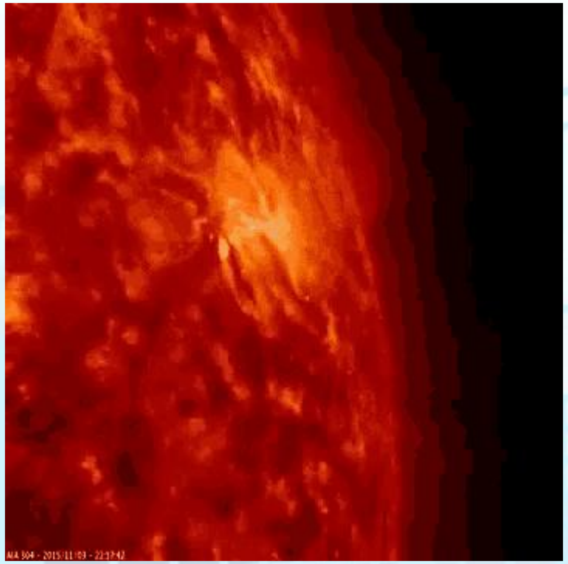
ЕУРАЗИЯ ҰЛТТЫҚ УНИВЕРСИТЕТІ

Title:

Using solar energy for gasification of solid organic matter



Lecture:

PhD, Associate Professor,
Zhumagulov M.G.

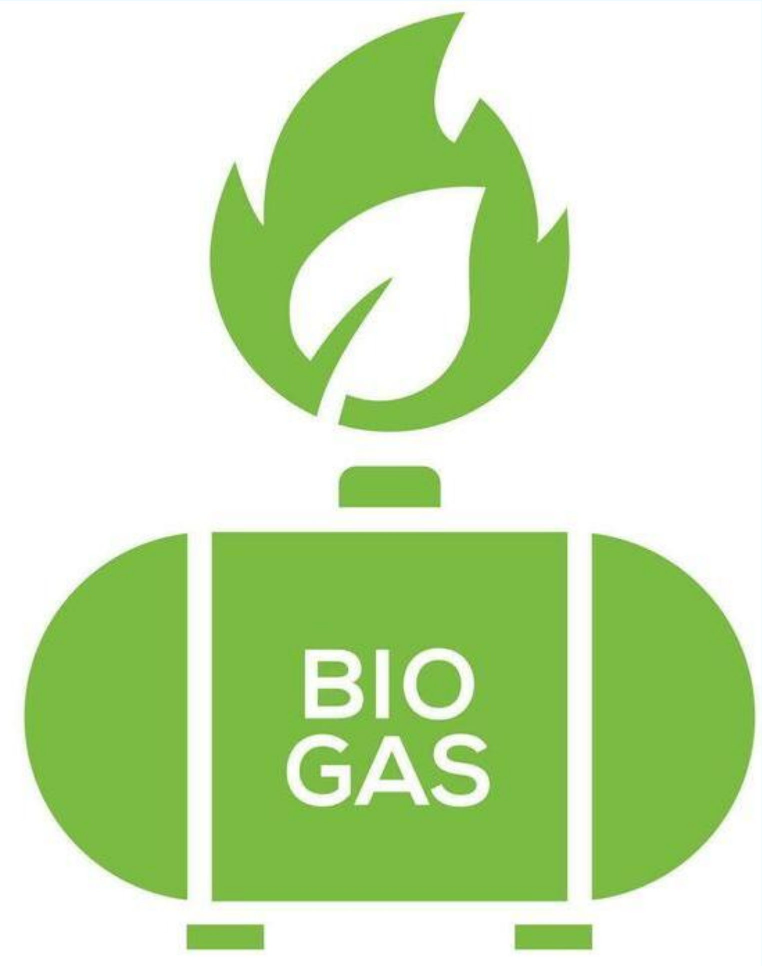
Background

Solar oven

Technical specifications:
- Temperature inside – 127 ^{o}C (North Kazakstan, summer);
- Thermal Efficiency – 41 %;
- Insulation material - mineral wool;
- thermal conductivity – 0,035 W/(m·K);
- Research period – 2015.

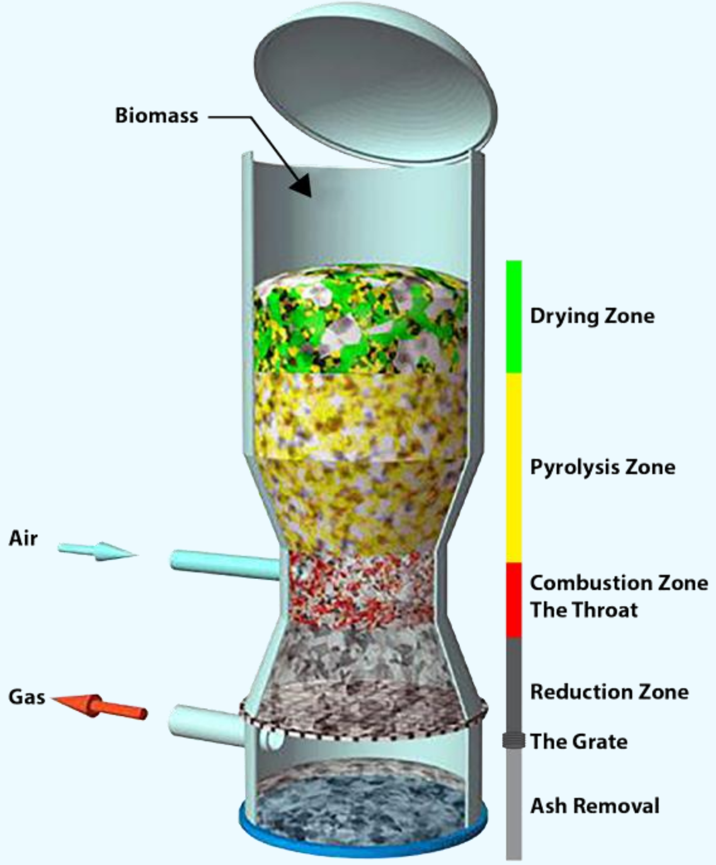
Methods for processing of solid organic matter

Biogas



Yeast and heat

Gasification



Gasification types

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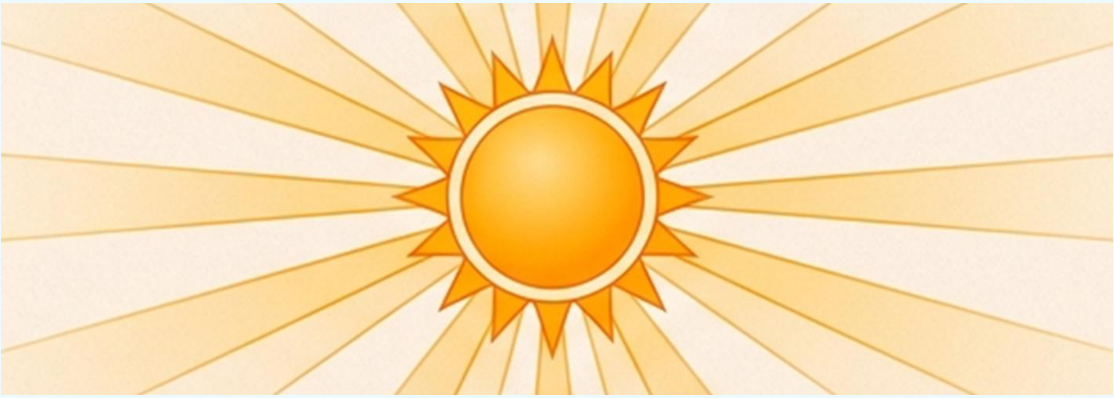
Classic Autothermal Gasification

- Requires burning up to 30-45% of the initial raw material itself to provide for endothermic reactions.
- Energy efficiency inevitably decreases.
- Pollution of the target product and environment with CO_2 ballast (about 1 kg per kWh).

Allothermal Solar Process

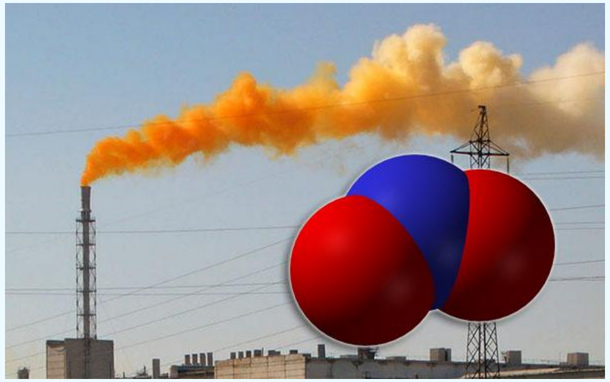


- Solar energy is absorbed by endothermic reactions and “stored” in the form of chemical bonds.
- Increases total calorific value by 20-45% compared to the feedstock.
- Syngas becomes an accumulator of solar energy and organic fuel.
- Maximum product yield: absence of internal combustion produces almost twice as much syngas per ton.

Benefits of using solar energy in gasification

- Maximum product yield: the absence of internal combustion allows for the production of almost twice as much synthesis gas per ton of carbon-containing feedstock

- High gas purity: the product contains less nitrogen and combustion products, which significantly simplifies subsequent purification



- Environmental factor: the process allows for a reduction in specific CO_2 emissions by half compared to traditional stations, as combustion is replaced by a “solar” source

Gasification stages

Stage 1 (300-1000 °C):

Primary Pyrolysis

Thermal decomposition of fuel macromolecules.

Release of volatiles (H_2, CO, CO_2, CH_4), tars, oils, and solid coke residue formation.

Stage 2 (> 1000 °C):

Secondary Gasification

Endothermic reactions of carbon with gasifying agents.

Steam gasification:

$$\boldsymbol{C + H_2O \rightarrow H_2 + CO}$$

(ΔH = +131,3 kJ/mol)

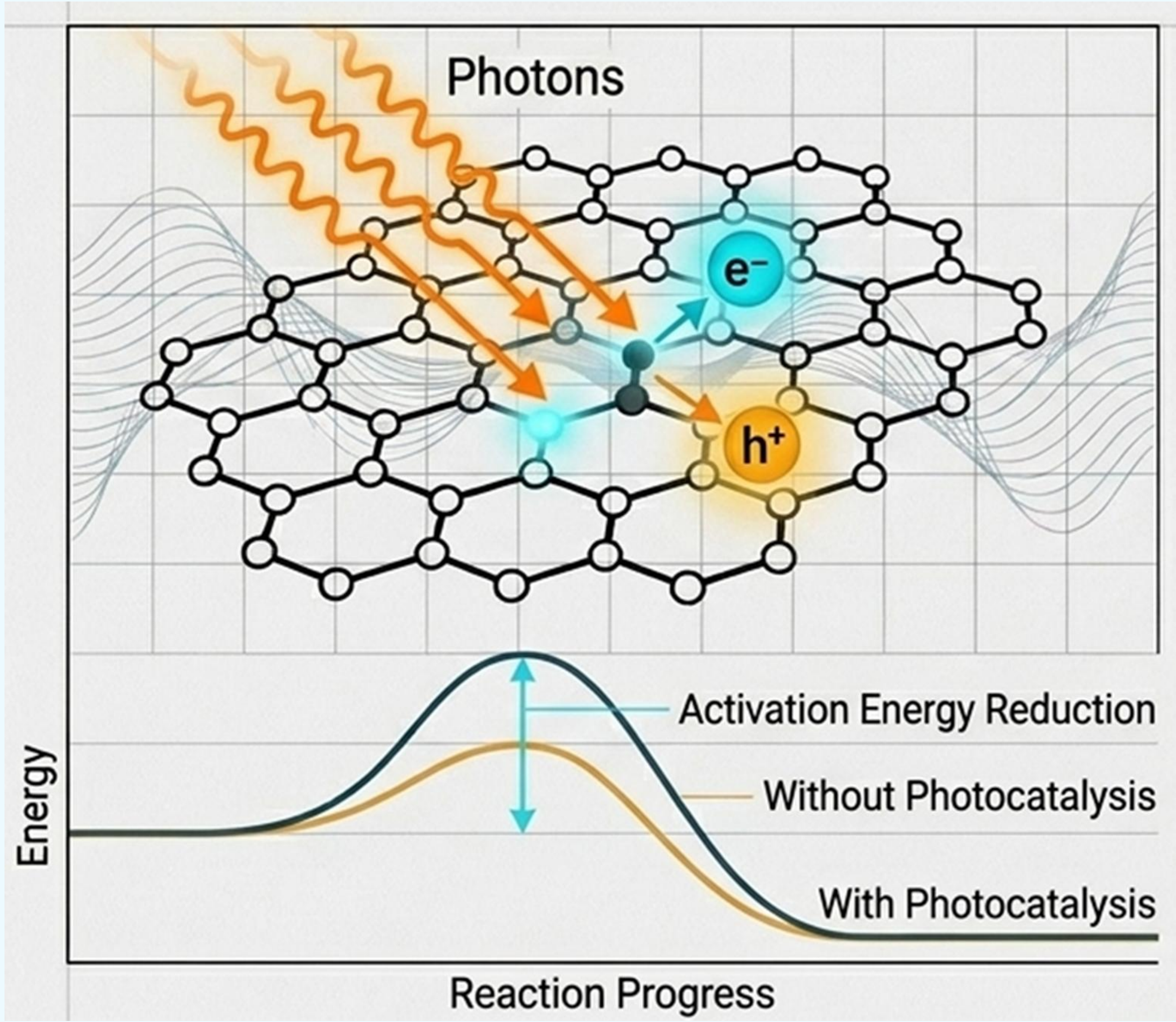
Boudouard reaction:

$$\mathbf{C + CO_2 \rightarrow 2CO}$$

(ΔH = +172,5 kJ/mol)

The Non-Thermal B Photocatalytic Effect

Photons of sunlight are absorbed by graphite structures... forming "electron-hole" pairs (e- and h+).



Step 1: Excited electrons and holes interact with gasifying agents (H_2O or CO_2).

Step 2: Creation of highly reactive free radicals (OH^-, 0^{2-}).

Step 3: They attack stable aromatic rings... converting them into reactive aliphatic carbon chains.

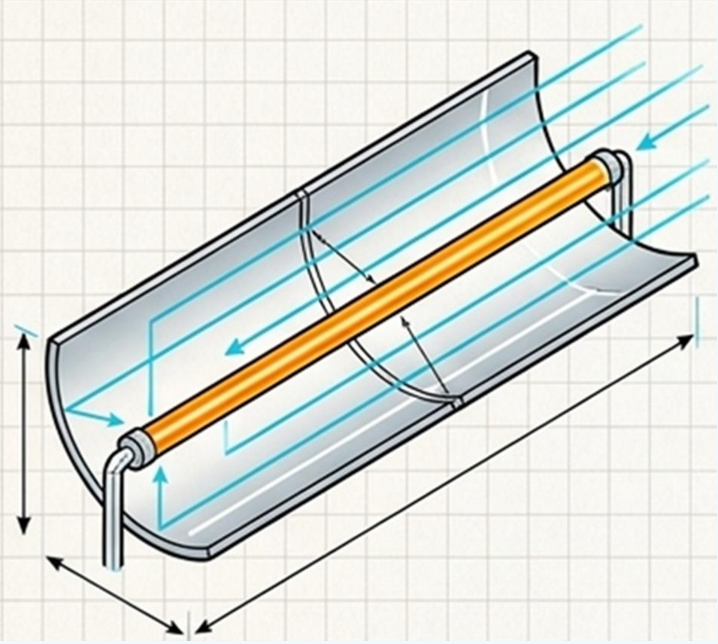
Reduces activation energy of CO_2 reduction from **217 kJ/mol** to **92 kJ/mol** (at 150 suns).

Reduces reaction onset temperature by **150 °C** (reaction starts at 500 °C instead of 650 °C).

Optical Concentration Technologies

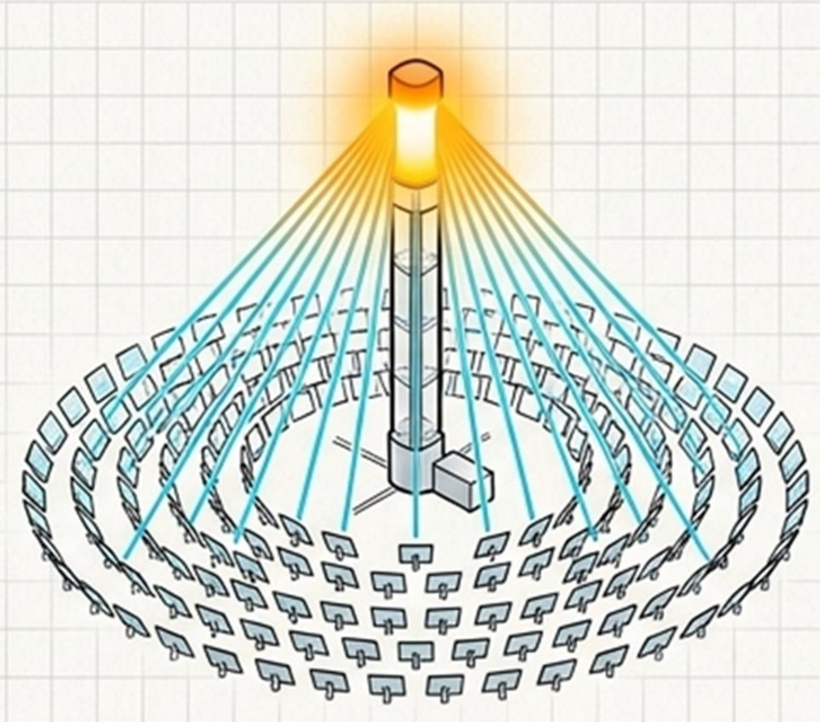
Concentration Ratio ($C = Q_f/I$). Measured in “suns” (1 sun = 1 kW/m^2).

Linear Concentrators



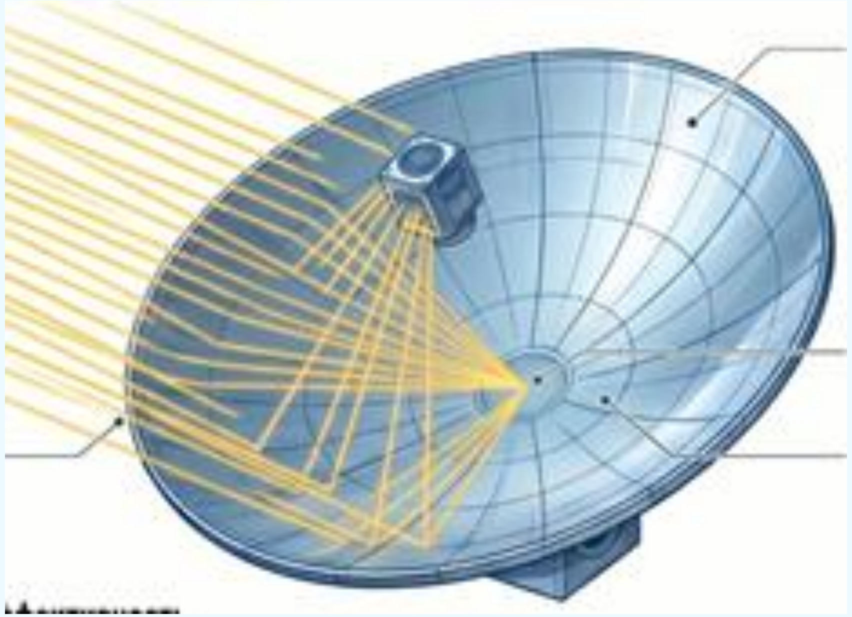
Moderate concentration (30-100 suns), temperatures up to 800 K. Suitable for preheating heat carriers.

Solar Towers



Point concentration. Array of heliostat mirrors. 500-1500 suns. Scalable to megawatt level (10-100 MW).

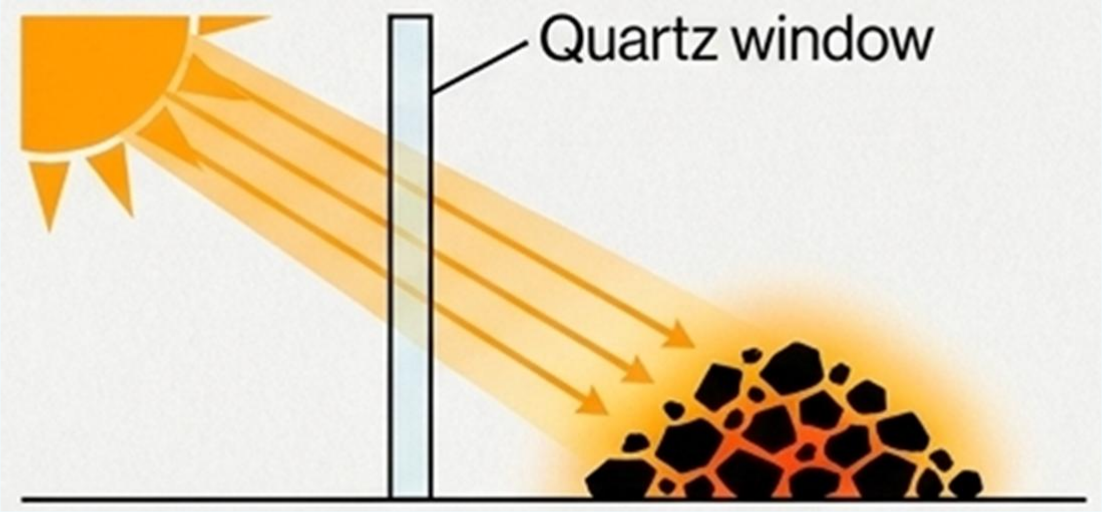
Parabolic Dish



Highest coefficients (1000-5000+ suns), >1500 K. Beam-Down optics redirect rays to ground level, simplifying reactor maintenance.

Reactor (receiver) classification

Direct Irradiation

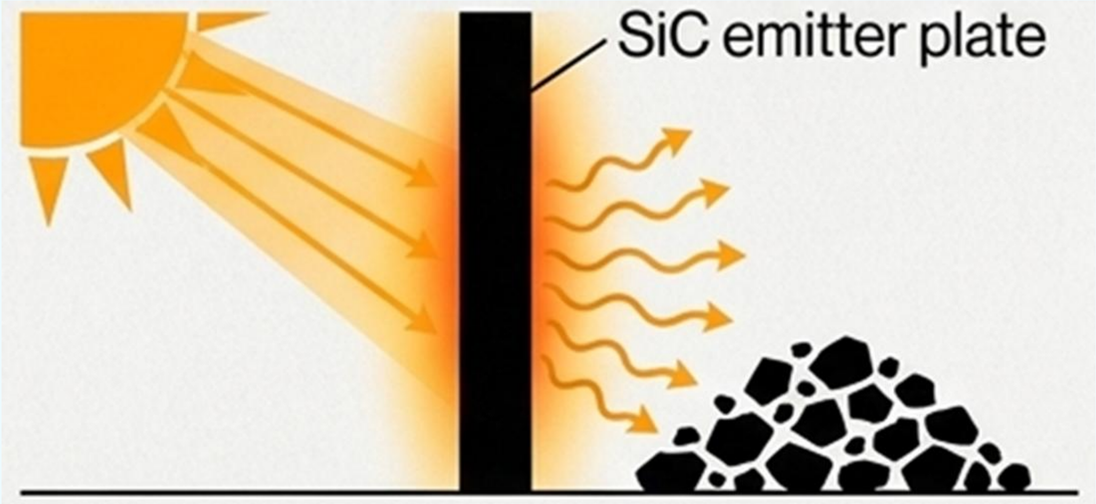


Concentrated flux shines directly on carbonaceous particles via transparent quartz window.

Pros: Intermediate thermal wall resistance is not exist. Extreme heating rates (up to 1000 K/s).

Cons: Technological difficulties with quartz window contamination by pyrolysis tars and dust.

Indirect Irradiation



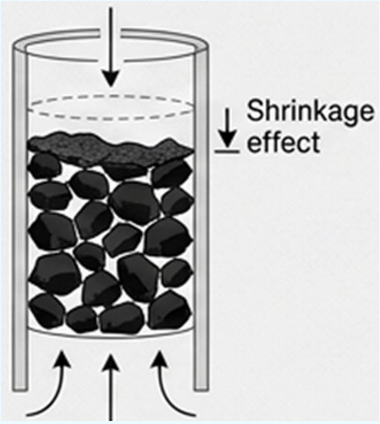
Opaque absorber wall or emitter plate (e g., SiC) transfers heat via conduction, convection, and secondary radiation.

Pros: No window contamination. Allows raising internal pressure to 6 bar.

Cons: Lower efficiency due to absorber temperature limits and heat transfer losses.

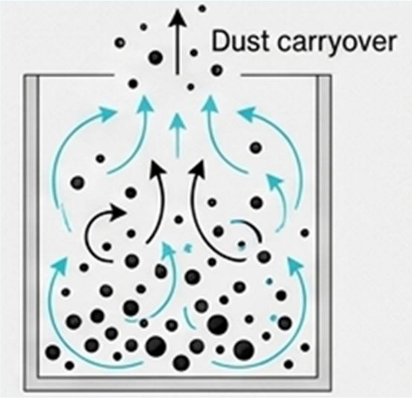
Solar Reactors

Packed Bed



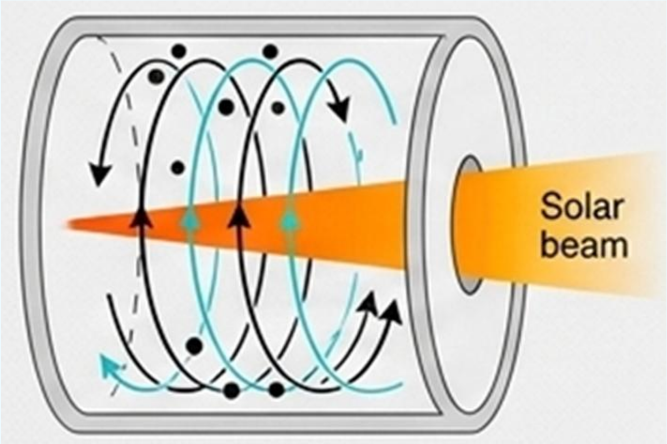
• Simplicity and reliability (batch operation).
• Problem: "Shrinkage effect" during gasification causes the focal point to slip.

Fluidized Bed



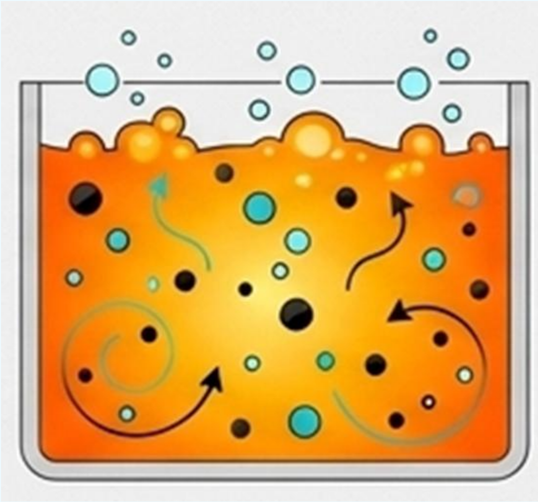
• Improved heat and mass transfer via intensive mixing.
• Drawback: Sensitive to raw material particle size (<1 mm), creating dust carryover risks.

Vortex Reactors



• Particles move in a spiral trajectory along cavity walls.
• Increases residence time in the high-flux zone with compact dimensions.

Molten Salt Reactors



• Melt acts simultaneously as a heat carrier and a powerful catalyst.
• Prevents tar formation and accumulates heat during variable solar loads.

Key Performance Indicators

Carbon Conversion, X_c	Completeness of carbon conversion into gaseous products (CO, CO_2, CH_4). Reaches 87% at T >1300 K.	
Calorific value conversion factor U	$U = \frac{Q^{d}_{i\,syn-gas}}{Q^{r}_{i\,source}}$	
Solar-to-Fuel Efficiency, $\eta_{solar\text{-}to\text{-}fuel}$	$\frac{Q_{syngas}}{Q_{feedstock} + Q_{solar}}$ Thermodynamic modeling of MW scale with optimized insulation reaches 55-63%.	
Solar-to-Chemical Efficiency, $\eta_{solar\text{-}to\text{-}chem}$	$\frac{\Delta H_{reaction}}{Q_{solar}}$ Fraction of incoming solar energy directly stored as chemical reaction enthalpy. Achieves up to 40-48%.	

Comparison of Solar Gasification Technologies

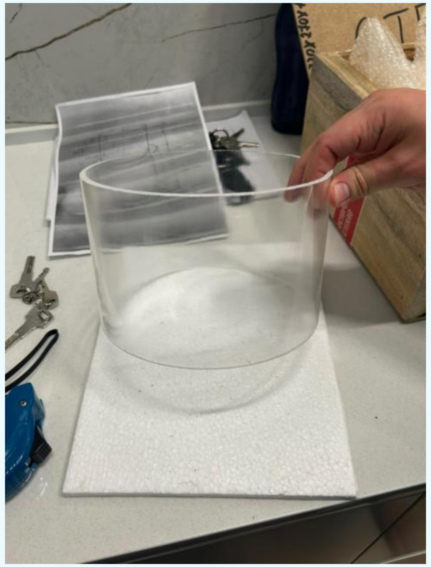
Reactor	Temp (°C)	Upgrading Factor (U)	Carbon Conversion (X_c)	$\eta_{solar\text{-}to\text{-}fuel}$	$\eta_{solar\text{-}to\text{-}chem}$
Direct Irradiation	1027–1527	1.21–1.25	69.1%	16.9%	0.5–9%
Indirect Irradiation	1009–1273	1.35	94.4%	19.7%	—
Packed Bed	902–1302	1.07–1.30	77–87%	22–35%	17.3–29%
Fluidized Bed	1000–1177	1.15–1.20	73–80%	—	8–14%
Vortex Reactors	1027–1527	1.20	87%	20%	9–20%
Molten Salt	927–977	1.26*	47–93%	30–45%	30–55%*

Key Insight: U has approximately the same values across types, demonstrating this metric depends more on solar concentration than reactor design.

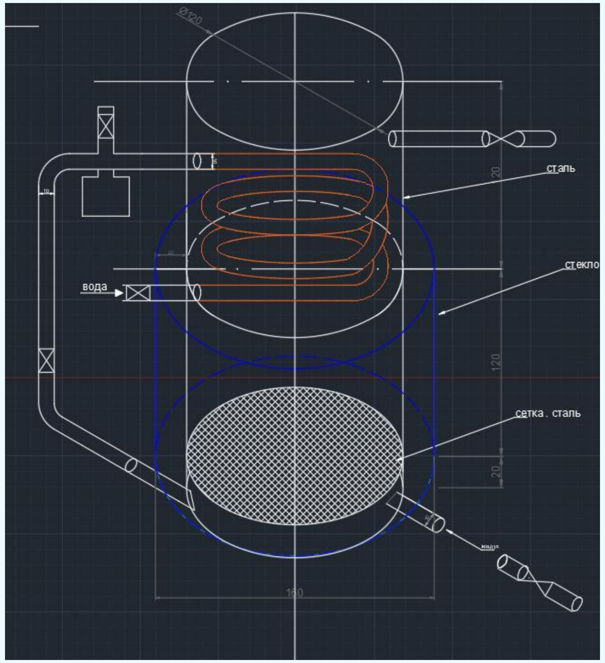
Components for future assembly

Parabolic dish

Mirror film



Quartz glass



Metal Design

Finish

Thank you for your attention!