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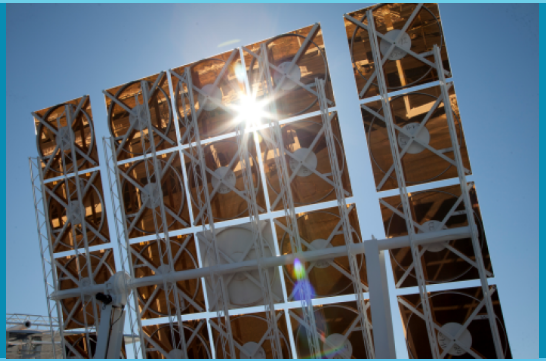
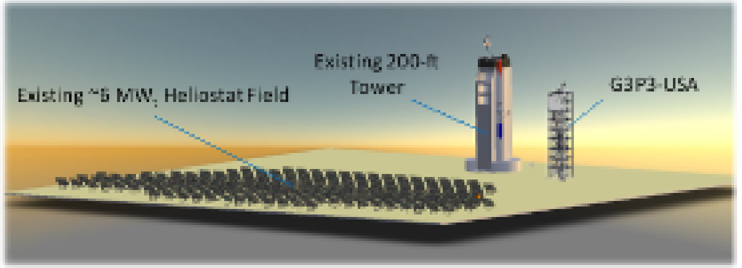


Computational Fluid Dynamics Modeling of Solar Thermal Dry Reforming of Methane in a Parabolic Trough



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Introduction

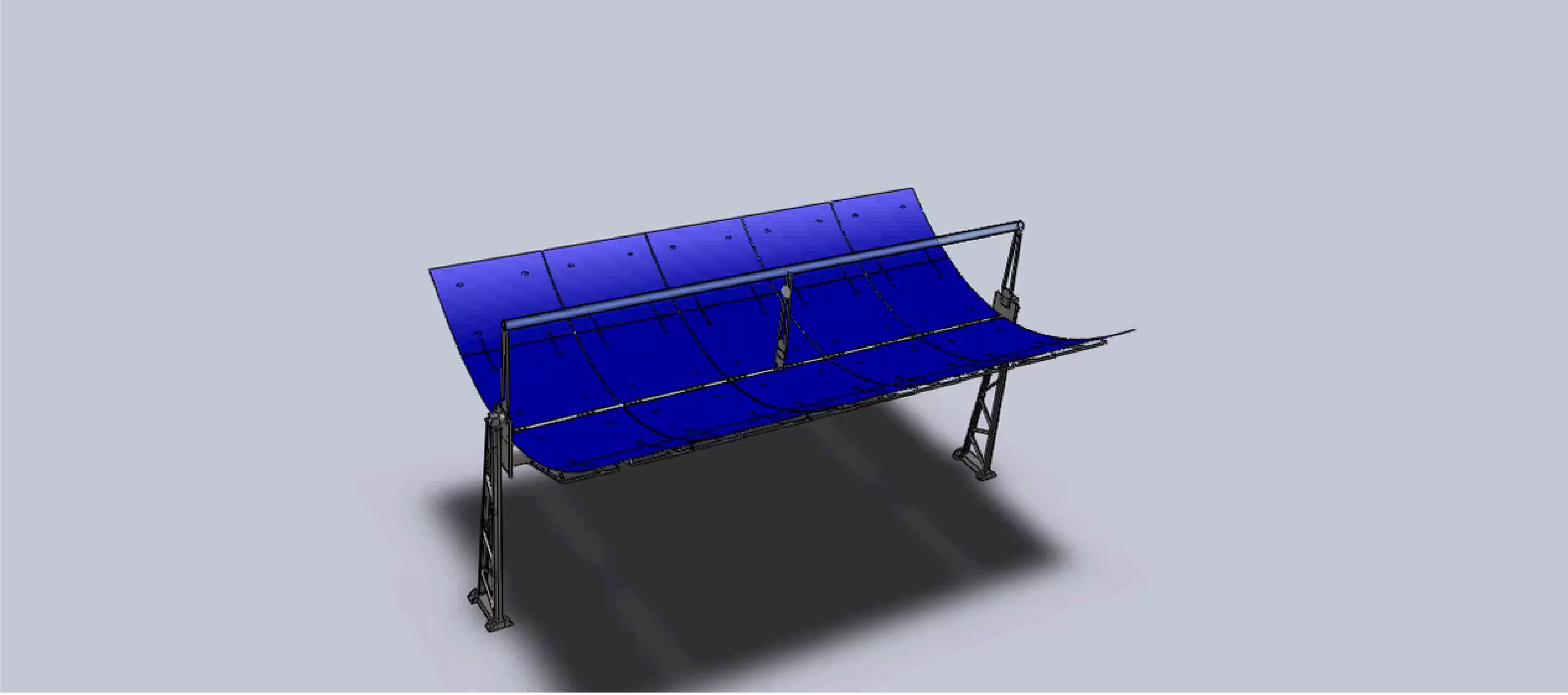
- Flaring (or combustion) of natural gas occurs during production and extraction of oil from the subsurface
- Due to the expense of current techniques used to capture or recover the natural gas, the gas is often burned for safety, economic, or operational reasons
- Global flaring results in ~300 – 600 million metric tons of CO_2 being emitted into the atmosphere annually

Objectives

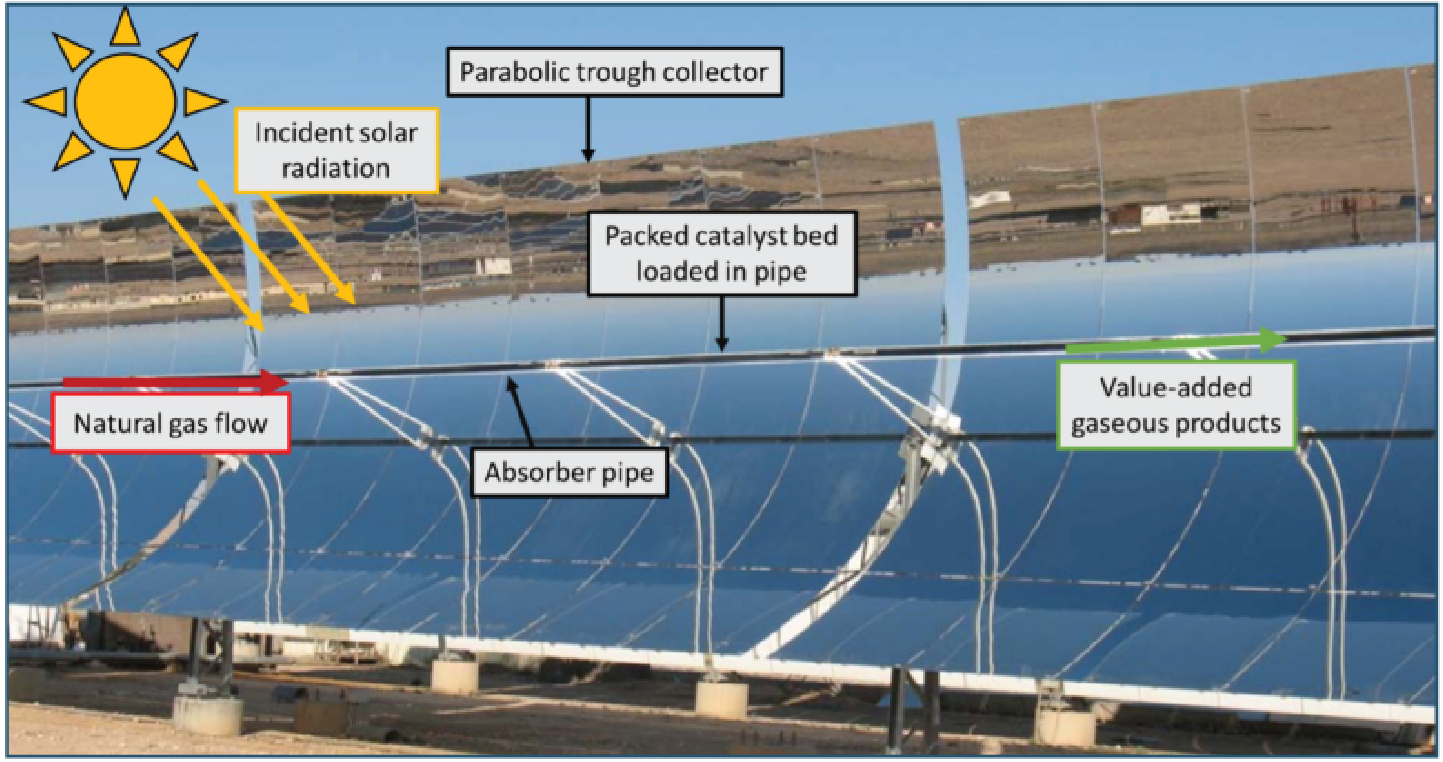
- Develop a solar-thermal system to process natural gas currently wasted at extraction sites through routine flaring
- Use compositionally complex, multi-cationic aluminate spinel catalysts to convert $CH_4 + CO_2$ to $H_2 + CO$
- Use a trough-type collector to concentrate and direct sunlight onto a specially designed tube reactor to heat the contained catalyst to relevant reaction temperatures (700 °C – 800 °C)
  - Mobile design
  - Identify configurations to achieve desired temperatures

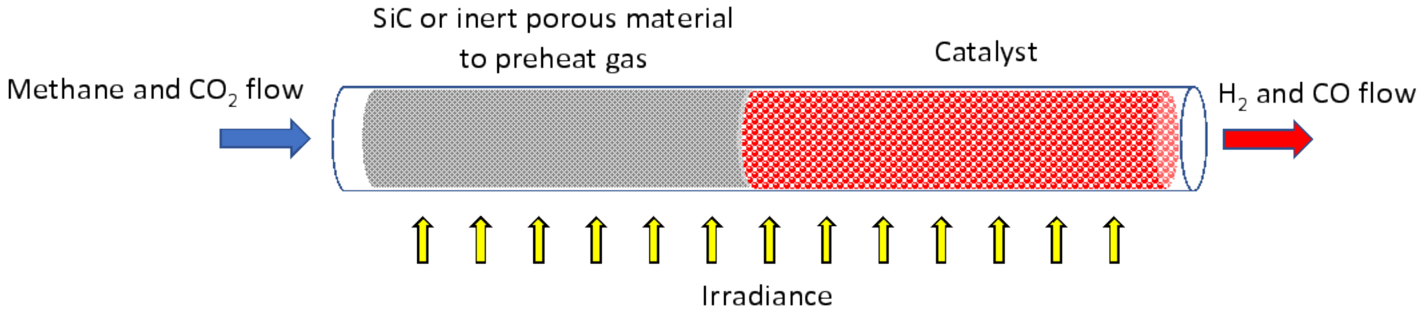
Parabolic Trough Configuration

LS-2 Parabolic Trough



Solar Thermal Dry Reforming of Methane

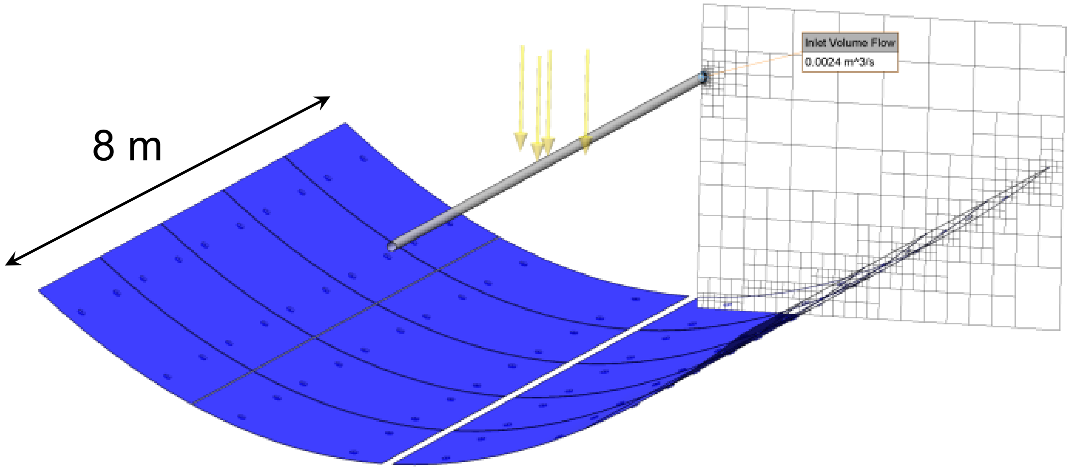


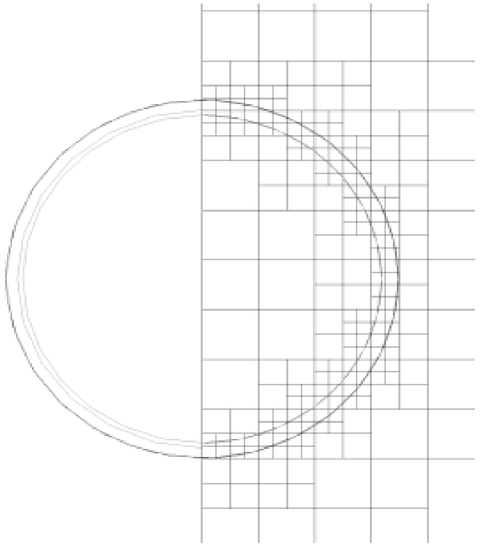


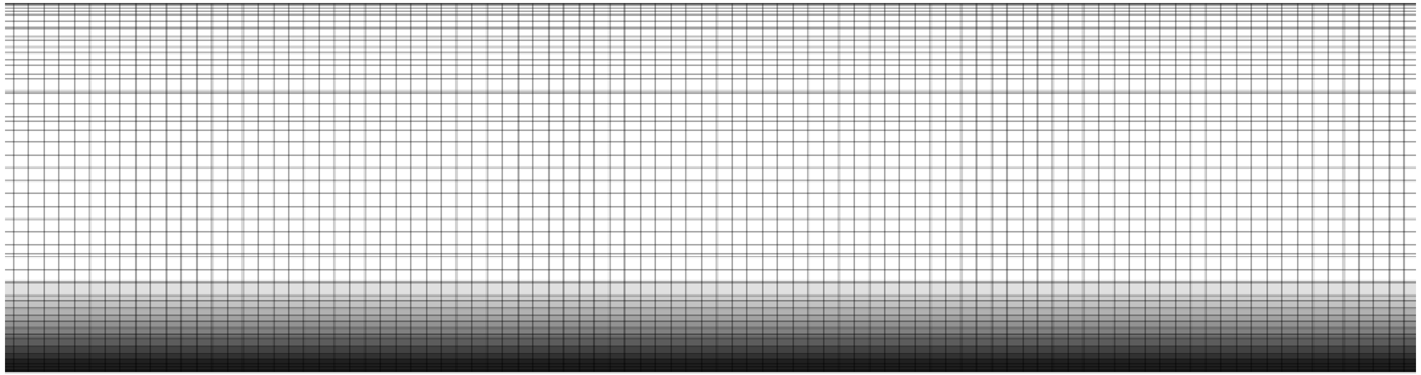
Computational Fluid Dynamics (CFD) Modeling

Solidworks Flow Simulation Summary
CFD model employs half-symmetry

LS-2 collector from SEGS plant





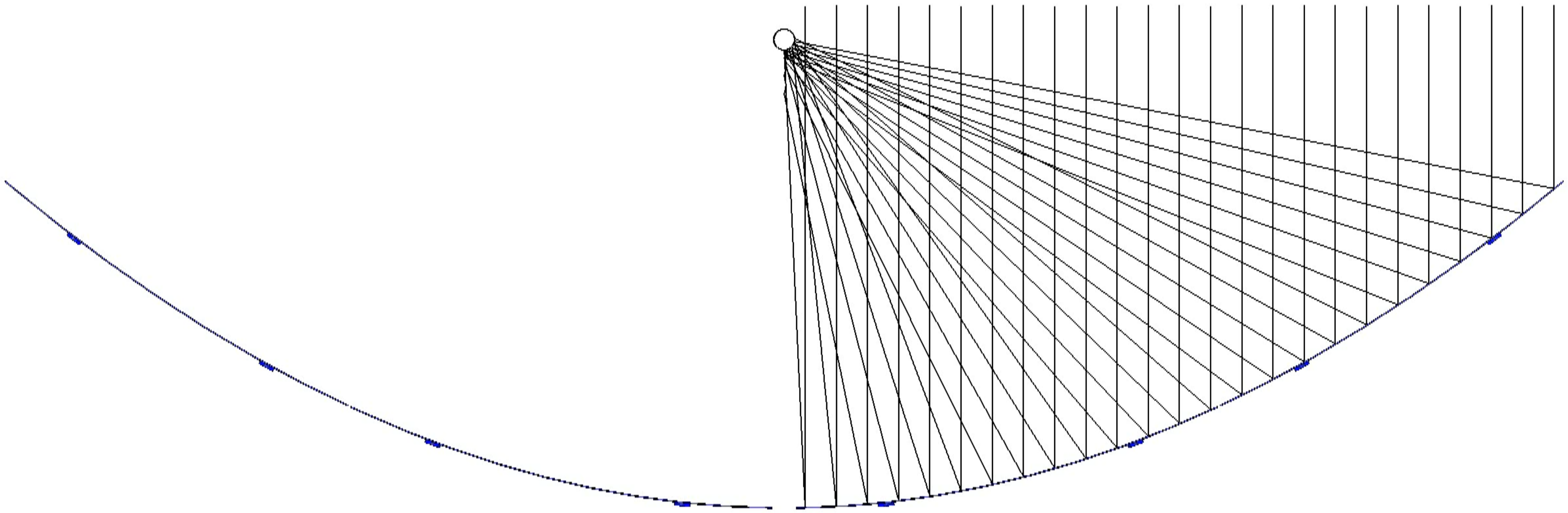


Assumptions

- Product of the heat of reaction (259 kJ/mol) and molar flow rate of each reactant gas used to determine thermal power (heat sink) required for the reaction
  - The kinetics of reaction are neglected
  - Reaction assumed to be complete within the prescribed catalyst bed
- The solar irradiance on the parabolic-trough collector was 1000 W/m^2 with a normal incidence angle and 94% collector reflectivity
- Both radiative ($\alpha = \varepsilon = 0.9$) and convective heat loss from the receiver were simulated under quiescent conditions

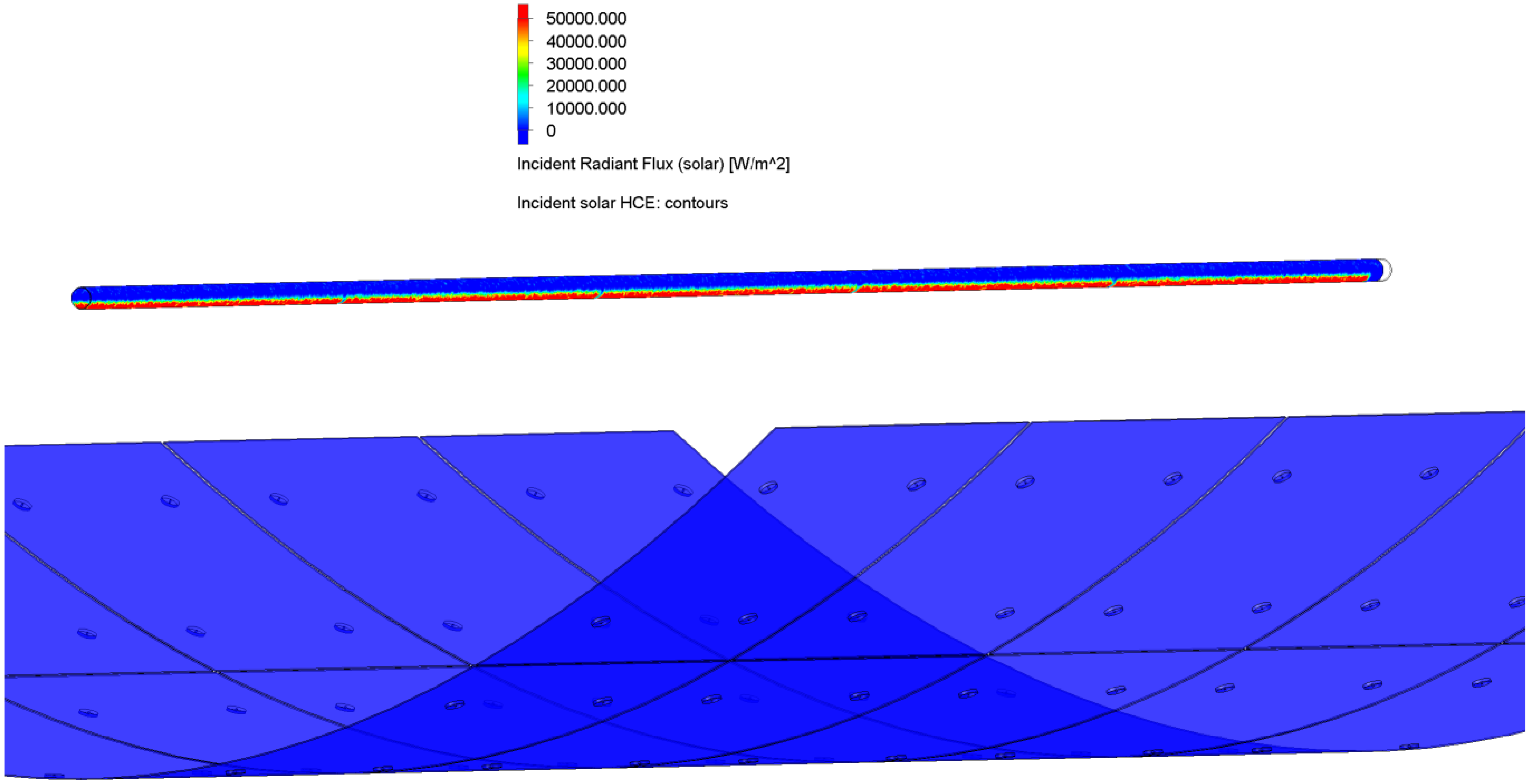
Optical Analysis

Solar Ray Tracing



Optical intercept factor = 0.97 – 0.98

Incident solar radiation on receiver tube



CFD Results

Parametric Analysis

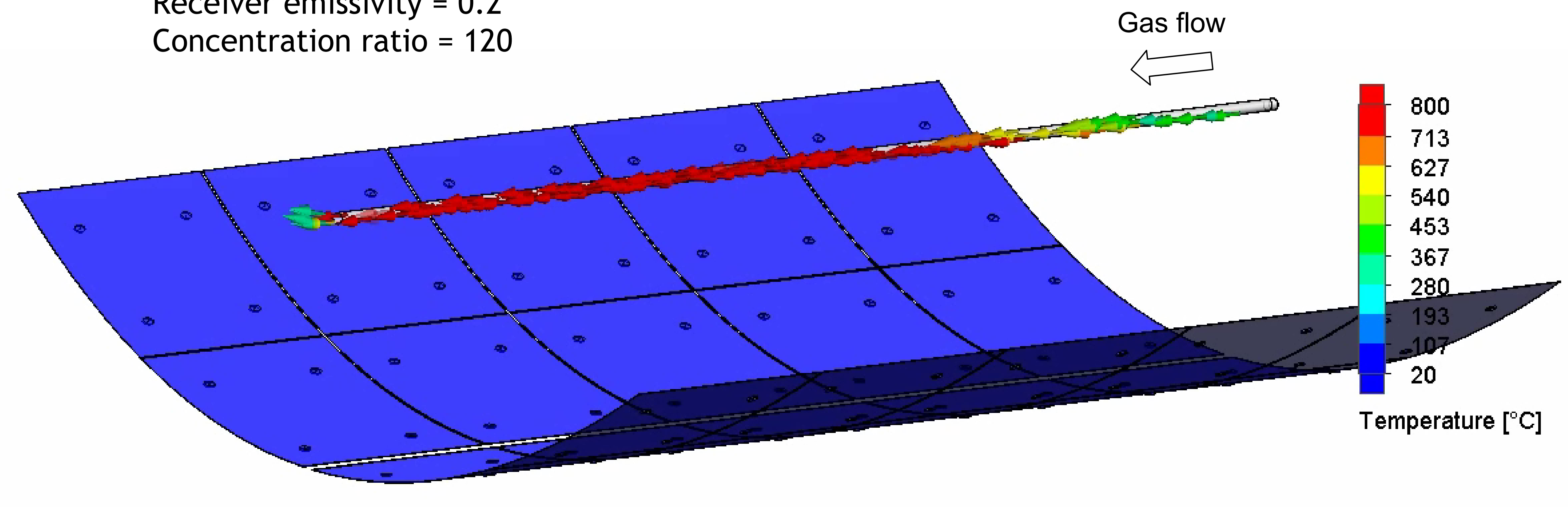
Run	Gas Flow Rate (cfm)*	Receiver Emissivity	Concentration Ratio**	Bulk Average Catalyst Temperature (°C)
1	1	0.9	~70	444
2	10	0.9	~70	353
3	1	0.2	~70	688
4	10	0.2	~70	556
5	1	0.9	~120	558
6	10	0.9	~120	497
7	**1**	**0.2**	**~120**	**876**
8	**10**	**0.2**	**~120**	**777**

*1 cfm = 0.000472 m^3/s

**Trough apertures of 5 m and 8.4 m yield geometric concentration ratios of ~70 and ~120, respectively, with a receiver tube diameter of 0.07 m.

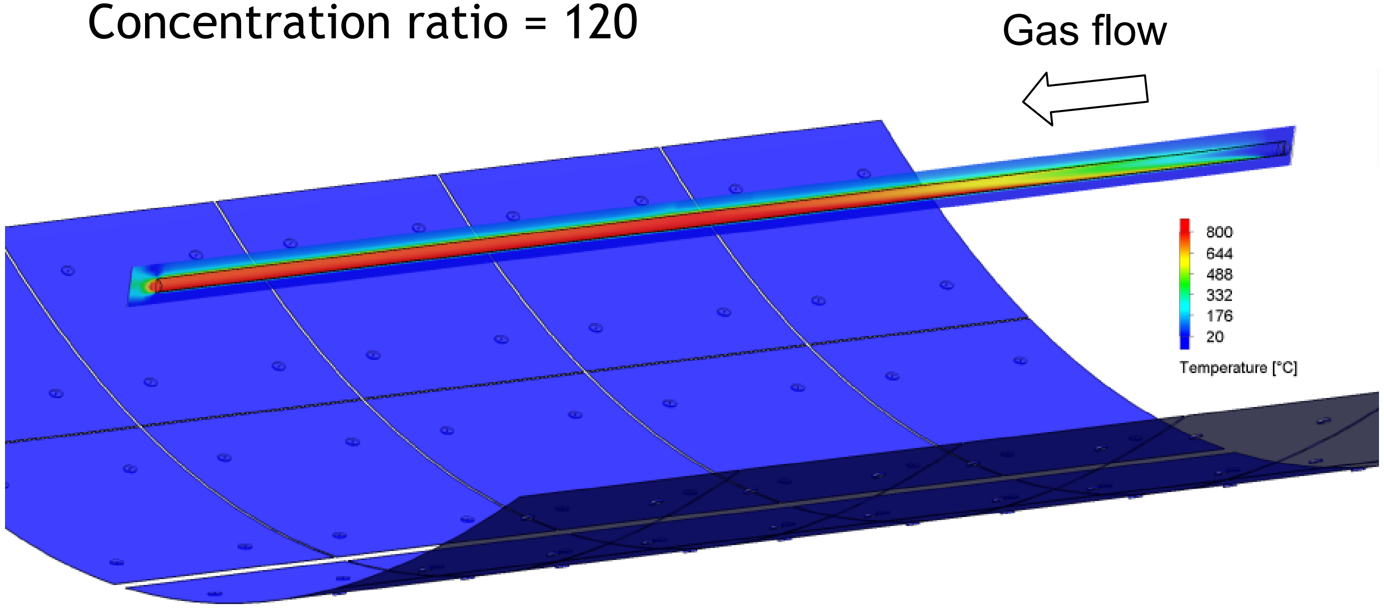
Gas flow trajectories colored by temperature

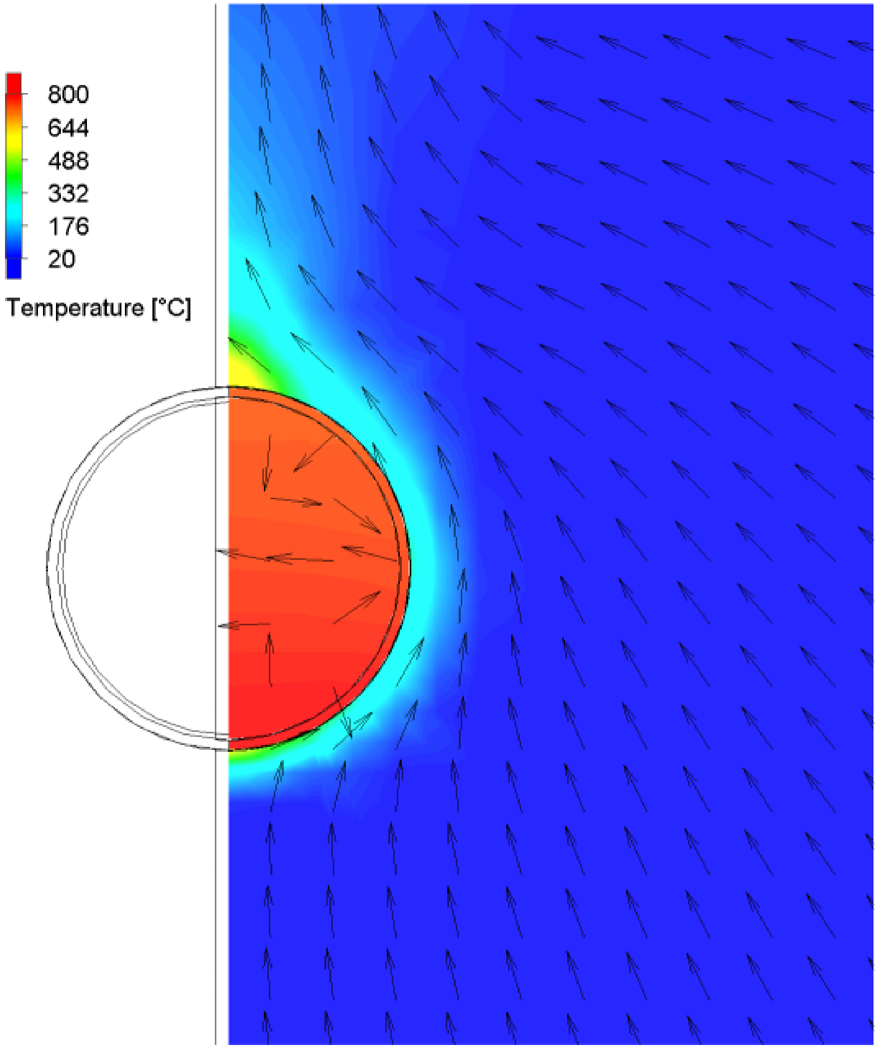
Gas flow rate = 10 cfm
Receiver emissivity = 0.2
Concentration ratio = 120



Temperature profile within receiver tube

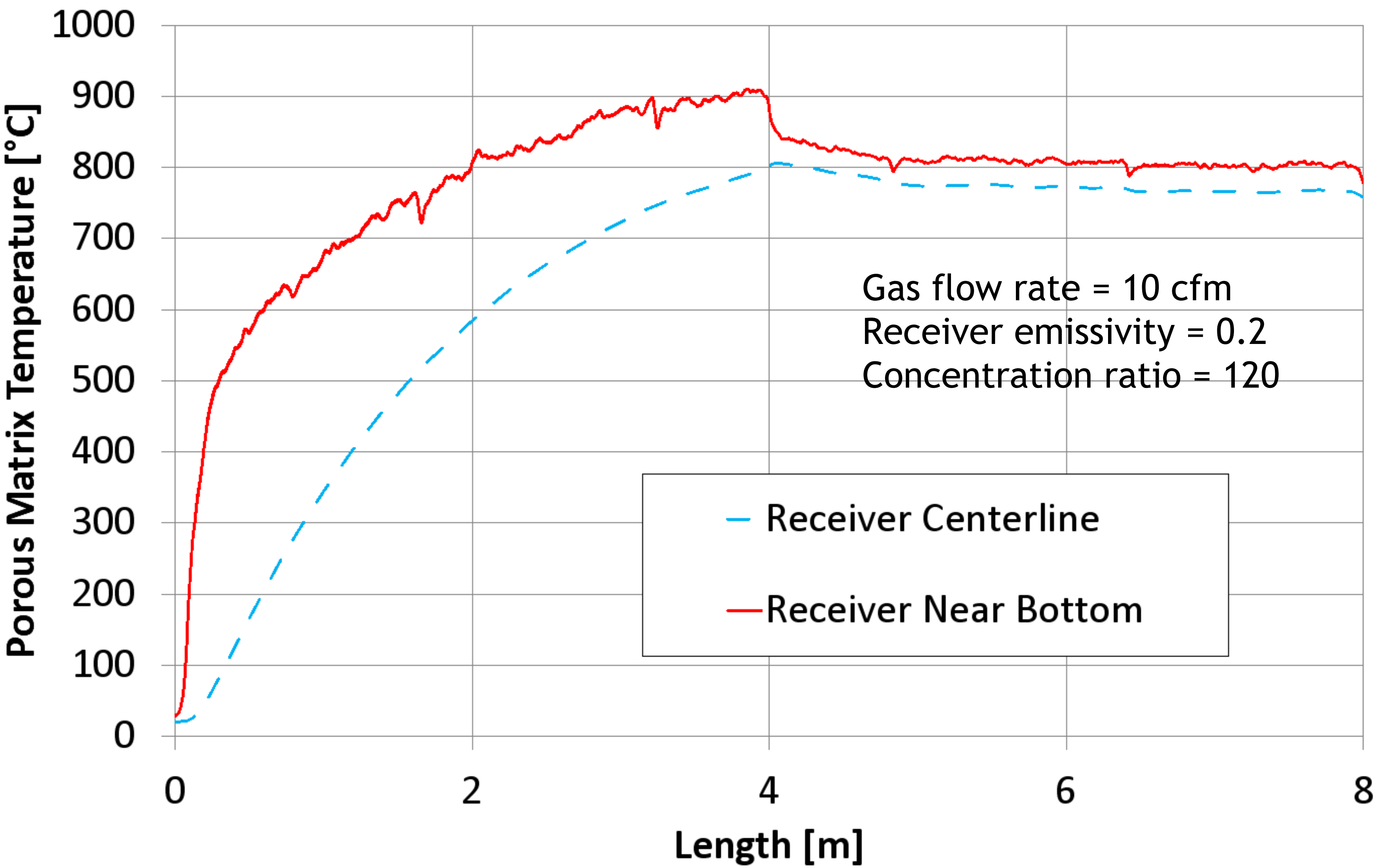
Gas flow rate = 10 cfm
Receiver emissivity = 0.2
Concentration ratio = 120





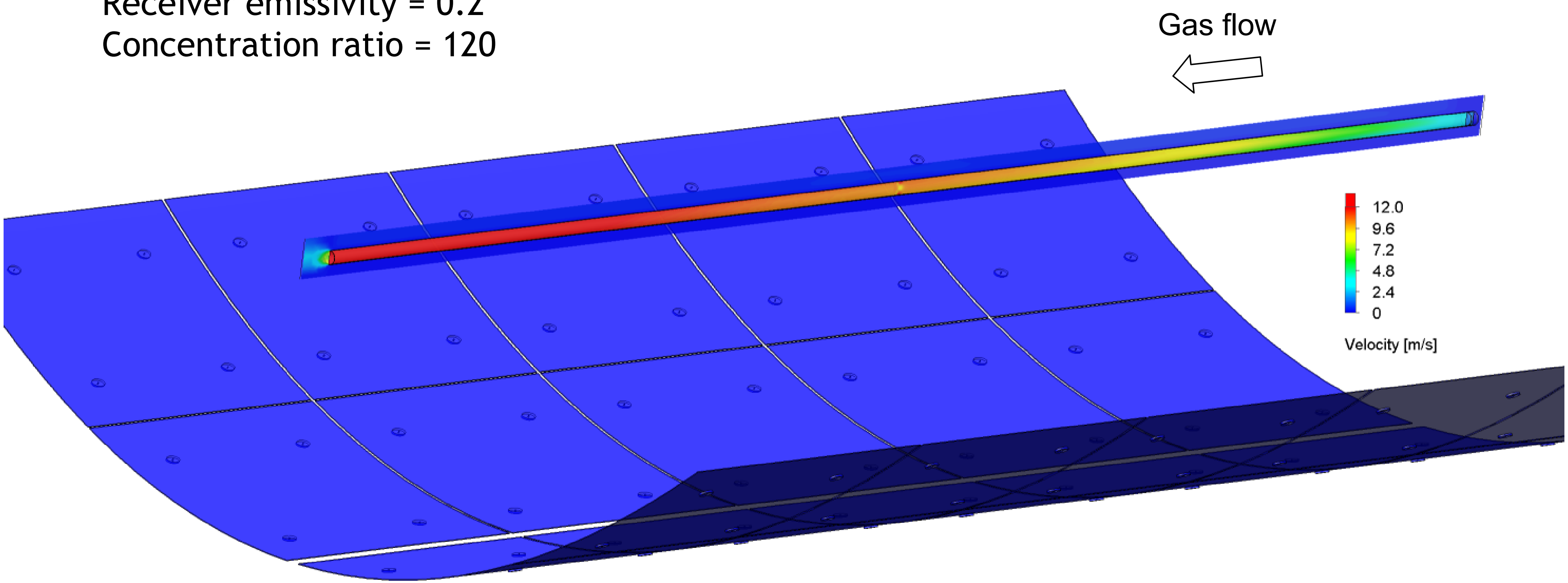
Temperatures and velocity vectors near end of catalyst bed

Temperatures along centerline and bottom of receiver



Gas velocities along receiver tube

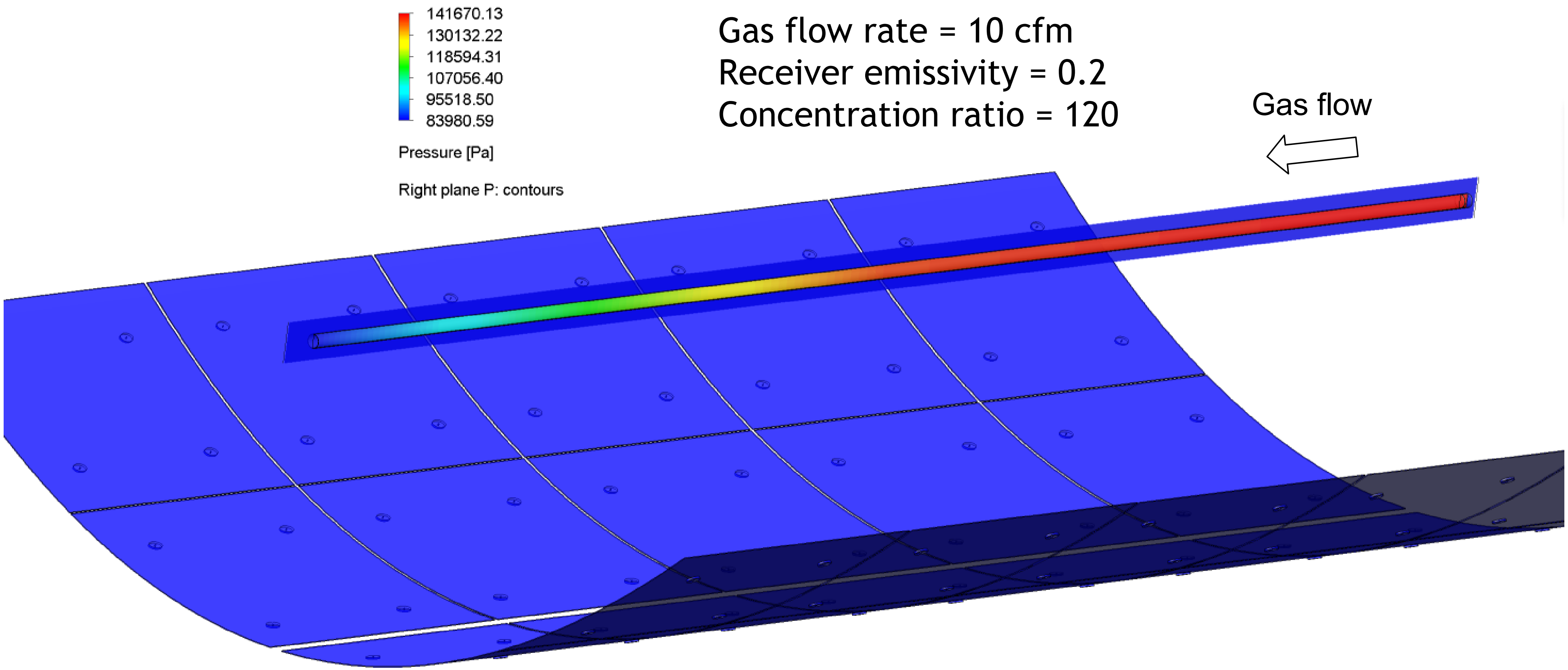
Gas flow rate = 10 cfm
Receiver emissivity = 0.2
Concentration ratio = 120



Pressure drop along receiver tube

Reference pressure in Albuquerque, NM is 84,000 Pa

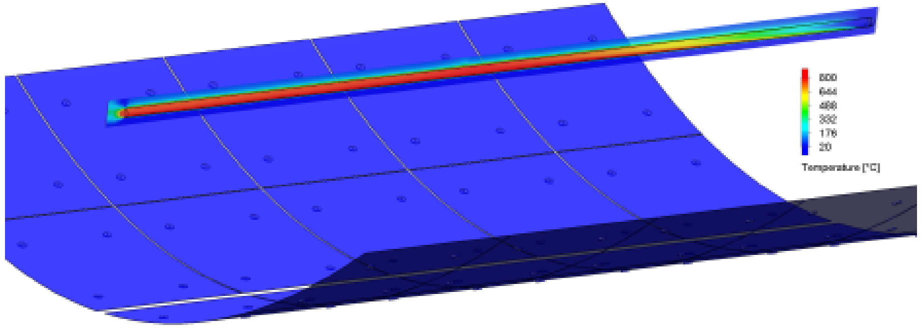
Gas flow rate = 10 cfm
Receiver emissivity = 0.2
Concentration ratio = 120

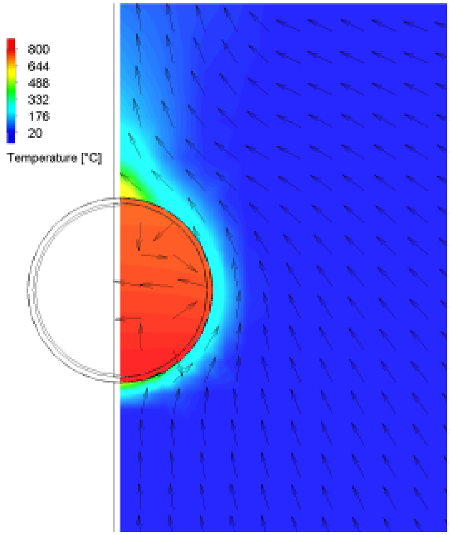


Conclusions

Conclusions

- CFD analyses of solar thermal dry reforming of methane (DRM)
  - LS-2 parabolic trough collector
  - CO_2 and CH_4 gas flow = 1, 10 cfm
  - Receiver tube emissivity = 0.2, 0.9
  - Geometric concentration ratio = 70, 120
- >700 °C average catalyst bed temperature achieved with high concentration factor and low receiver emissivity





Future Work

- Evaluate technoeconomic trade-offs
  - Larger trough apertures (5 m to ~8 m) to increase concentration ratio from ~70 to ~120
  - Use of selective coatings and materials to reduce receiver-tube emissivities to ~0.2
- Parasitic power requirements of the blower
- Kinetics of reaction and required length of the catalyst bed as a function of flow rate and other operating conditions