USE OF SPILLAGE WITH CONCENTRATING PHOTOVOLTAICS: SIMULATION AND EXPERIMENTAL CAMPAIGN

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AZUR SPACE ENABLING TECHNOLOGIES

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Why use Concentrating PV (CPV) with a thermal receiver?

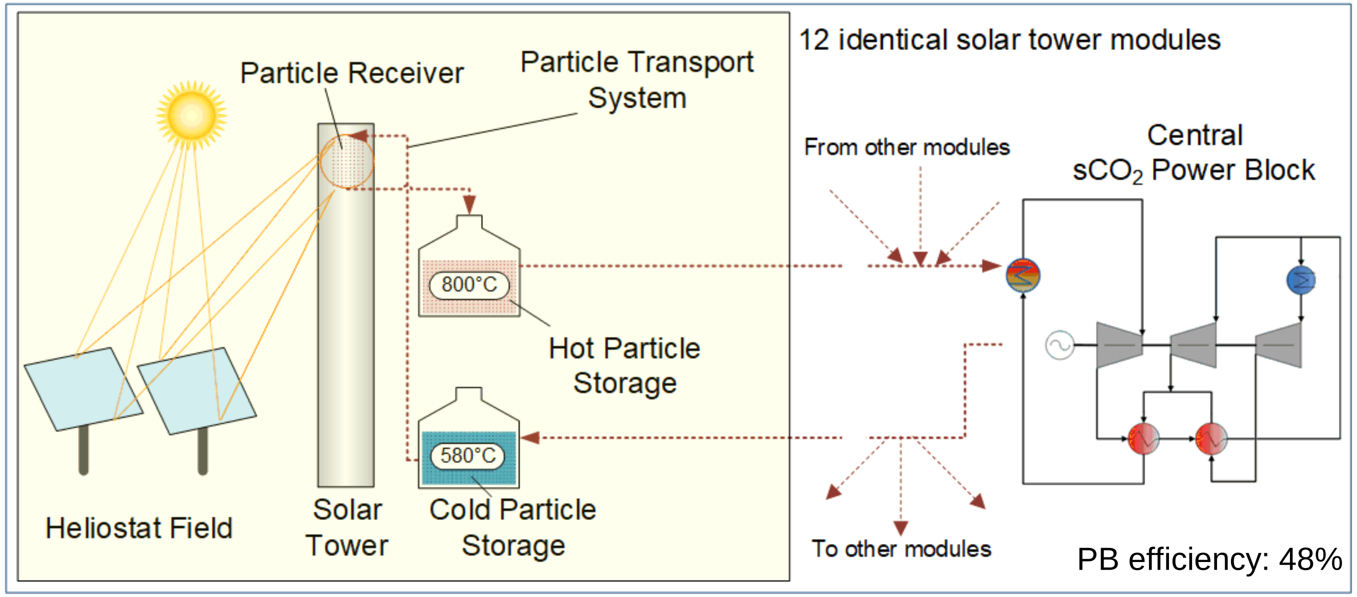
- CSP/CST application trend is towards higher temperatures
  - Higher process efficiency
  - High temperature process heat application
- Optimization for high temperature receiver systems
  - Trade-off between
    - Thermal losses ⇒ decrease with reduced aperture area
    - Intercept losses ⇒ increase with reduced aperture area
- Higher receiver temperature
  - higher impact of thermal losses tends to reduce aperture area
    ⇒ higher spillage losses
- Use of CPV is a promising way to capture spillage radiation for cost reduction

Techno-Economic Analysis of Solar Hybrid Systems
(Thermal Receiver + CPV)

- Analysis of cost reduction options
  - Improvements vs. reference case
- Reference case:
  - Multi-tower configuration:
    - 12 modules, each 41.6 MW @ design point
  - receiver outlet temperature: 1000 °C
  - site: Daggett, USA, annual DNI: 2719 kWh/m²a
- New configurations:
  - “Street-size” centrifugal particle receiver:
    - aperture diameter fixed at 3.1 m (maximum size for factory-assembled receivers)
  - Smaller heliostats: 8.1 m²
  - Receiver power and number of solar modules optimized

Reference System

- Taken from paper "Techno-economic analysis of multi-tower solar particle power plants", Buck & Sment, Solar Energy Vol. 254, 2023(1)
- Solar particle system, 100 MW_e sCO_2 cycle, (part of G3P3 project)
  - Multi-tower system: 12 identical subsystems
    - Receiver thermal design power: 41.6 MW
    - Transport of energy with insulated containers to central power block
- Selected case: "1000 LL"
  - Receiver exit temperature: 1000 °C
  - Low primary HX cost
  - Low tower cost
- Cost assumptions: G3P3, based on DoE input
- LCOE: 50.46 USD/MWh



(1) https://doi.org/10.1016/j.solener.2023.02.045

Optimization Procedure

- optimization using genetic algorithm
- For each configuration during optimization:
  - Create oversized field
  - Evaluate annual yield per heliostat
  - Select best heliostats for new design power
  - Evaluate efficiency map: eta_{field} = f(sun elevation and azimuth)
  - Evaluate annual energy yield (using hourly time series)
  - Evaluate cost and LCOE
- “Direct”: recalculation for optimized configuration
  - Calculate each (solar) time step with raytracing

Integration of CPV Modules into Radiation Shield

Example: CPV module of Raygen
(about 10 cm x 10 cm)

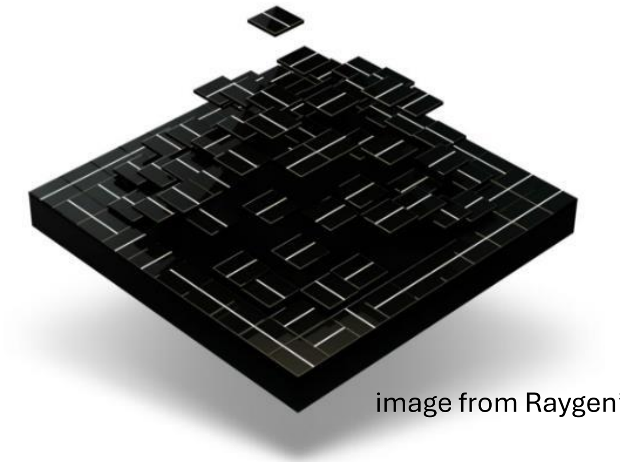
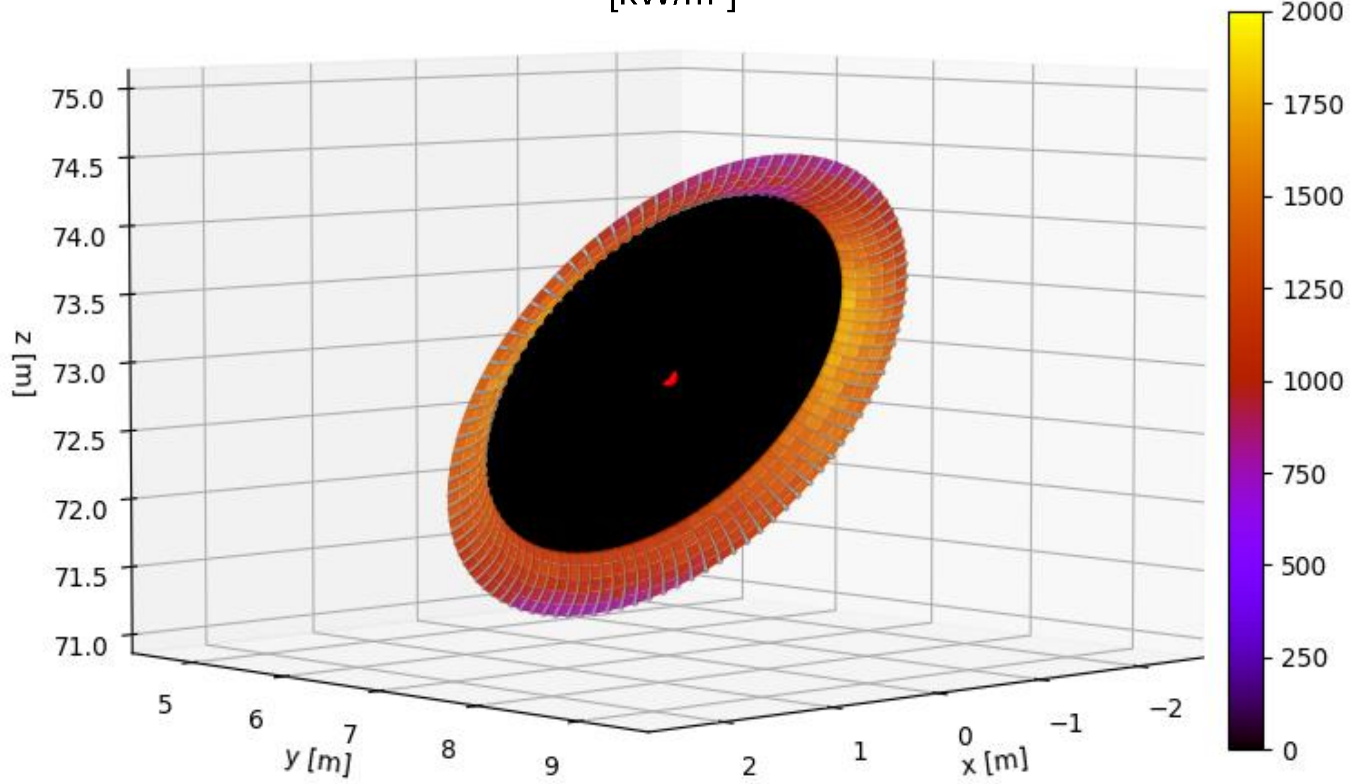


image from Raygen's webpage

- Evaluation for 5 CPV module rings
- Raytracing on specific receiver and CPV design
- Hourly time series to get annual yield of receiver and CPV modules
- CPV + inverter cost: 46‘000 \$/m²

Solar flux distribution on CPV modules at peak flux conditions
[kW/m²]



Results of Techno-Economic Analysis

- LCOE results are relative values compared to reference system
  - under common assumptions are quite optimistic (former DoE assumptions from G3P3)

case	LCOE optimized [$/MWh]	P_{th} of receivers per tower [MW_{th}]	Number of modules	Maximum flux CPV [MW/m²]
Reference (paper)	50.5	41.6	12	
SS 1R	49.7	18.4	31	
SS 2R	46.2	35.5	17	
SS 1R CPV	43.4	25.8	23	1.88
SS 2R CPV	41.6	41.0	15	1.49

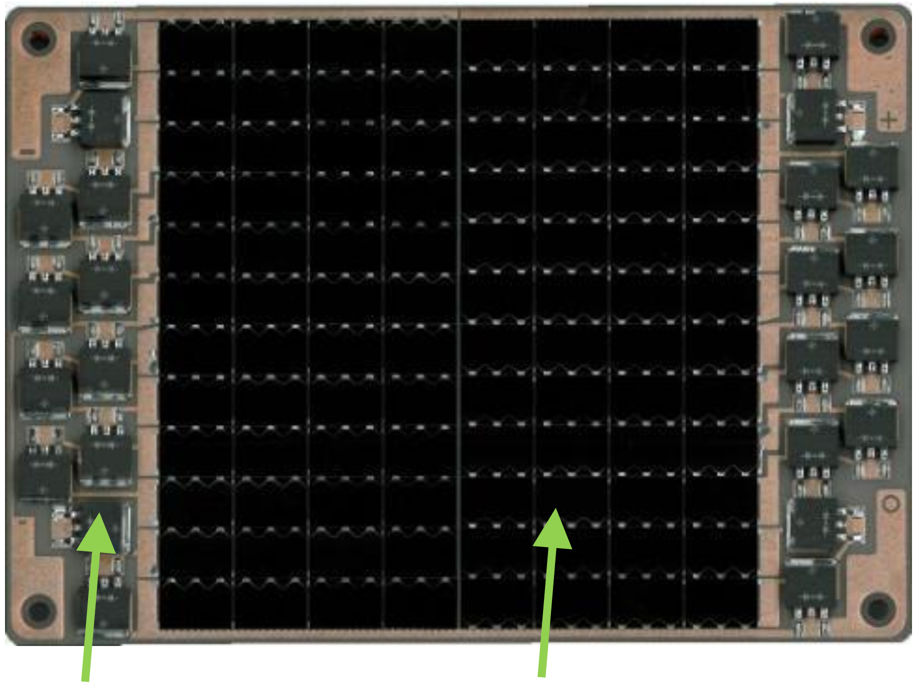
SS: “street-size” receiver; 1R/2R: number of receivers per tower; CPV: integration of CPV modules into front shield

Test of CPV Modules in HEHTRES Receiver

- Test of CPV modules: 6 ADAM modules integrated into HEHTRES receiver aperture shield
- ADAM modules: previous cell and module technology of AZUR SPACE
- Bypass diodes protected with water-cooled casing, with integrated air channels for dust removal
- Solar tests ongoing in solar tower Jülich

- ADAM CPV module main specifications:
  - Cell material: GaInP/GaAs/Ge on Ge substrate
  - active CPV area: 11.8 cm x 12.1 cm = 142.4 cm²
  - Power output: 3.2 kW (DP: 700 suns, MPP)
  - DP efficiency: 32%
  - DP parameters: I_{MPP} = 50 A; U_{MPP} = 64 V

Advanced Dense Array Modules (ADAM) from AZUR SPACE for demonstration tests



bypass diodes

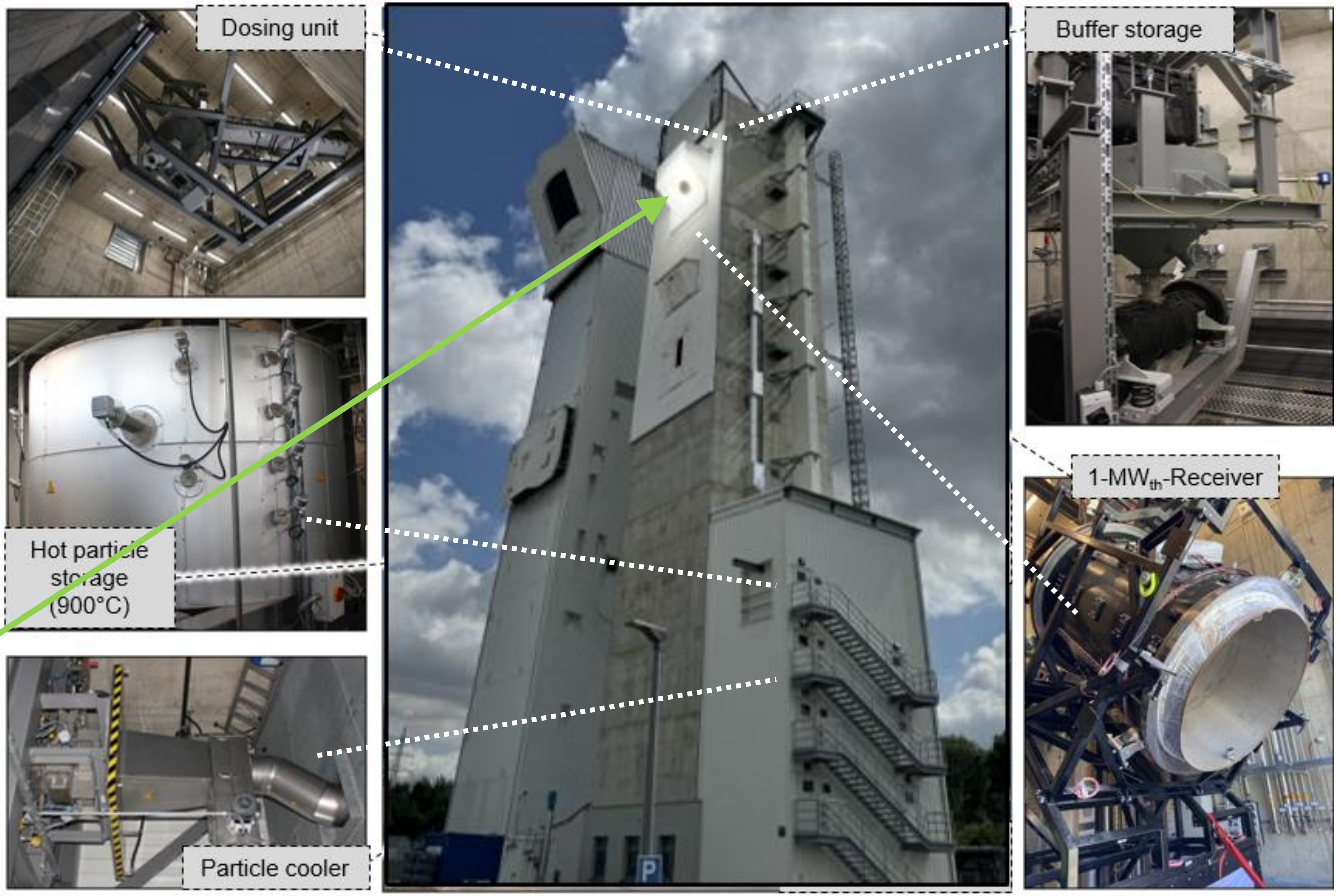
96 triple-junction CPV cells

DLR HEHTRES facility in Jülich

High Efficiency High Temperature REceiver System

Test facility HEHTRES with complete particle loop

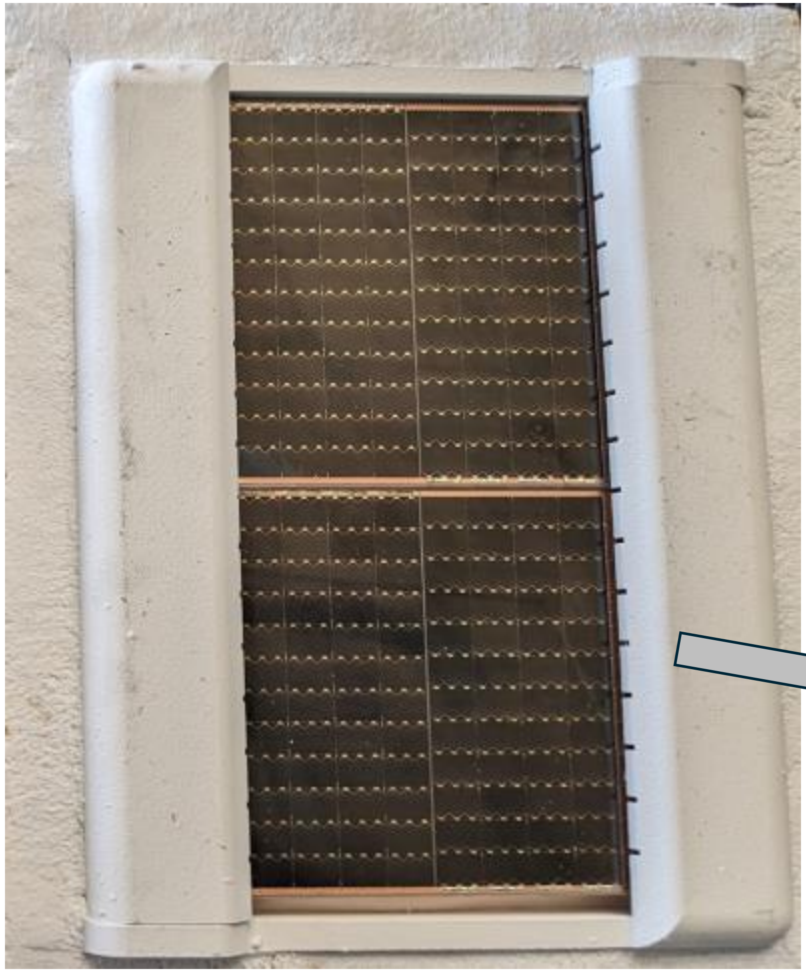
- Receiver:
  - Centrifugal particle receiver CentRec
  - 1 MW_{th} design power
  - 400 °C ⇒ 900 °C
- Hot and cold storage, 8 t capacity
- Particle lift bucket elevator, 400 °C
- Particle cooler
- CPV modules integrated into aperture shield of receiver

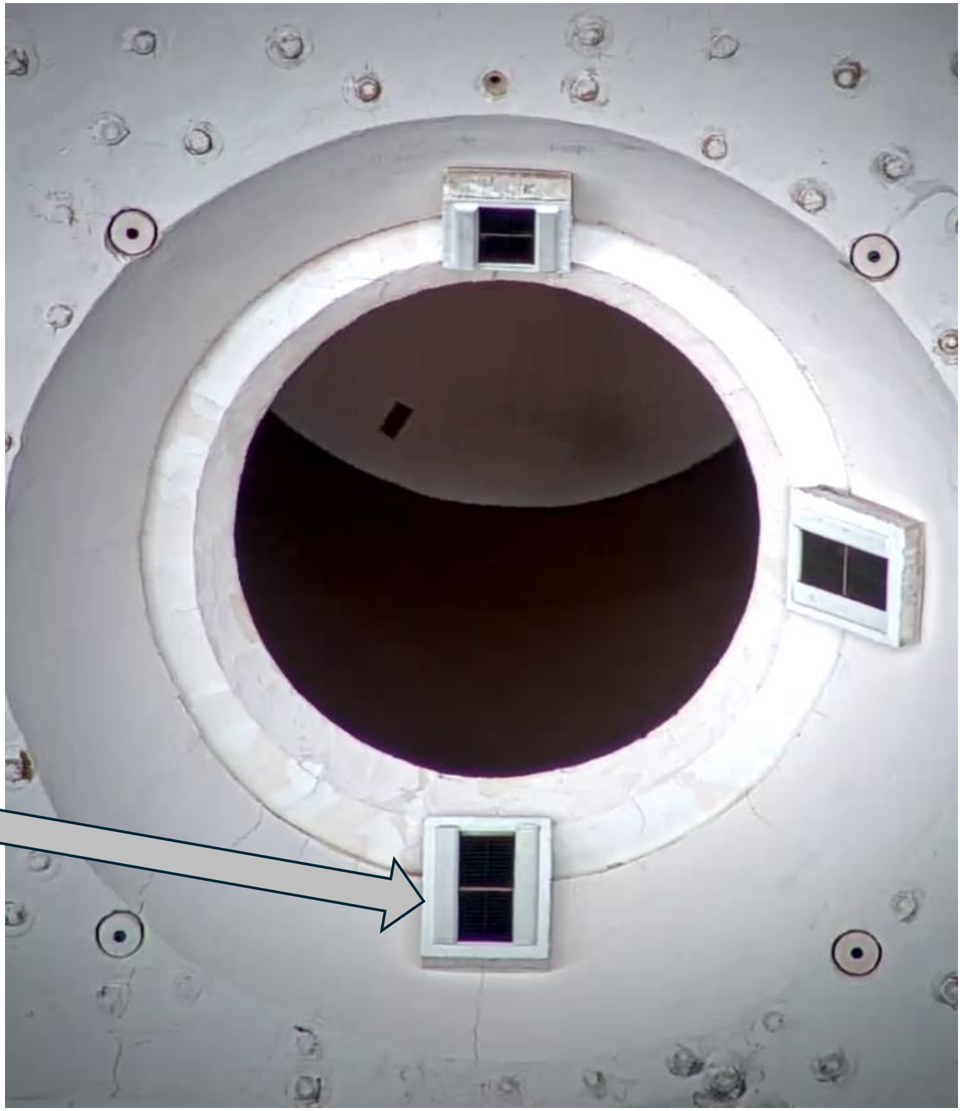


CPV Integration Details

3 CPV units in HEHTRES radiation shield

2 ADAM modules in water-cooled casing





Test Results

- First solar test
  - initial sensor problems solved
  - tests are ongoing

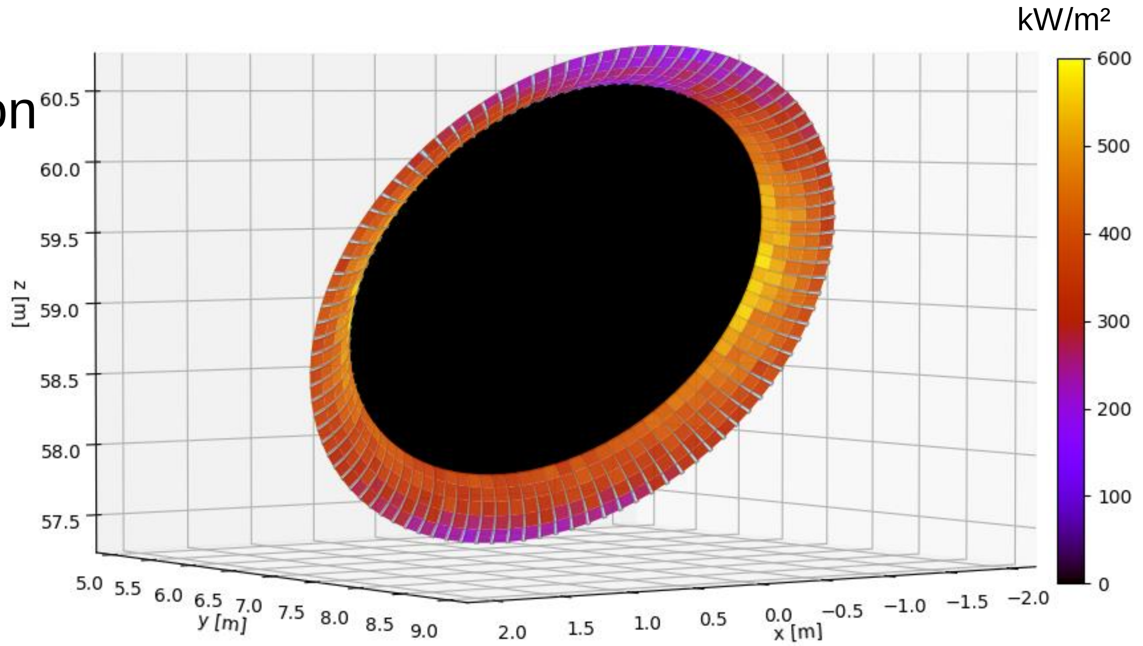
- Experimental data to be compared to predicted power output
  - Power from CPV modules calculated from:
    - Datasheet information from Azur Space
    - Average solar flux on CPV module (from raytracing)
    - Solar flux inhomogeneity
    - CPV module temperature

Conclusions and Outlook

- Use of CPV modules to capture spillage can
  - significantly increase annual energy production
  - significantly reduce LCOE

- 6 CPV modules have been integrated into the aperture shield of HEHTRES receiver

- CPV integration is a promising option for any high temperature receiver system



Thank you for your attention!

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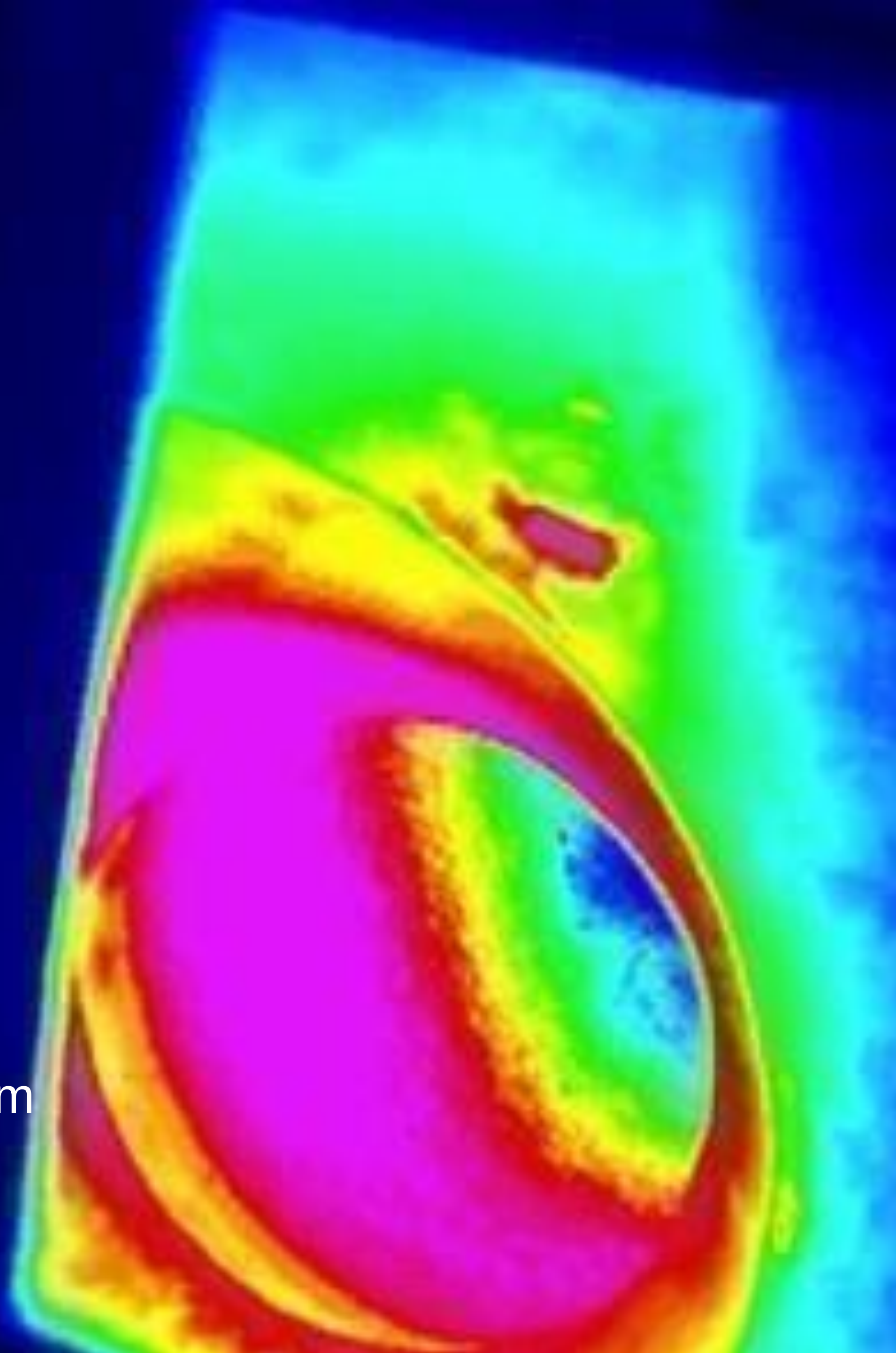

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