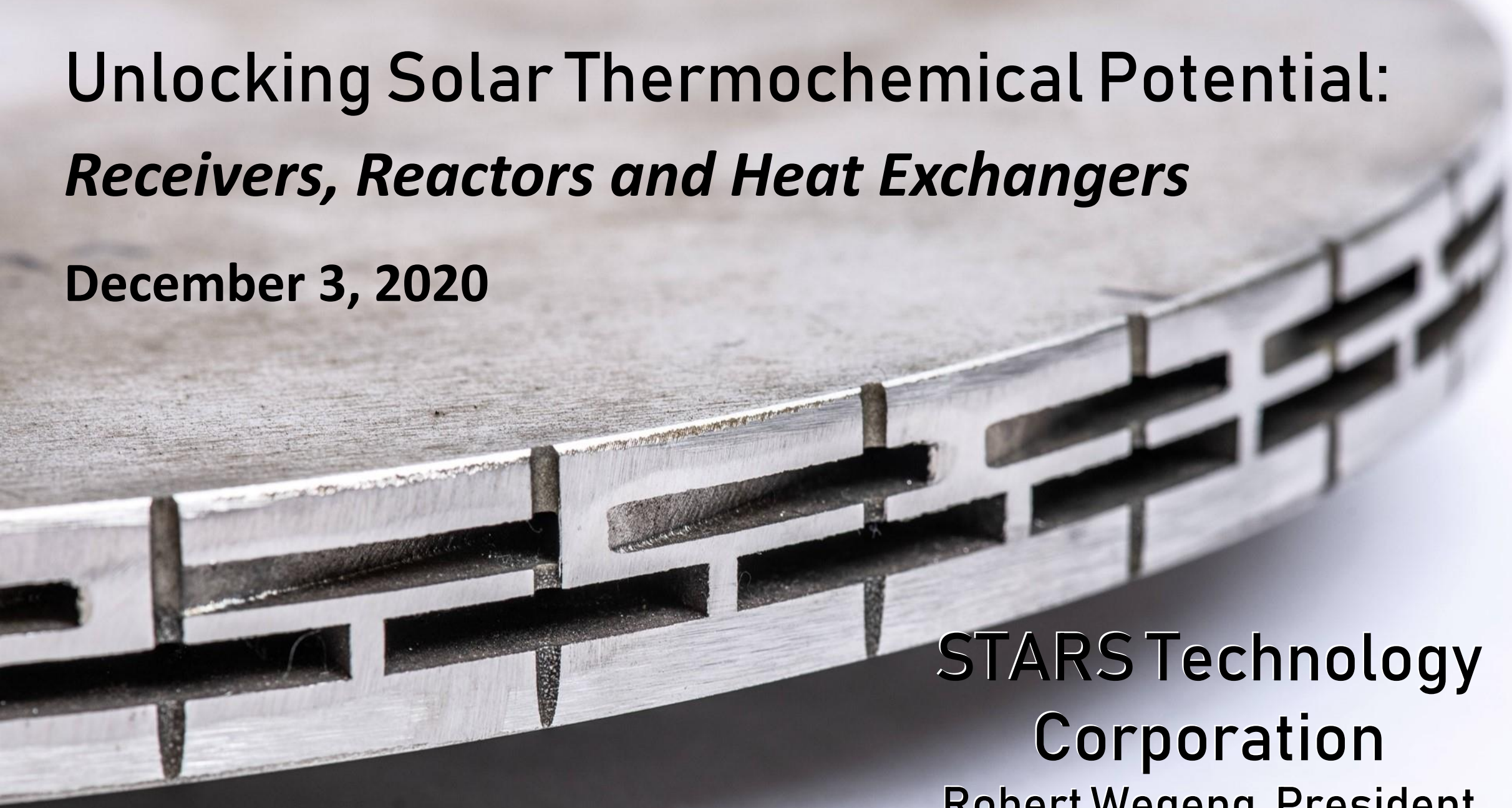
Unlocking Solar Thermochemical Potential:

Receivers, Reactors and Heat Exchangers

December 3, 2020



STARS Technology Corporation

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Solar Methane Reforming Demonstrations

Steam-Methane Reforming (2010-2020)

STARS

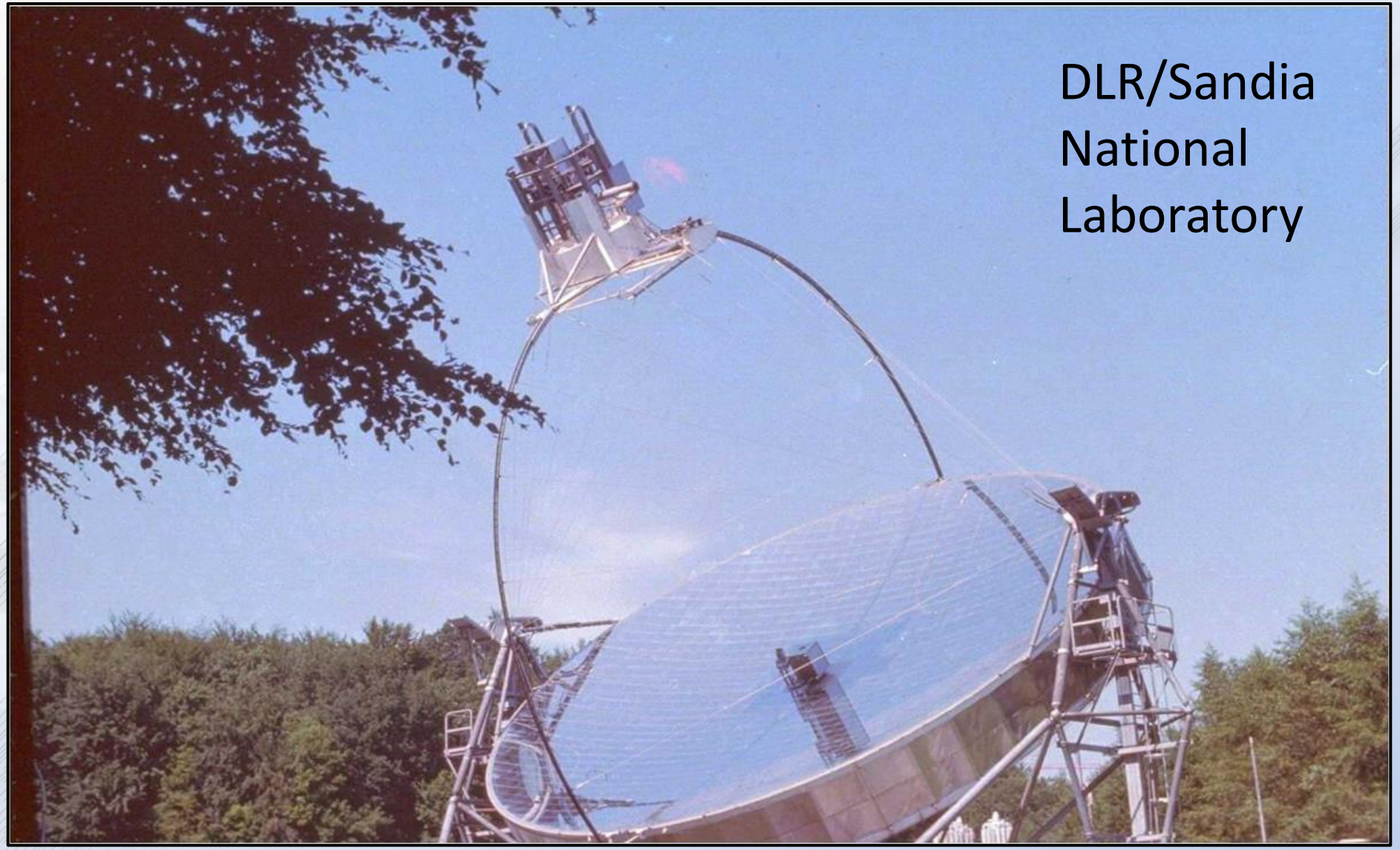
SoCalGas

DOE -- Pacific NW National Laboratory

- Based on compact, process-intensive, microchannel process technology
- Solar-to-Chemical Energy Conversion Efficiency: ~70%
- Commercial Demonstrations in 2021

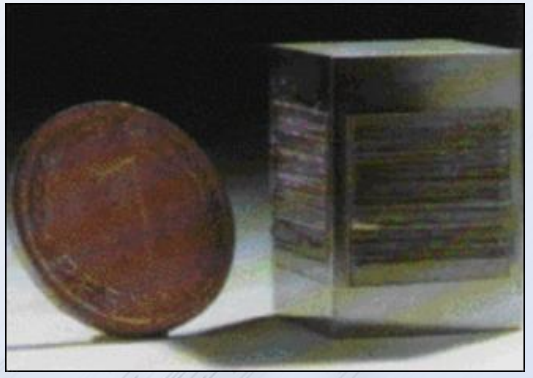
Solar Methane Reforming Demonstrations

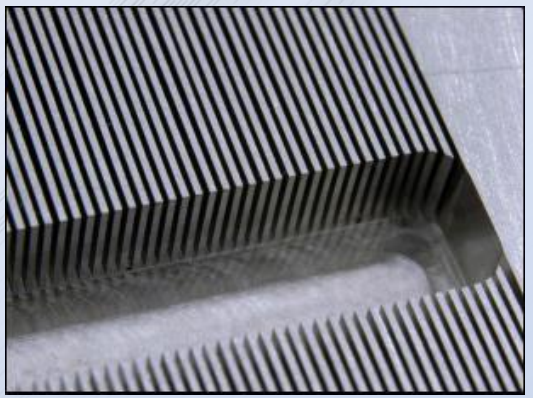
CO_2-Methane Reforming (~1990-1993)

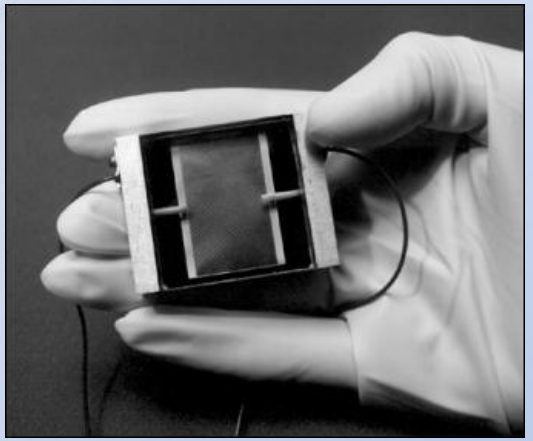


Presentation Contents

- Introduction
- Example: Solar Thermochemical Advanced Reaction System (STARS)
- General Principles: Integration of Solar Concentrators with Chemical Process Systems (and more)
- Focus Question: Can Concentrated Solar Thermochemical Systems Help Achieve a Carbon-Neutral Future?
- Summary & Conclusions

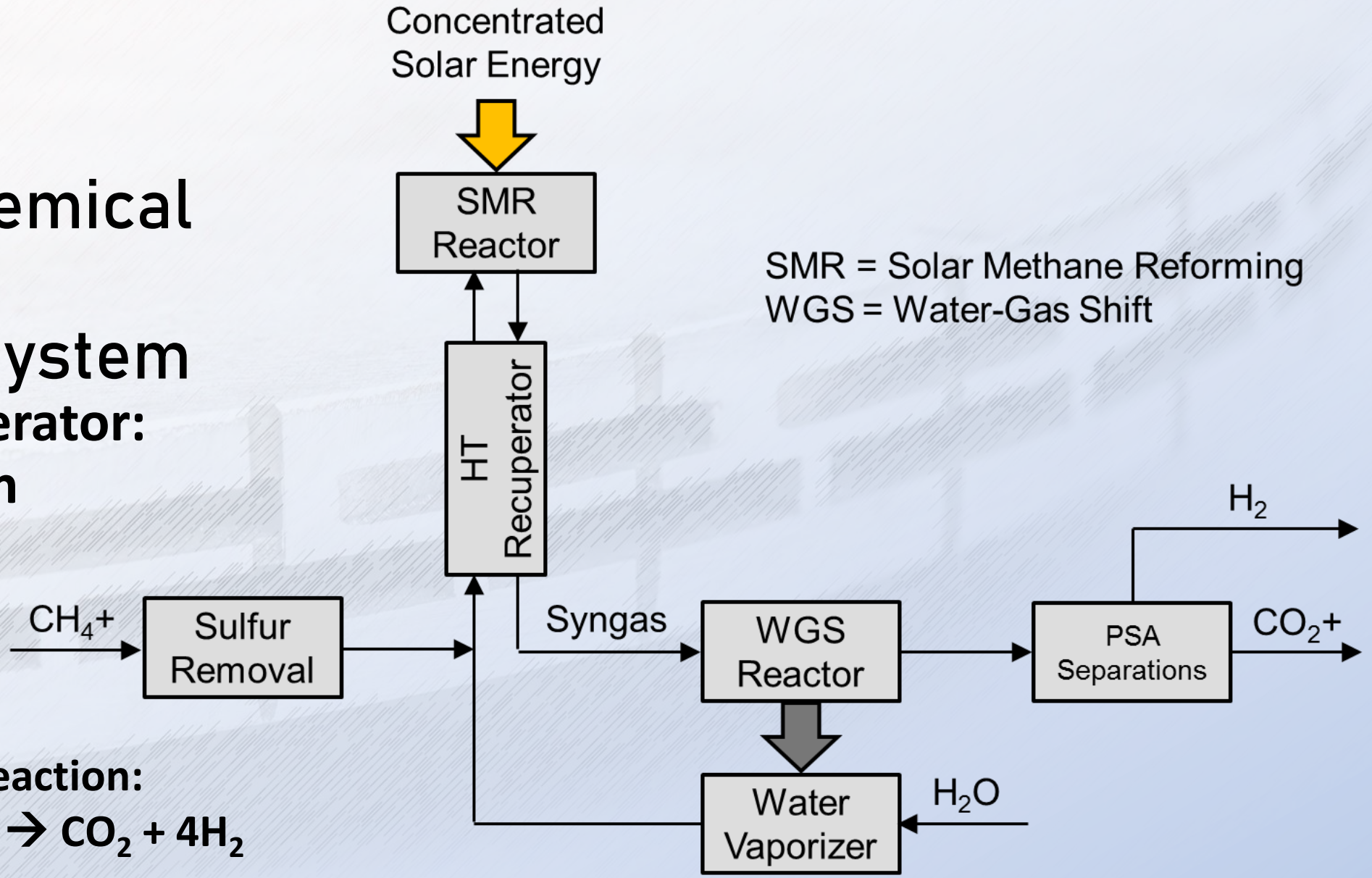






Solar Thermochemical Advanced Reaction System

Solar-H_2 Generator: Level 2 Design

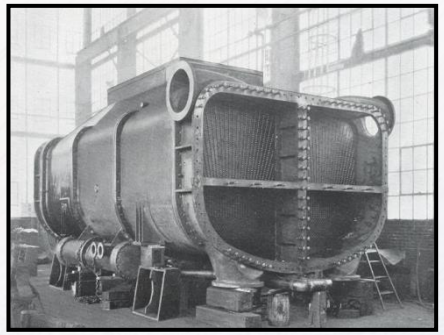


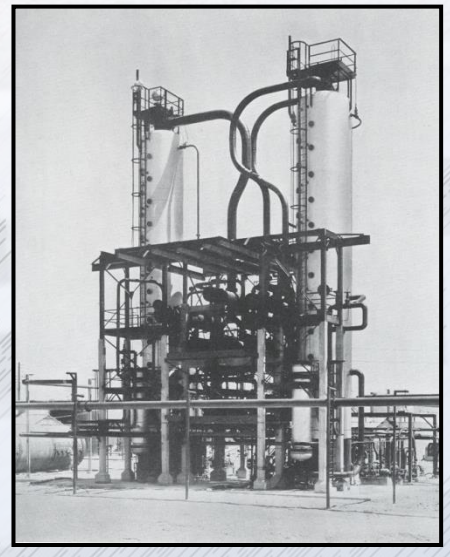
Net Reaction:

$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

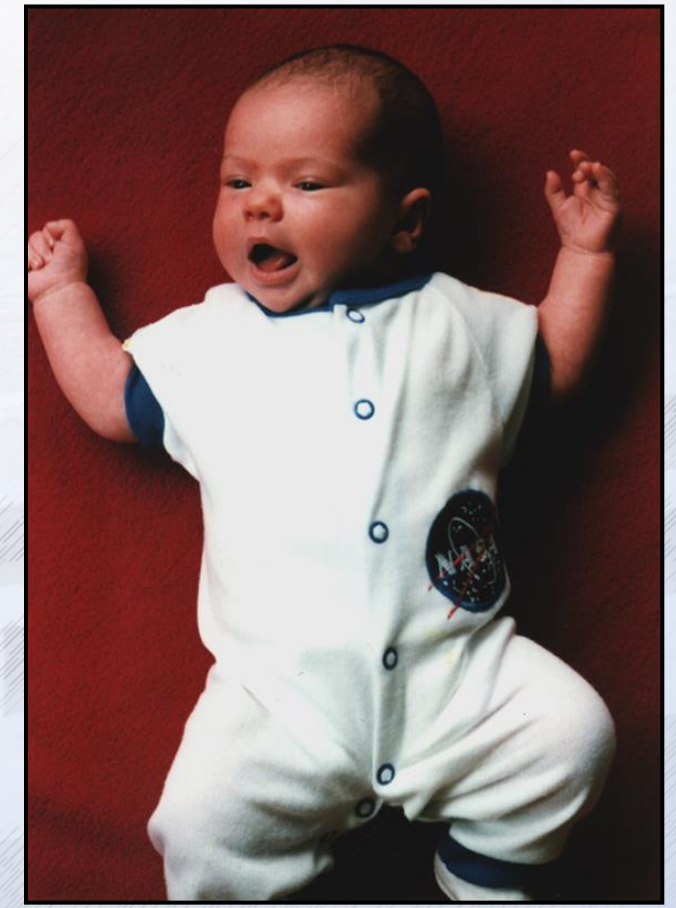
Microchannel Reactors and Heat Exchangers

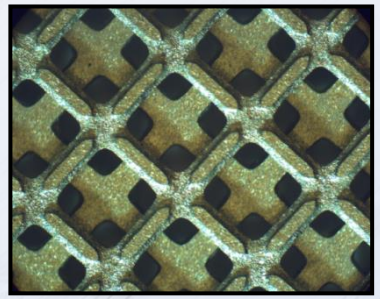
Over $50M in Development Projects at the DOE Pacific Northwest National Laboratory (PNNL) over 25+ Years

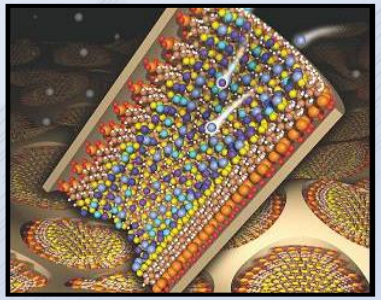




Conventional Process Technology (1920s)



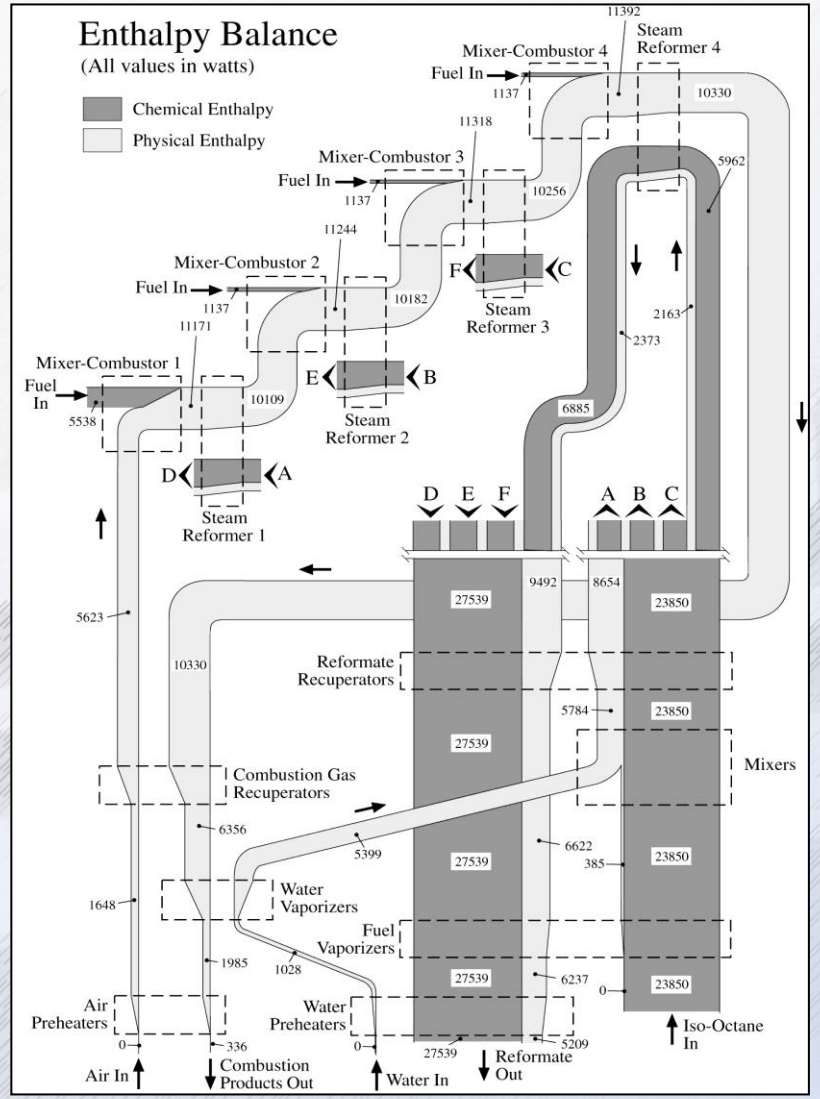


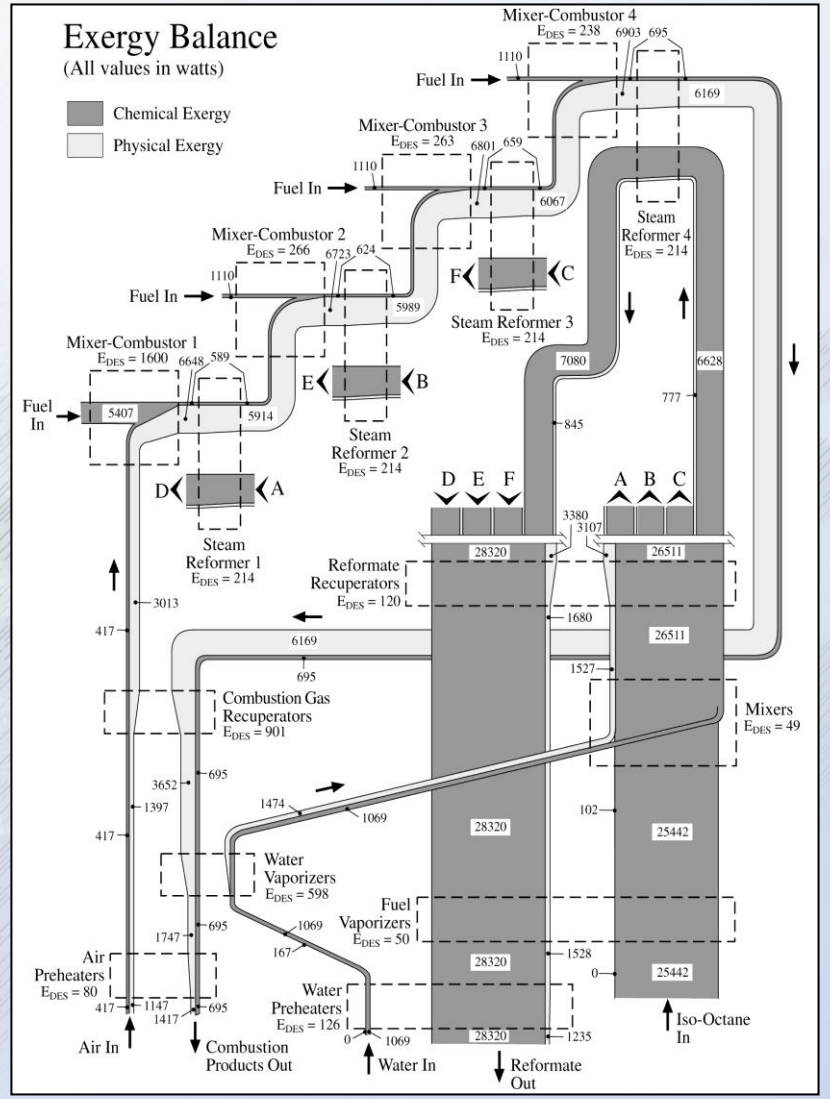


21st Century Micro- and Meso- Channel Process Technology (mimics nature)

Highly Efficient Microchannel Steam Reformer plus Heat Exchanger Network (2000)

General Principles: Concentrators, Receivers, Reactors, Separators, Heat Exchangers





Use the Second Law First:

- Endothermic unit chemical operations require exergy
- Exergetically efficiency components and systems accomplish the highest energy efficiencies

General Principles:

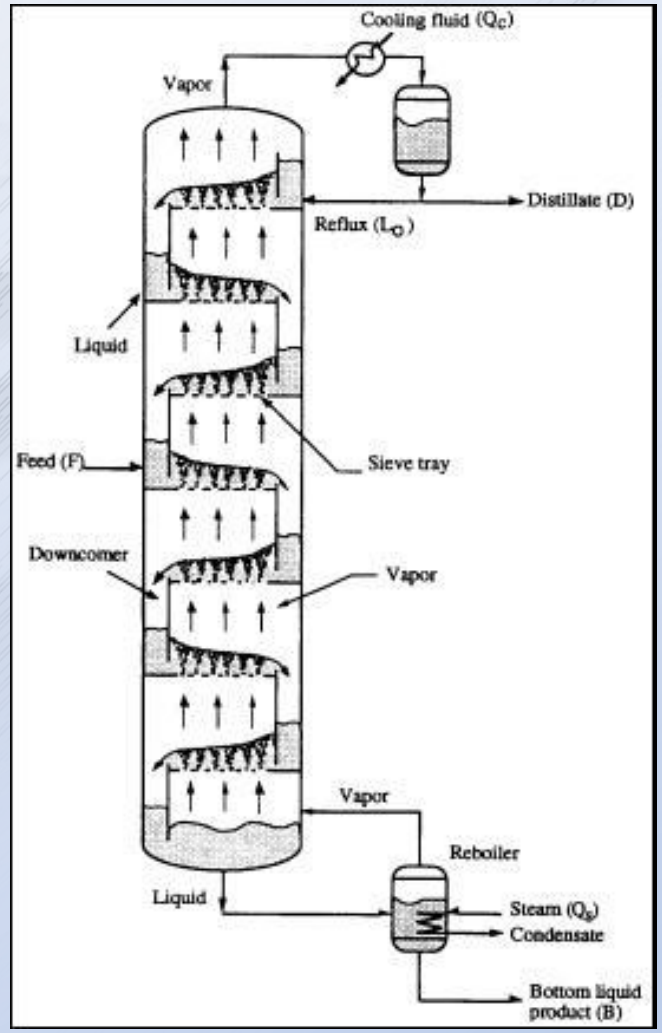
Concentrators, Receivers, Reactors…
Also Separators, Heat Exchangers

Match Solar Concentrators to the Unit Operation:

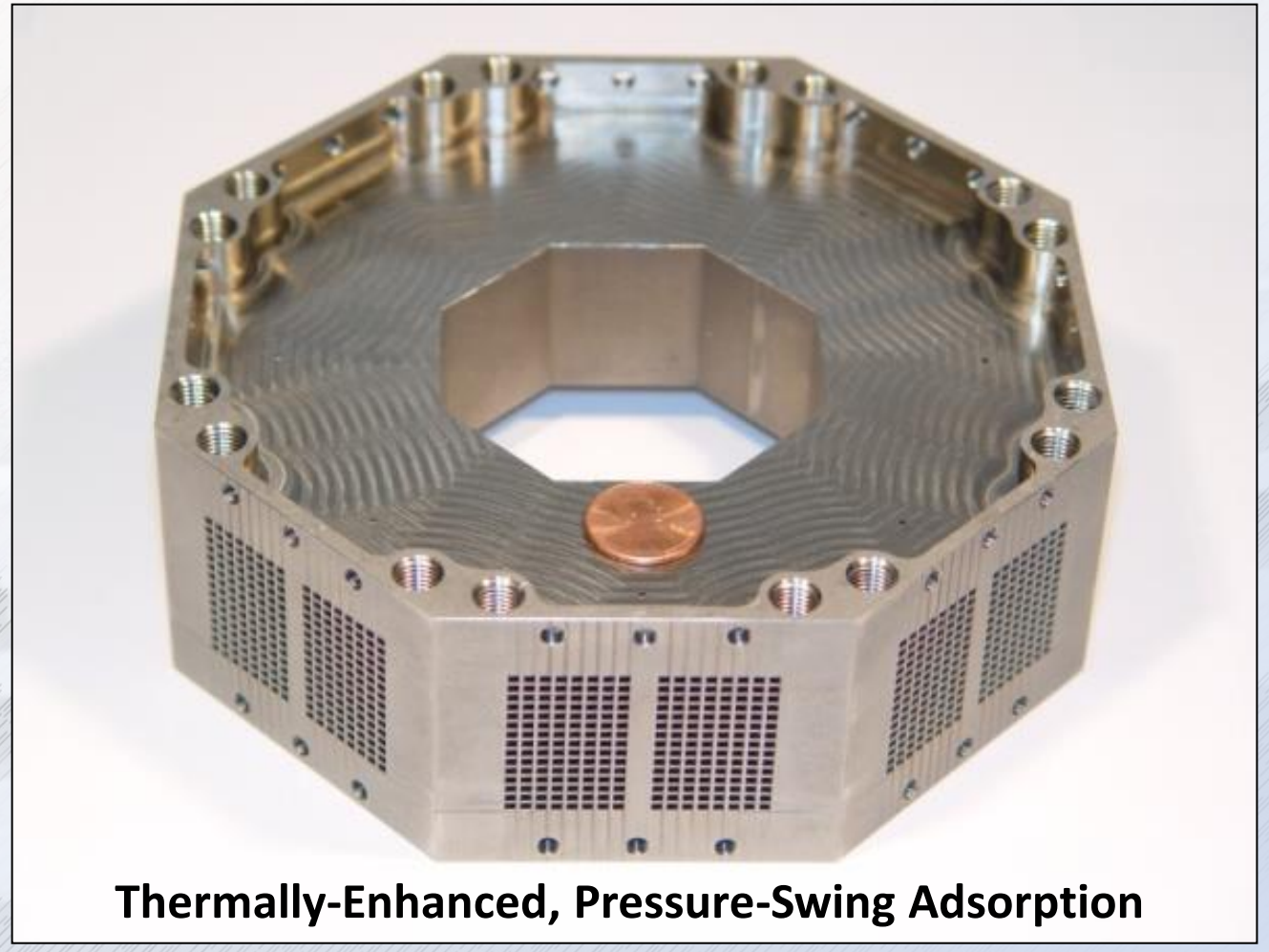
- Many unit chemical operations do not require high temperature heat
- High concentration ratios generate greater exergy content, but some solar concentrators produce thermal exergy at higher costs than others

Focus Question: Can Solar Thermochemical Systems Help Achieve a Carbon-Neutral Future?

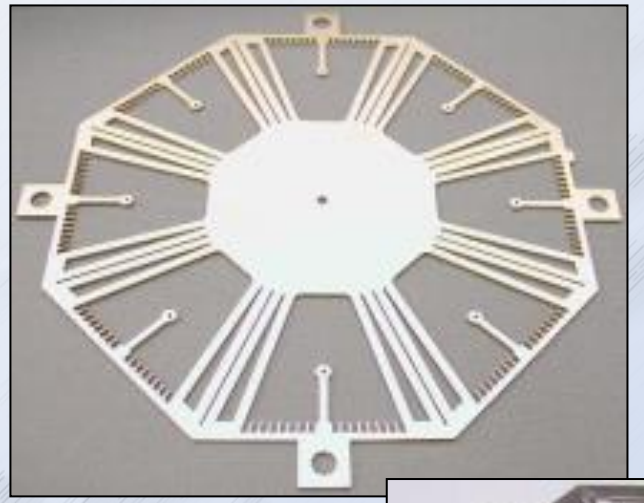
- Replace fossil energy with solar thermal energy
- Across a large range of temperature demands
  - Reactors
  - Separators (e.g., sorption, distillation…)
  - Steam Generators and other Heat Exchangers



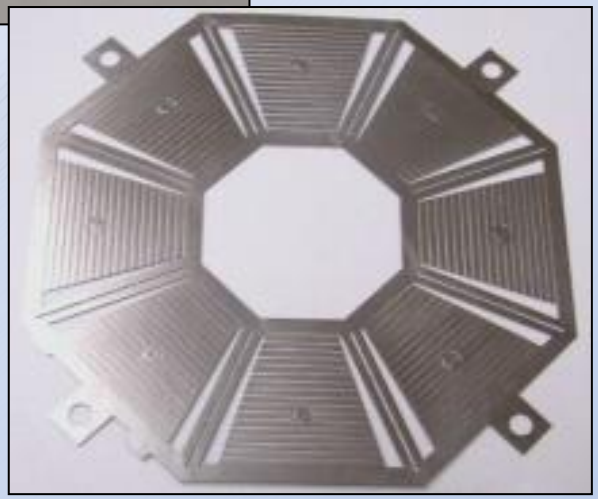
Focus Question: Can Solar Thermochemical Systems Help Achieve a Carbon-Neutral Future?



Thermally-Enhanced, Pressure-Swing Adsorption



Pacific NW National Laboratory/ NASA



Solar Thermochemical Capture of Atmospheric CO_2

Summary and Conclusions 1
Key Questions

Value Proposition

- Who has the “pain” and how are you alleviating it?
- What is the cost target?

Architecture

- Distributed or central? Economies of scale or economies of hardware mass production?
- Reactions, separations or other? What temperature heat is required?
- Concentrator options, including availability of value chain? What about solar-electric hybrid systems? Do they enhance economic feasibility?
- Energy storage? (Cheap or expensive?)
- Efficiency: What are the sources and magnitudes of exergy destruction?

Summary and Conclusions 2
Key Questions

Carbon Management Value Proposition

- How can concentrated solar thermochemical operations reduce the demand for fossil energy?
- Can we use solar thermochemical systems to go carbon-neutral?
- How about carbon-negative?

CCS: Can we use solar thermal to accomplish affordable Carbon Capture and Sequestration? *Yes*

CCU: How about Carbon Capture and Use? *Yes*

Shovel-Ready

Solar Thermochemical Projects

Coming Soon: Demonstrations