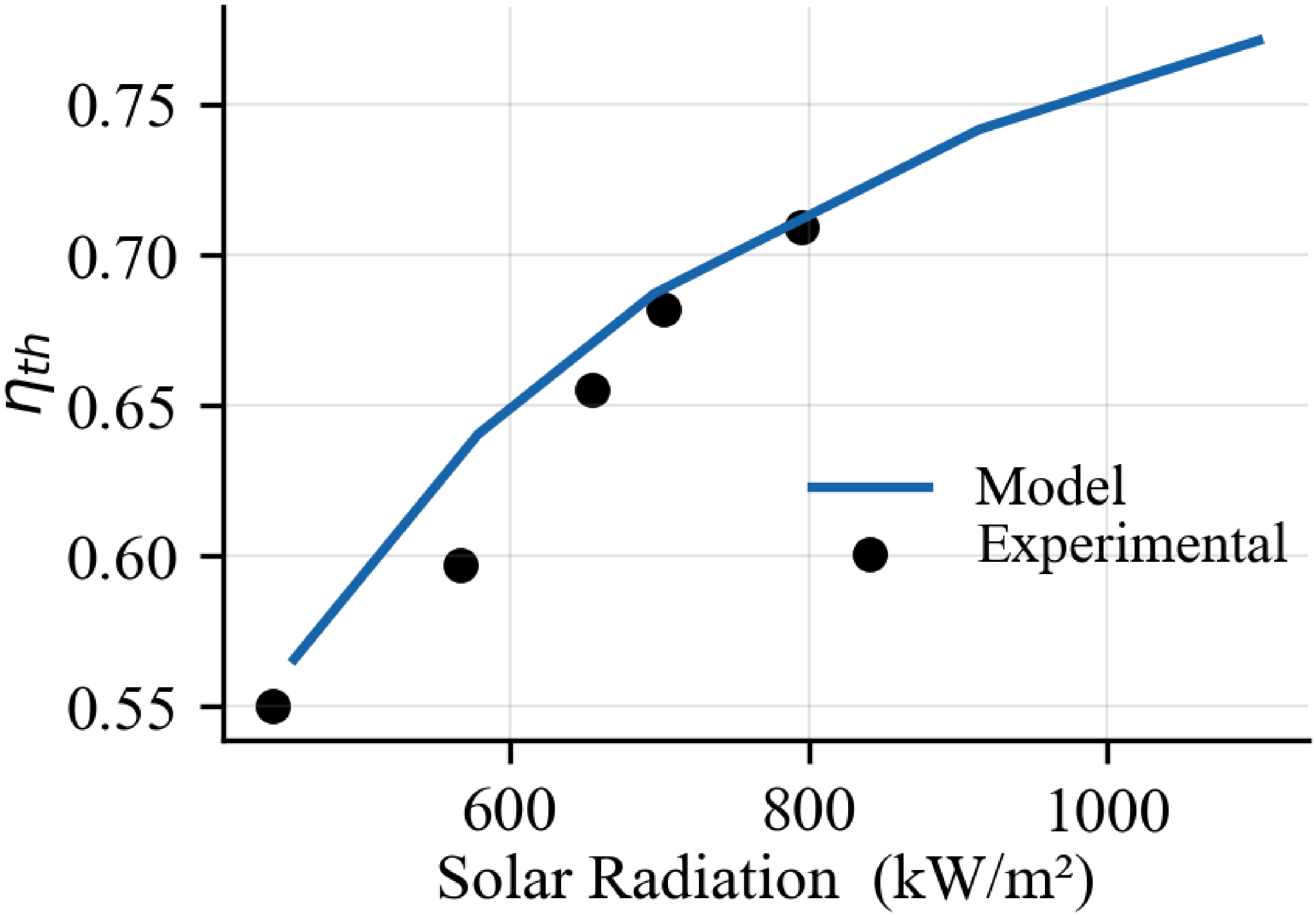
We now have modeled reactor behaviour to use for the thermal efficiency optimization



Model Validation

- Previous microreactor testing[1] used for model validation

- Increasing solar radiation improves thermal efficiency (Const. radidation loss, ↑heat consumption

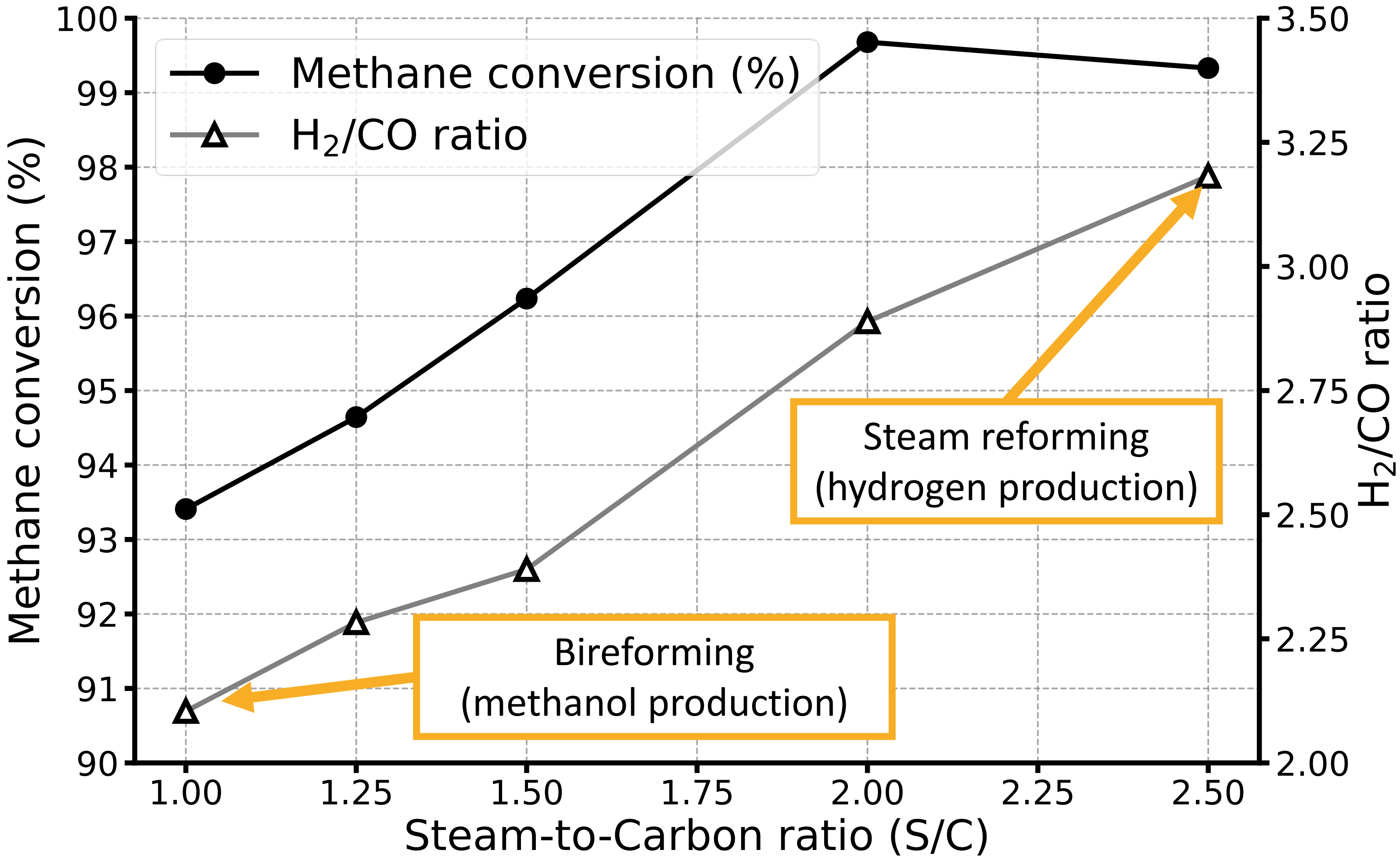


[1] Francoeur, D., Dufault , J.-F., Mehanovic, D., et Camus, P. « Solar Methane Reforming Microreactor Proof-Of-Concept With A 2X2 Array on a Full-Scale Dish ». *28th International Conference on Concentrating Solar Power and Chemical Energy Systems* 1 (janvier 2024). https://doi.org/10.52825/solarpaces.v1i.886.

Microreactor for various reforming regimes

Interesting characteristics:

- ➢ Short transient behavior after heat input change (< 5 min)
- ➢ Tunable H_2/CO syngas ratio :
  - Steam methane reforming (SMR)
  - Dry Methane Reforming (DMR)
  - Bireforming (SMR + DMR)

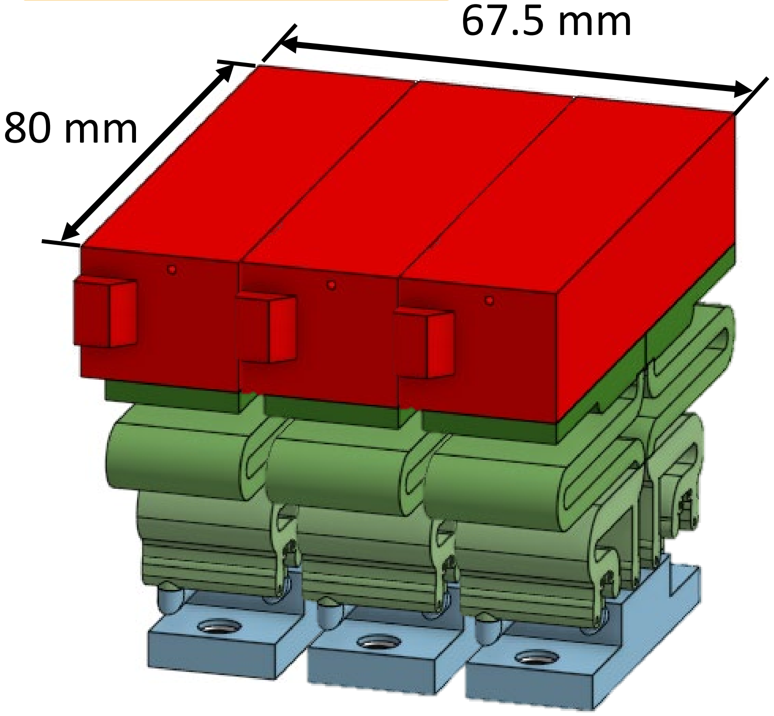


Steam reforming (hydrogen production)

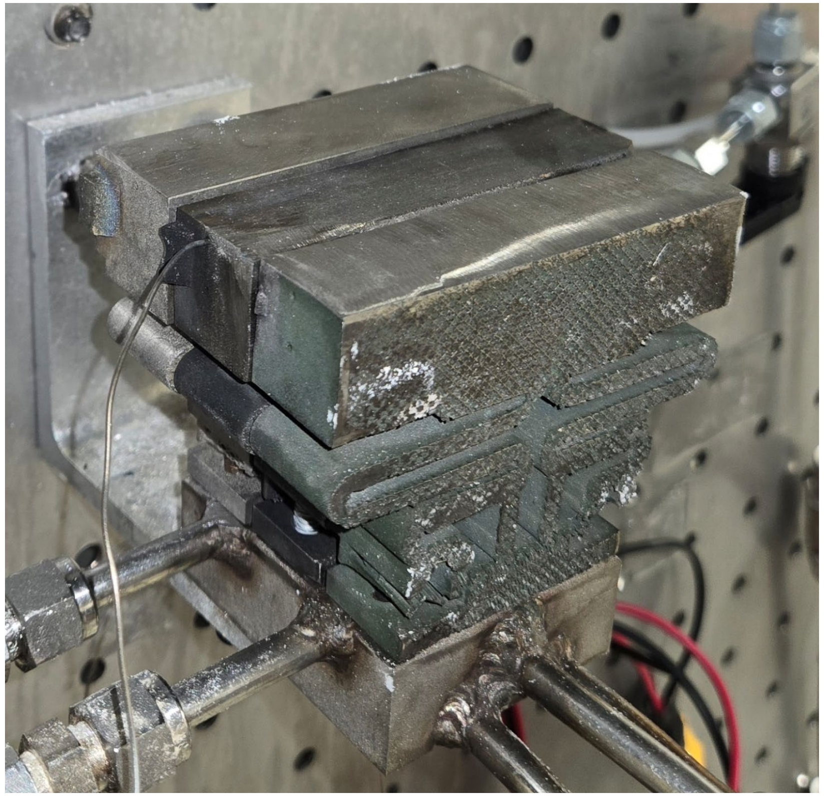
Bireforming (methanol production)

Microreactor Array Demonstration

54 cm^2 array



CAD view



Microreactor view

- Single flow control of parallelized microreactors
- Representative of a pixel in a receiver

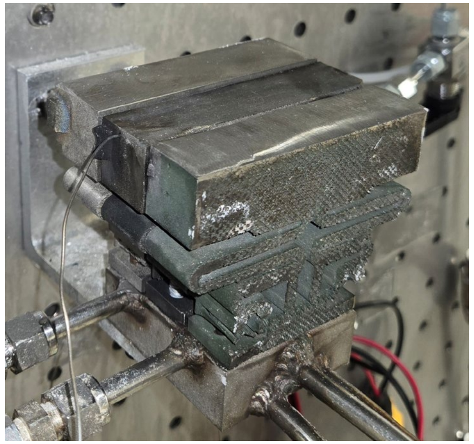
Reactor array results

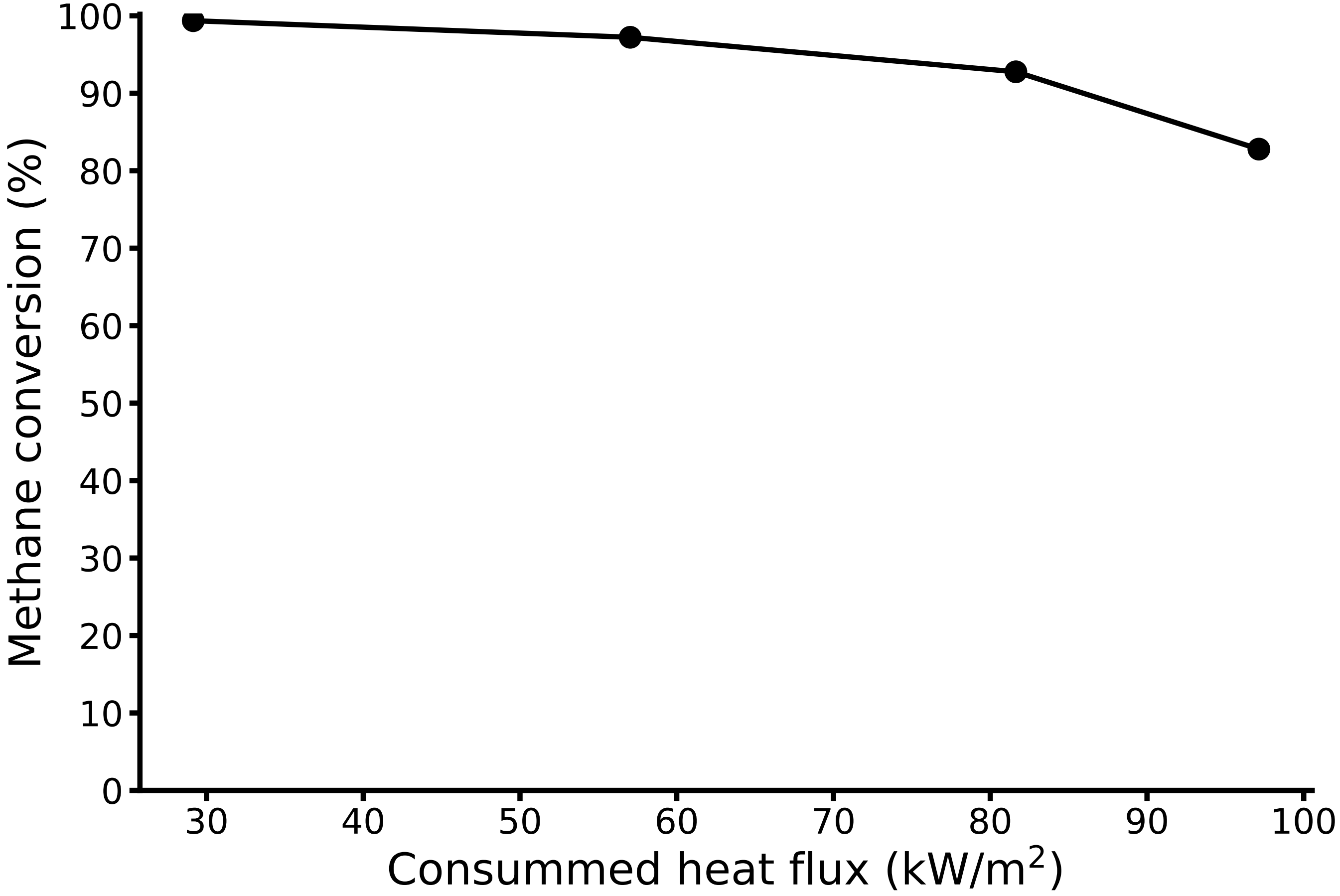
Tested by resistive heating

T = 850

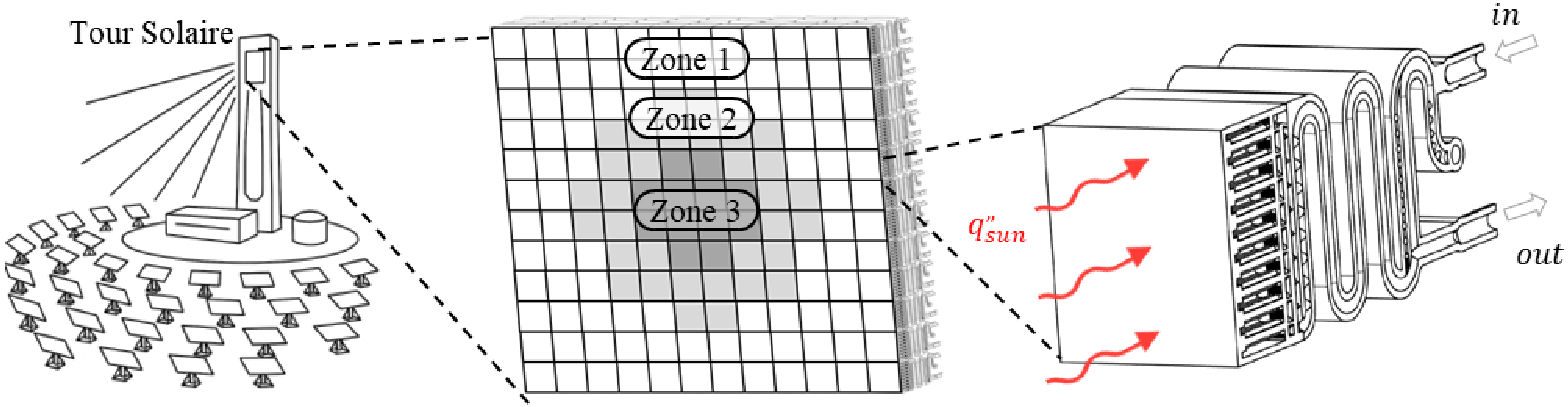
CO2 : H2O : CH4 = 1 : 2 : 3

WHSV = 10 000 – 40 000 mL/ g hr





Matrix and reactor architecture



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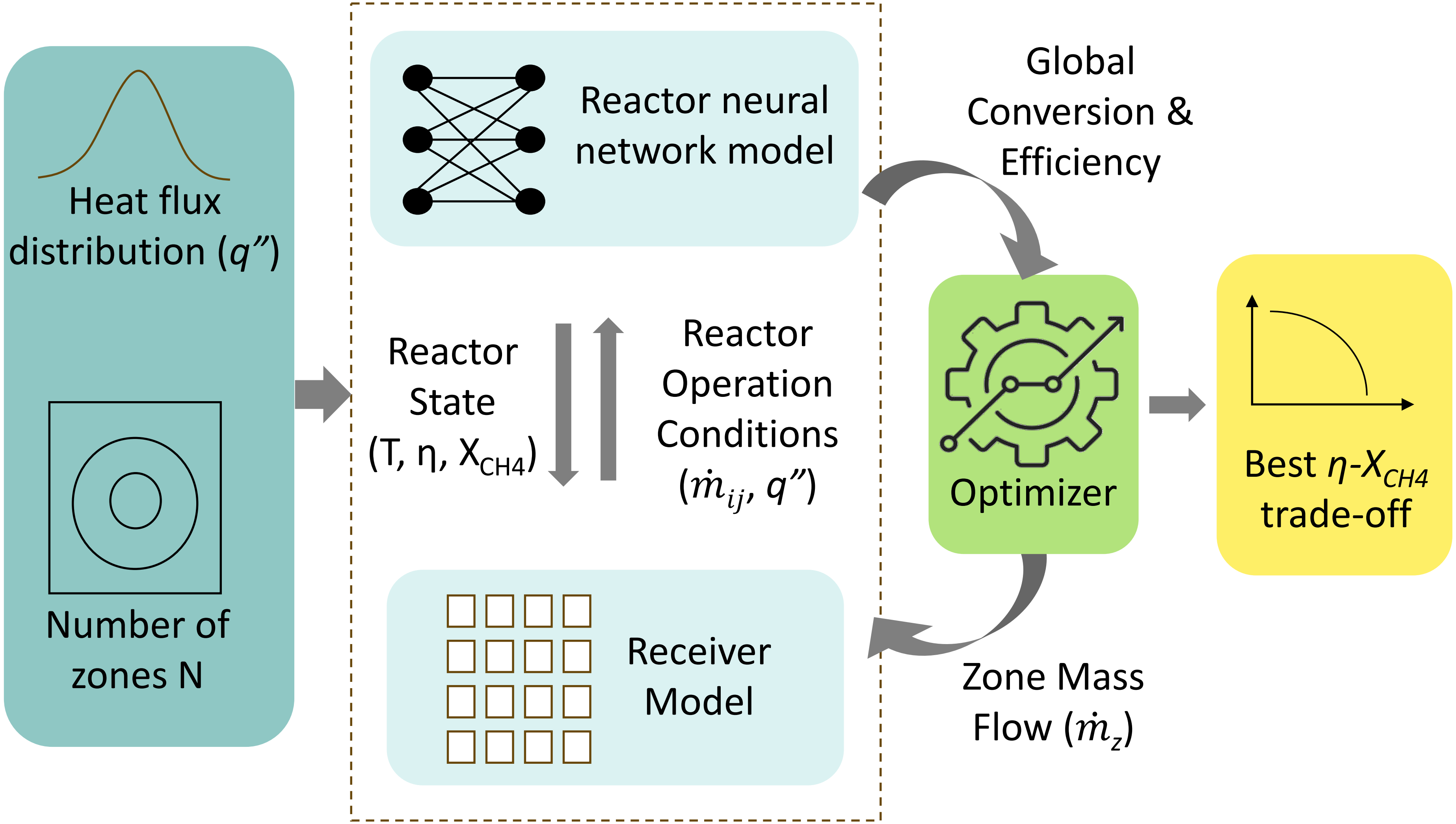
Optimization approach



Heat flux distribution (q'')

Number of zones N

Reactor neural network model

Reactor State (T, η, X_{CH4})

Reactor Operation Conditions ($\dot{m}_{ij}$, q'')

Receiver Model

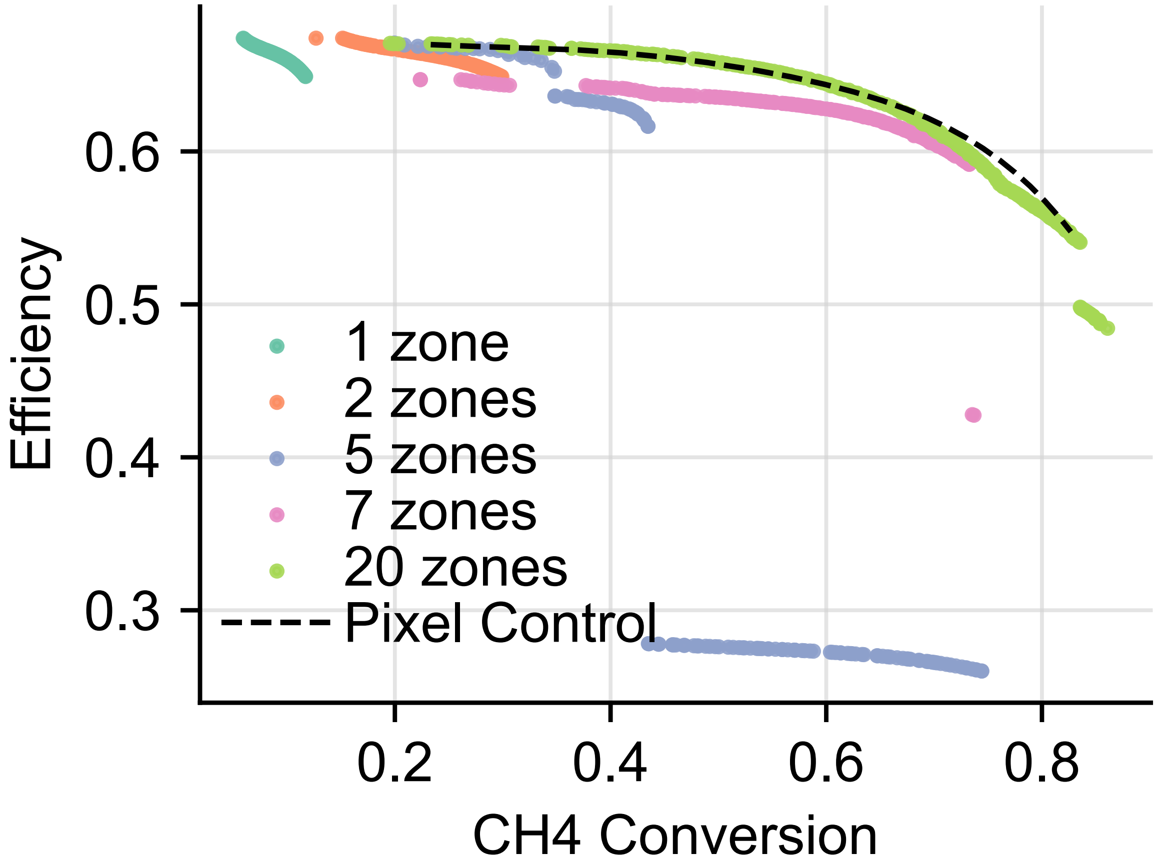
Global Conversion & Efficiency

Optimizer

Zone Mass Flow ($\dot{m}_z$)

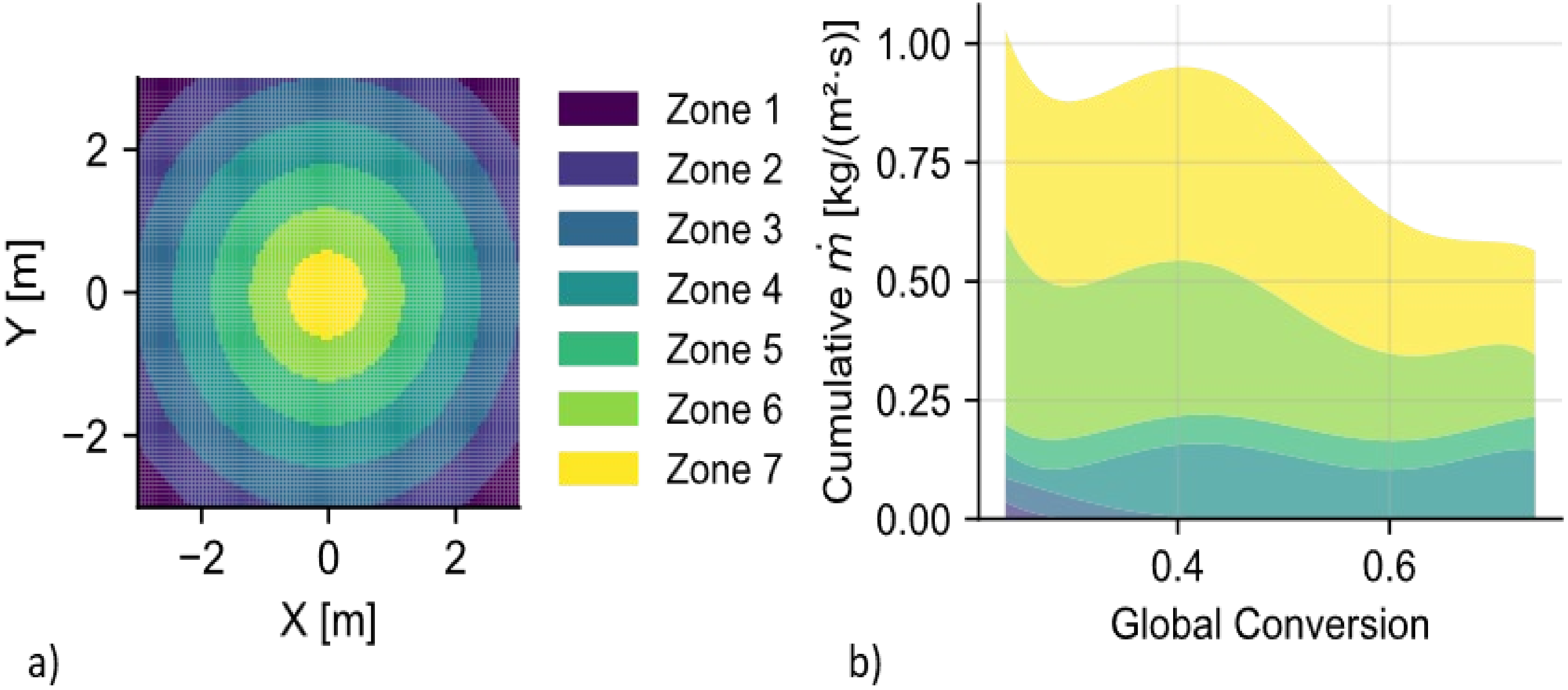
Best η-X_{CH4} trade-off

Pareto Front (Best Efficiency-Conversion Trade-Off)



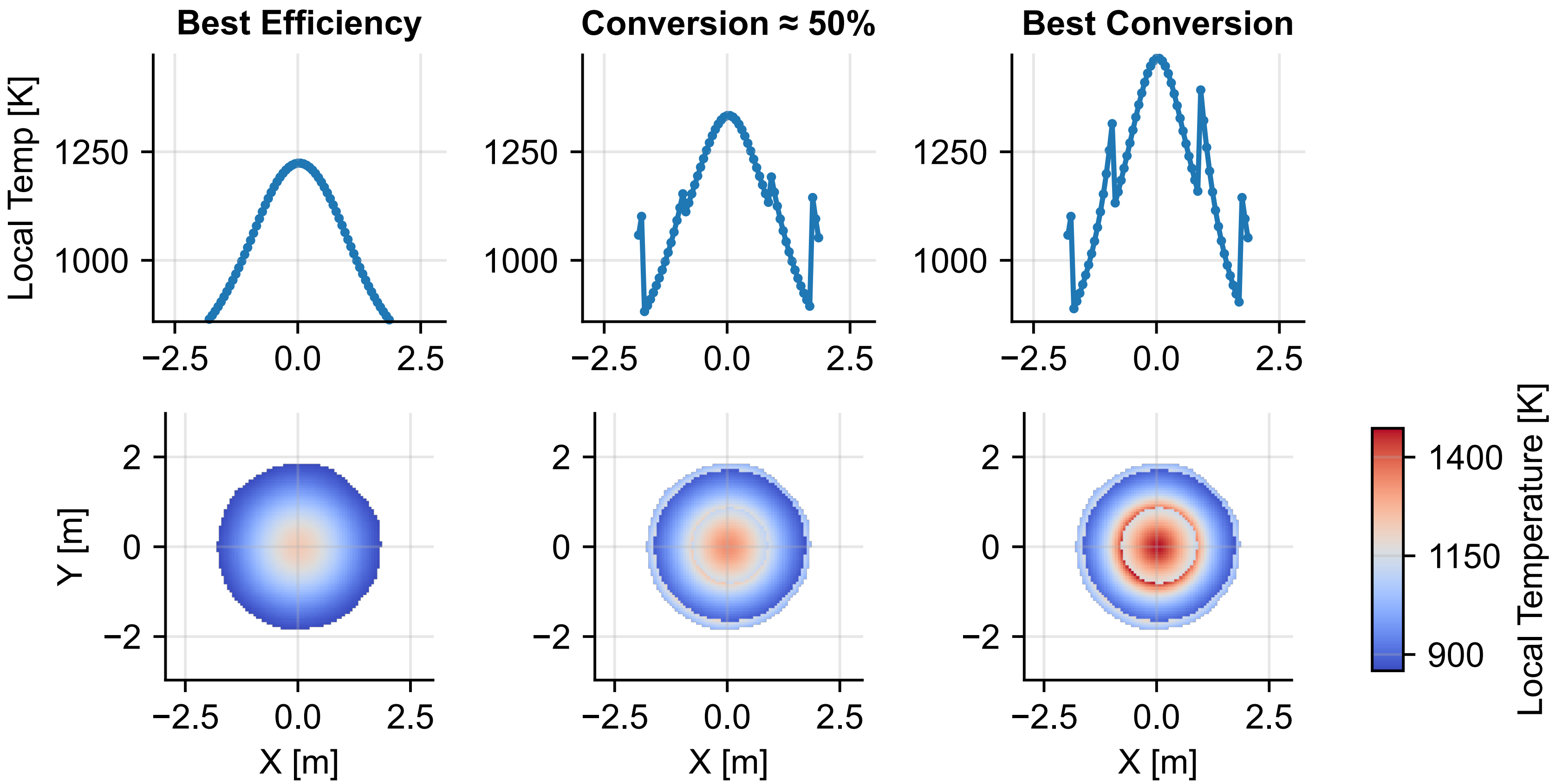
Efficiency vs. CH_4 conversion Pareto fronts for various number of zones. Maximum efficiency is similar at low conversion due to flow saturation. Higher zone counts improve performance, approaching pixel-level control.

Mass Flow Distribution for Optimal Operation points (pareto front)



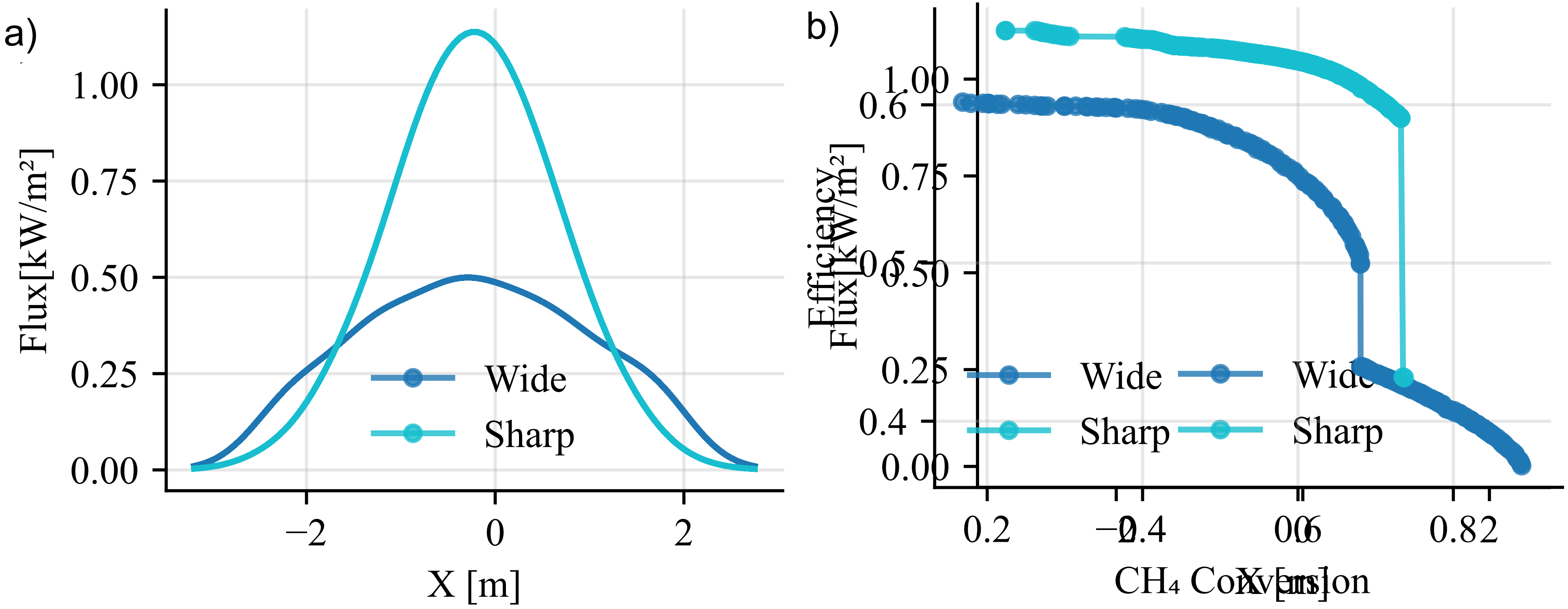
7-zones receiver partition and b) allocated flow for each point of the pareto front of

Receivers Temperature Profile For Three Different Optimal Solutions



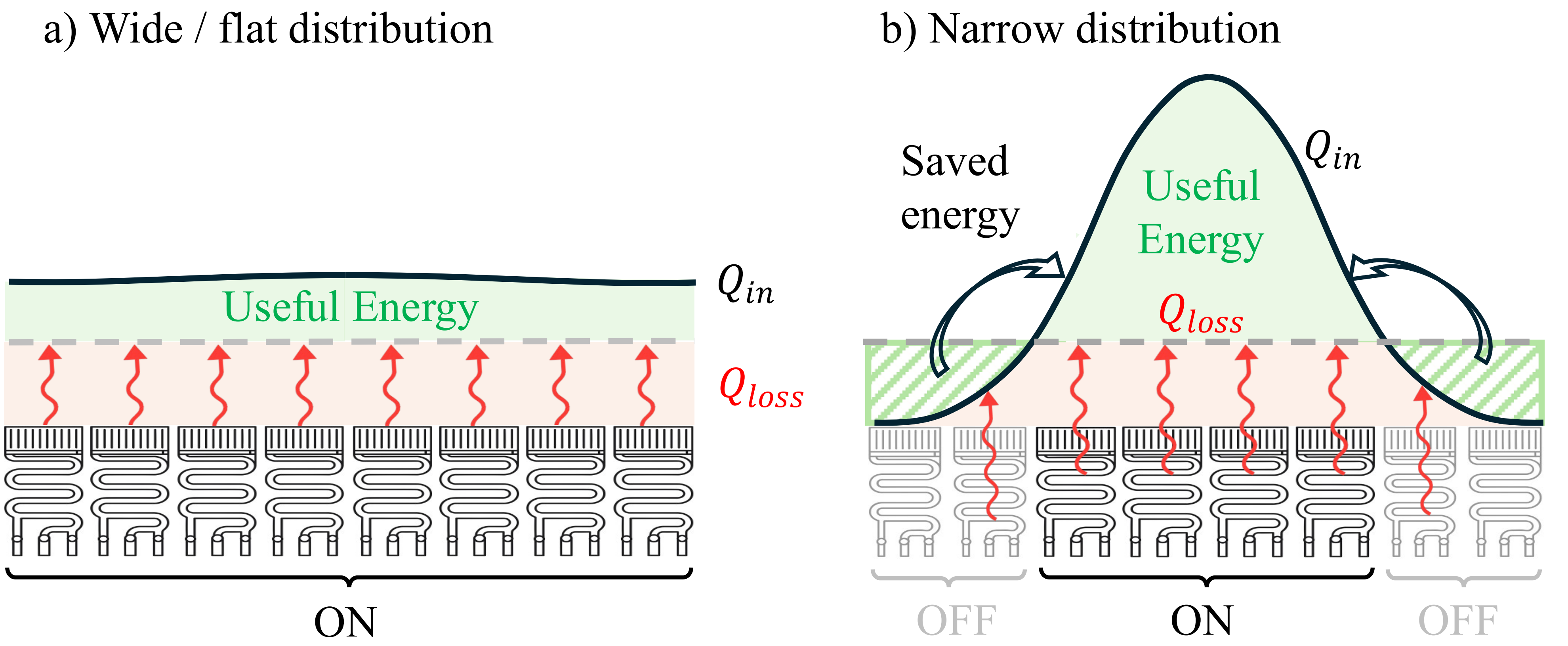
Temperature centerlines (Y=0) and maps for 3 points of the Pareto front: best efficiency, at 50% conversion, and best conversion.

Flux Distribution Impact



a) Centerline heat-flux profiles comparing the two distributions. (b) Efficiency-conversion trade-off achievable with zonal control under different flux profiles for 7 zones.

Flux distribution impact



Conceptual illustration of energy use: (a) Wide profiles distribute heat uniformly, but with more losses. (b) Narrow profiles enable selective activation and energy savings.

Conclusions

- Successful demonstration of microreactors performance
- Successful demonstration of the array architecture
- Modeled and optimized approach for temperature control
- High conversion-efficiency trade-off

Communicatons

1. Dufault et al. Modeling Of An High-Concentration Solar Reactor for Dry Methane Reforming, SolarPaces Proceedings. 2024.
2. Dufault et al., 80x80 Matrix Micro-Reactor Receiver Control Approach for High Efficiency and Conversion Dry Methane Reforming
3. Désilet et al. Dry methane reforming Ni catalyst regeneration supported by thermodynamic predictions. Presented at Solar Paces 2026.
4. Dufault et al. Localized-Flow Control for Performance Optimization of a Microreactor-Matrix Solar Methane-Reforming Receiver. Applied Thermal engineering. Under review. 2025.
5. Dufault et al. Thermochemical Modeling of a High-Concentration Solar Mi-cro-Reactor for Dry Methane Reforming. International Journal of Hydrogen Energy. Under review. 2025.
6. Riva et al. Modeling Of An High-Concentration Solar Reactor for Dry Methane Reforming. Written for Solar Paces 2026.