Particle Heating Receiver (PHR) and System Development Research at King Saud University in Collaboration with Georgia Tech

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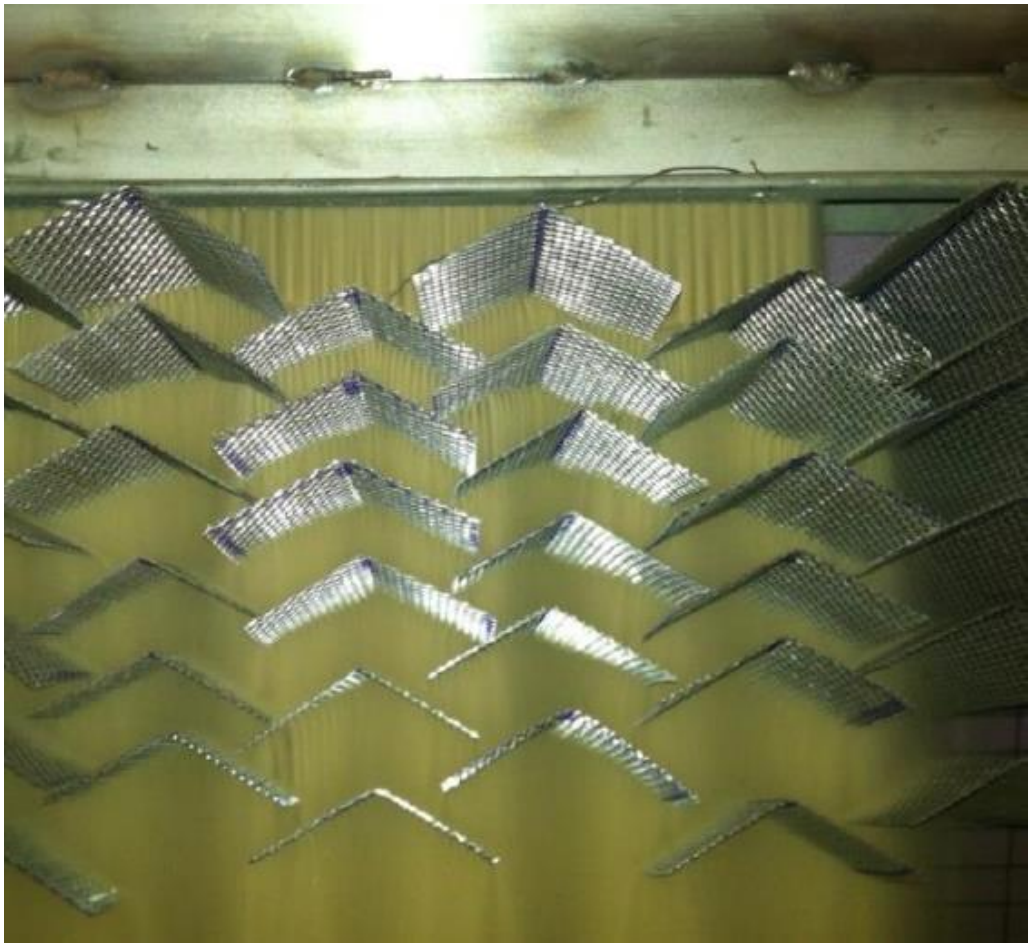
Outline

- Previous PHR research activities
- Current activities
  - **Study of low-cost particulate materials**
  - **Optimization of discrete structure receiver**
  - **Demonstration of integrated PHR system**
- Conclusions
- Acknowledgments

Previous PHR Research Activities

- KSU and GIT have been interested in PHRs since 2009
- A project was initiated in 2010 to develop a high-efficiency PHR
- The discrete structure receiver design was one of the main outcomes of the project

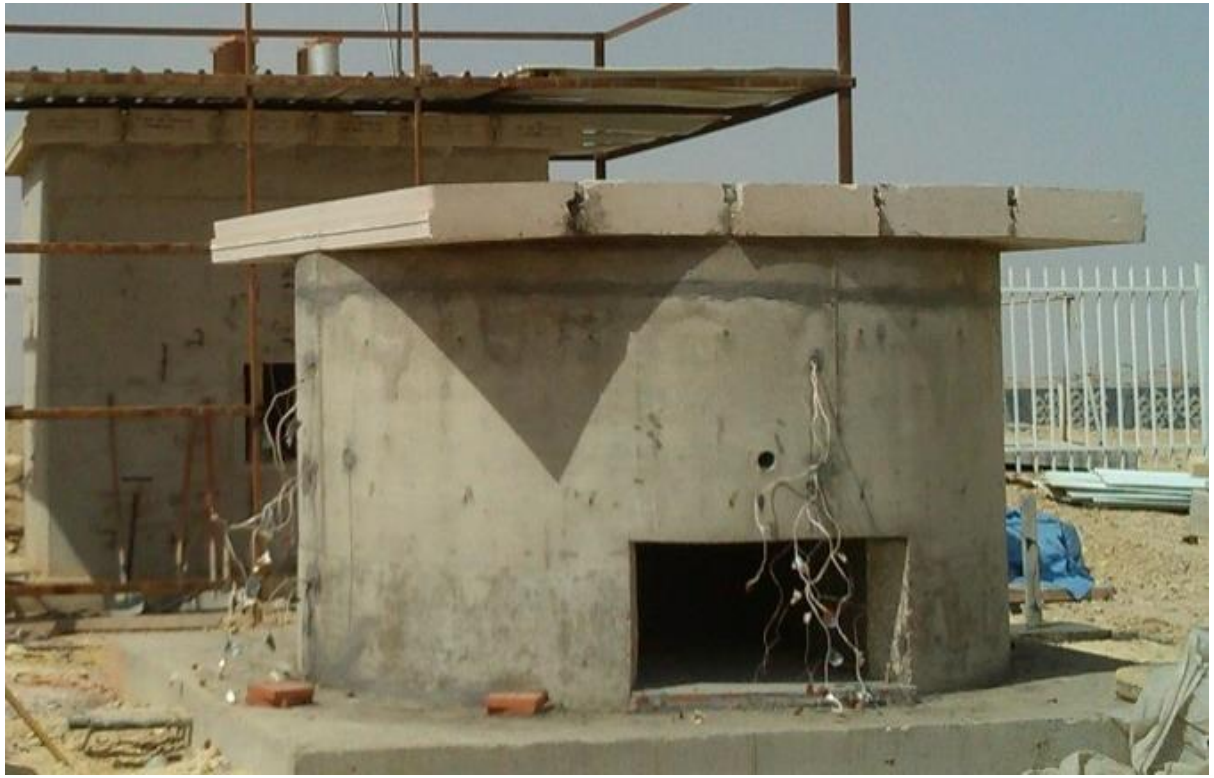


Previous PHR Research Activities

- KSU/GIT participated in the Falling Particle Receiver Sunshot project with SNL from 2012 to 2015
- The discrete structure receiver was tested at SNL and showed great promise
  - **Efficiencies as high as 90%**
  - **Temperature rises higher than 300°C per 1 m drop height**
- The design needed further refinement
  - **More on that later**

Previous PHR Research Activities

- A low-cost thermal energy storage system was developed as well
  - **Inexpensive, high-temperature masonry materials ($2.60/kWh)**
  - **Heat loss of less than 1% per day (large scale) was demonstrated**



Current Research Activities

- Study of low-cost particulate materials
- Optimization of discrete structure receiver
- Demonstration of integrated PHR system

Study of Particulate Materials

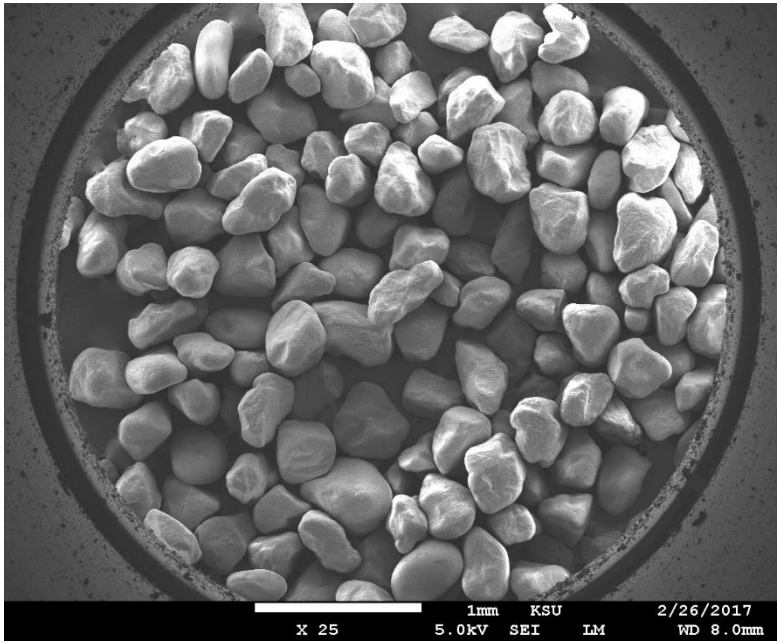
- Motivated by the facts that:
  - **Engineered particles are relatively expensive despite their superior optical properties**
  - **A "real" cavity receiver is less sensitive to the optical properties of the particulate material**

- Candidate materials:
  - **Red sand**
  - **Spent catalysts**
  - **Fly ash**

Looking for fruitful partnerships to identify other suitable natural materials

Study of Particulate Materials

- Red sand is particularly promising
  - **Abundant and very inexpensive**
  - **No sintering at temperatures as high as 1000°C**
- Depending on source, it can be relatively dark and round



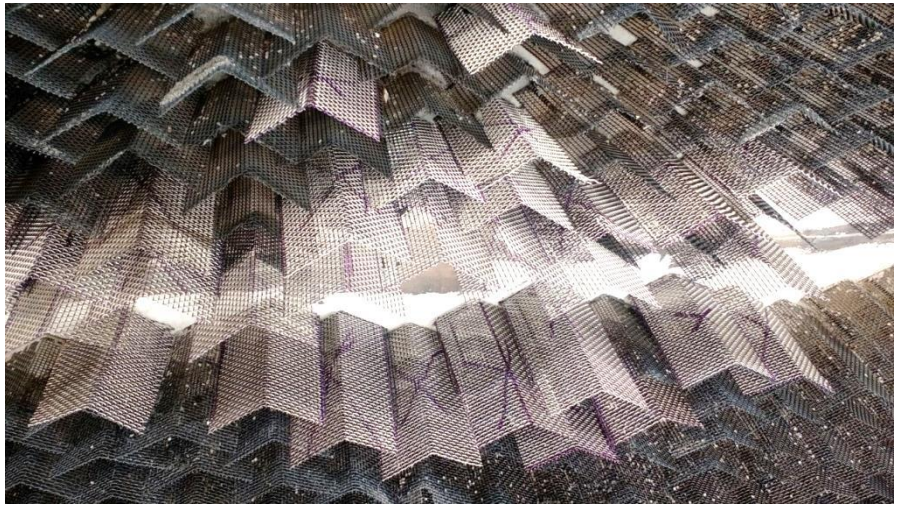
Study of Particulate Materials

- Preliminary on-sun tests are encouraging

Optimization of Discrete Structure Receiver

Lessons Learned from Testing at SNL and KSU

- Tips of original mesh screens were deformed after several hundreds of hours of testing
- Those tips were not properly covered by particles



New Meshes

Deformed Meshes

Optimization of Discrete Structure Receiver

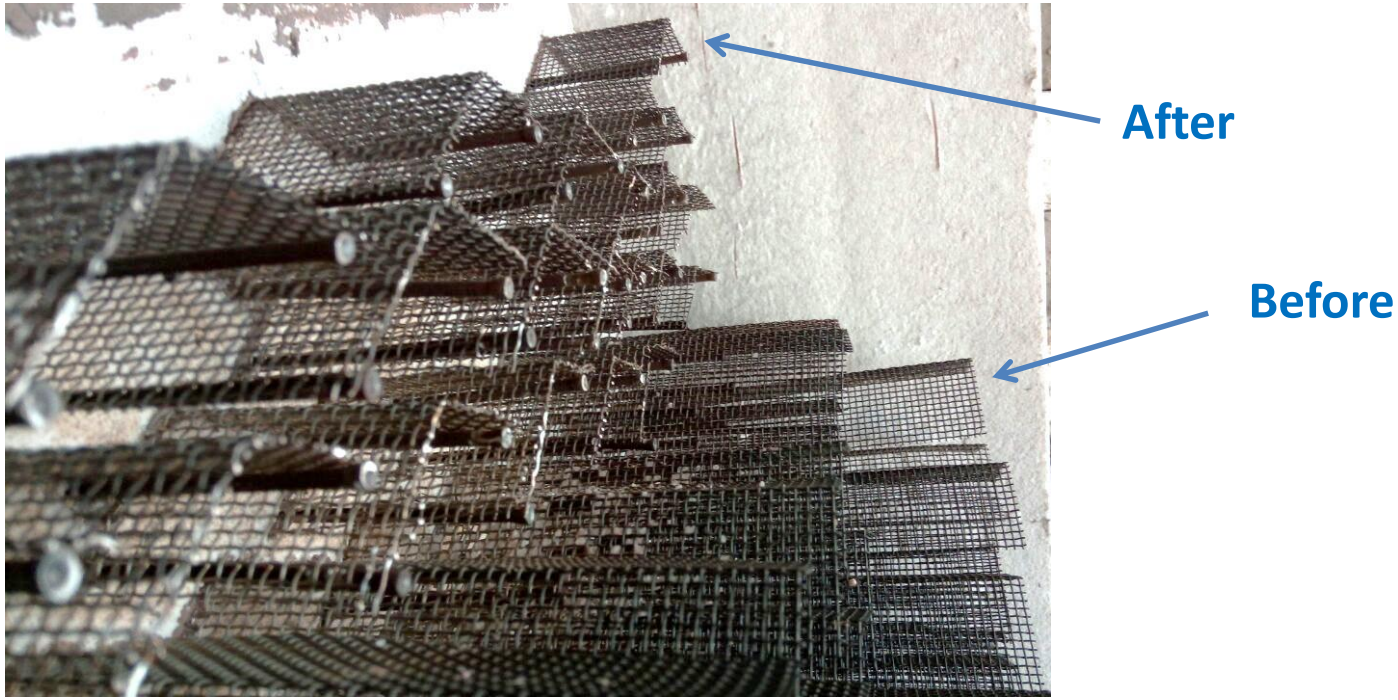
Lessons Learned from Testing at SNL and KSU

- Mesh material that was initially used was not suitable for high-flux operation (SS316)
- Vertical installation of the receiver can cause particle attrition and susceptibility to wind carryover
  - **Less so in a "real" cavity receiver**

Optimization of Discrete Structure Receiver

Improvements in Receiver Design

- Depth of mesh screens was reduced to minimize obstruction of sunlight by meshes
- Orientation of the receiver was improved to minimize particle attrition



Improvements in Receiver Design

- Successful tests at RTV were completed with the new improvements, with no signs of wear (even with SS316)
- Higher temperature metal will be used in the next receiver (Inconel 601) to increase durability
- Other variations of the discrete structure receiver are also being considered
  - **Example: Fully ceramic design**
    - **Harder to prototype**
    - **Could be an area of collaboration**

Demonstration of Integrated PHR System

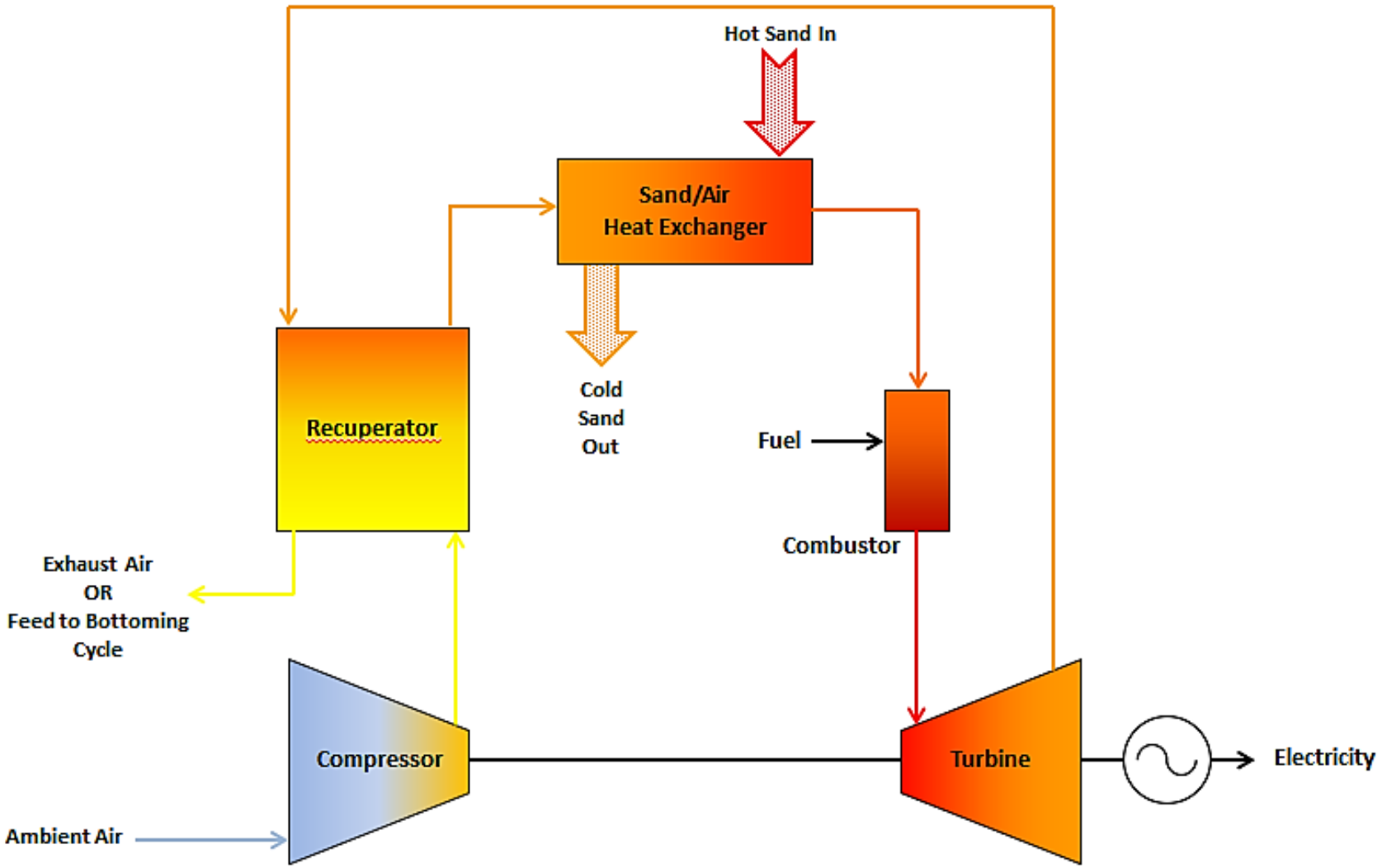
- Driven by the interest of SEC
- SEC sees an opportunity in off-grid locations
- Current cost of power generation with diesel generators in these areas is too high
  - **Transportation costs and fuel availability are the main issues**
- Large amounts of diesel are consumed due to the use of low-efficiency diesel generators
- Roughly 1000 MW is generated off-grid
  - **An ideal niche market where thermal energy storage and 100% backup is needed**

Demonstration of Integrated PHR System

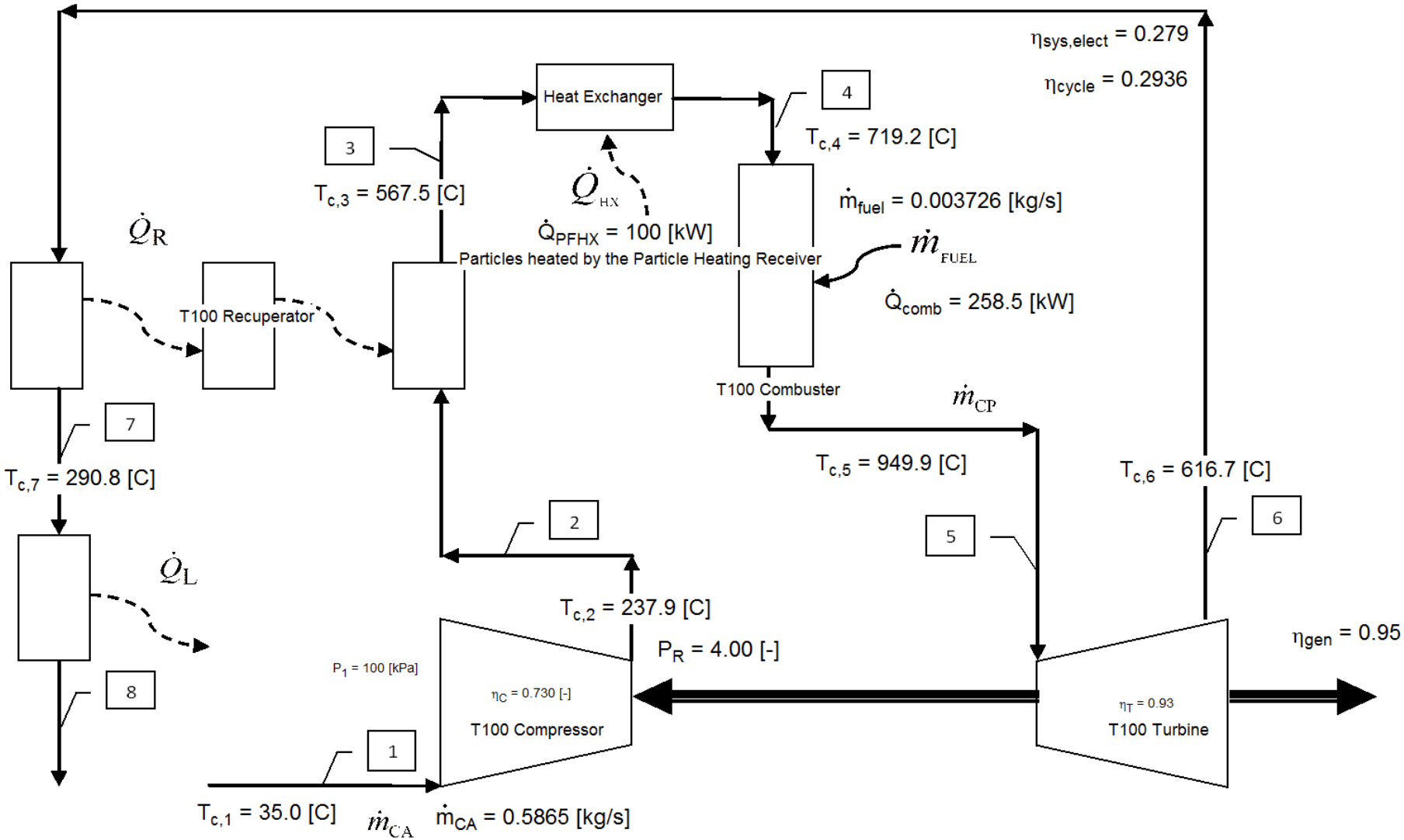
- Demonstration is taking place at RTV's 300 kW-th facility
- Custom-built facility for PHR research

Demonstration of Integrated PHR System

- Demonstration is based on the hybrid operation concept



Demonstration of Integrated PHR System



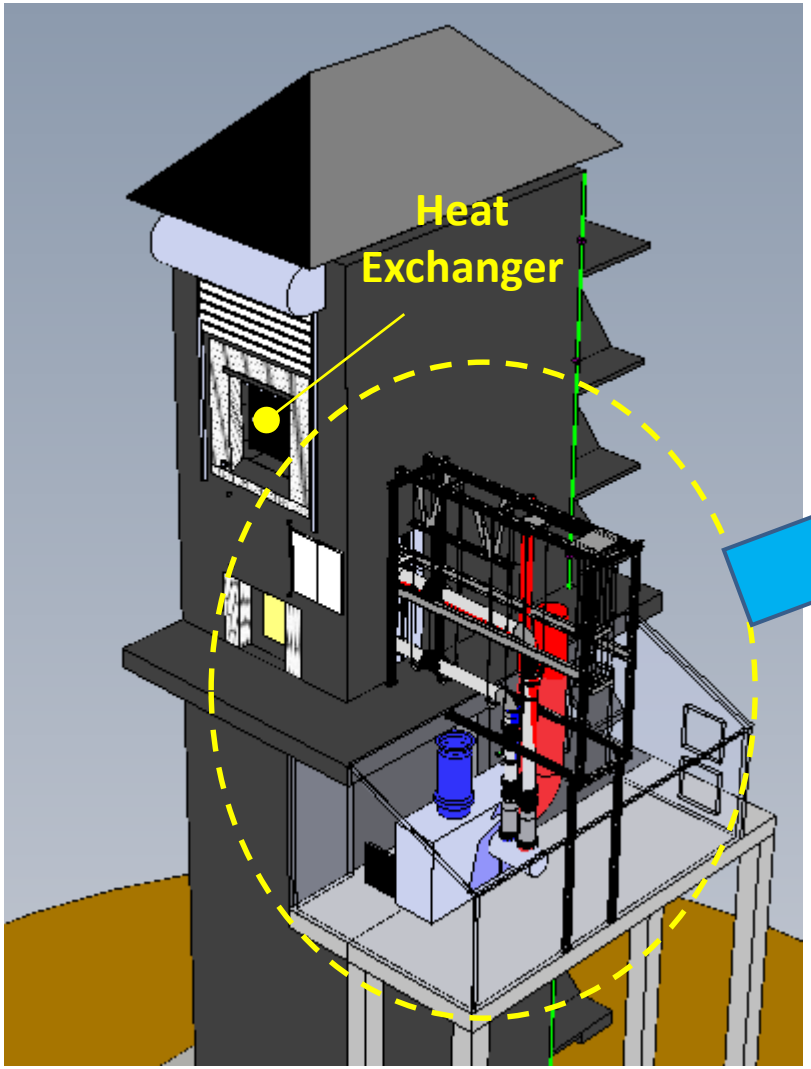
Advantages of Hybrid Operation

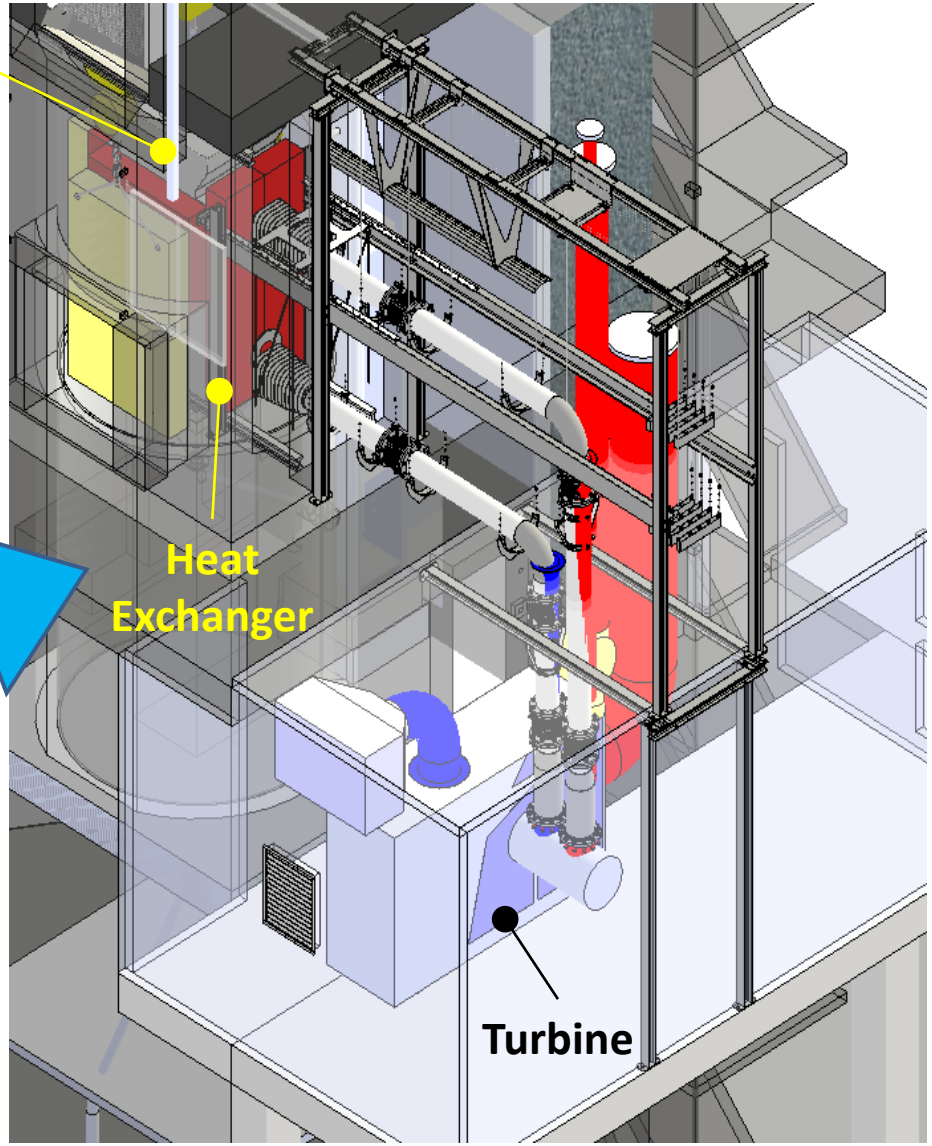
- Provides stable output, even during prolonged periods of unavailable solar resource
- Fuel use will still be minimal if sufficient storage capacity is built into the design
  - **Fuel is used last, i.e. late night when demand is lowest**
- Concept was demonstrated in Solugas project (but without recuperation)

Main Differences Between SEC and Solugas Demos

- Particle receiver vs. air receiver
- Storage capacity in SEC demo
  - **Solugas was not designed with storage**
- Storage is upstream of heat exchanger in SEC demo
  - **Allows constant temperature input to the turbine**

System Components





System Components

Receiver

- Discrete structure with red sand as the working medium
- Design outlet temperature: ≈ 750°C
  - **Limited by available drop height (can be higher)**

Turbine

- Turbec T100 (100 kWe)
- Efficiency: ≈ 30% (recuperated)
- Firing temperature: ≈ 950°C
- Modified by Ecergy AB to work with hot air from heat exchanger and combustion (in series)

System Components

Heat Exchanger

- Custom-made by Grenzebach GmbH
- Tubular design
- 6-pass with counter flow
- Surface area: ≈ 90 m^2

Hot Storage Bin

- Nominal size of about 1 m^3
- Sufficient for 1 hour of operation (for demonstration purposes only)

Conclusions

- Results of research in PHR, thermal energy storage, particulate materials, and system integration at KSU/GIT have been very encouraging so far
- A number of collaboration opportunities are envisaged
  - **Identification of natural particulate materials with superior properties**
  - **Cost-effective manufacturing processes for fully ceramic discrete PHR designs**
  - **Fluidized bed heat exchangers**
- KSU/GIT are open to other collaboration ideas that are synergistic in nature

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King Saud University

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Thank You