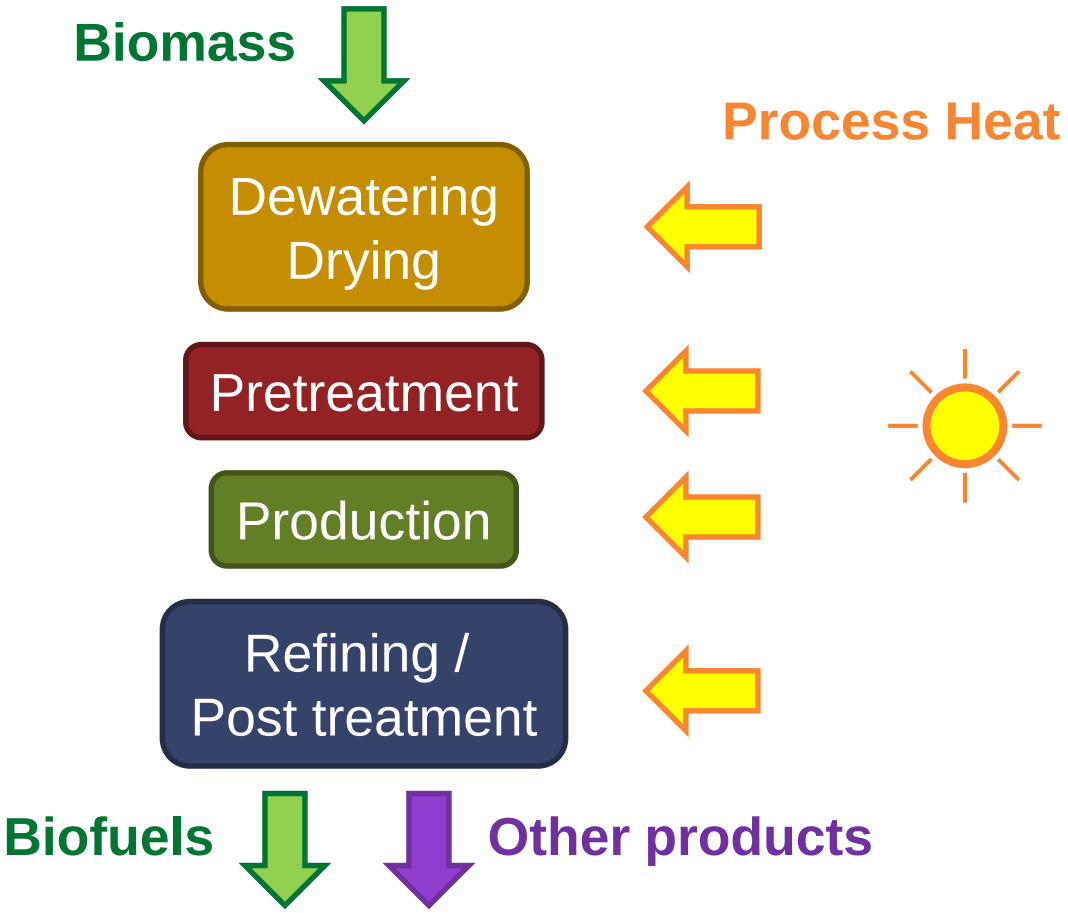
Biomass Processing with Solar Energy

A. Kribus — School of Mechanical Engineering
M. Epstein — Porter School of Environmental Studies
Tel Aviv University

Support:
Israel Ministry of National Infrastructure, Energy and Water

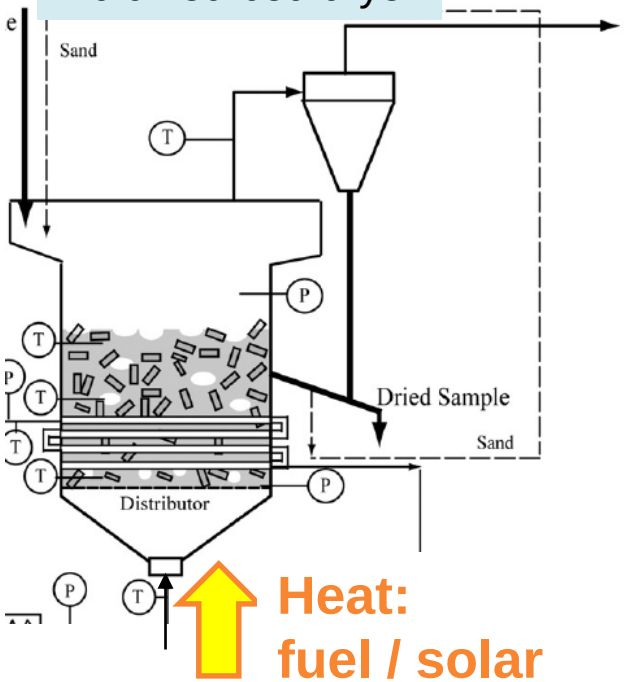
Marine Offshore Biorefinery in Israel Workshop
May 2017, Tel Aviv

Biomass Processing



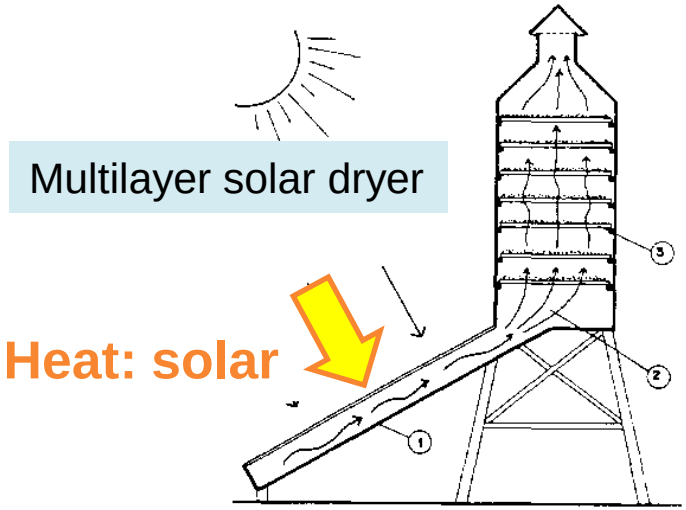
Solar Drying

Fluidized bed dryer

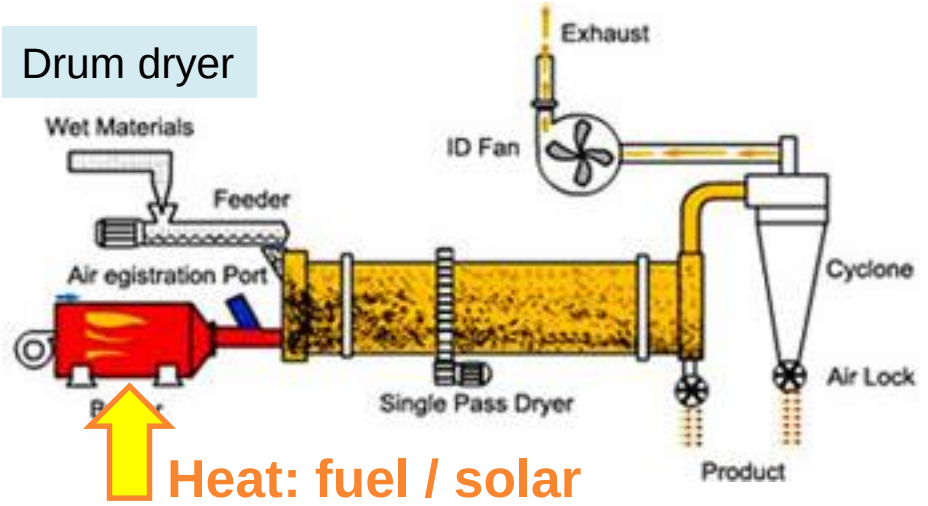


Liu et al., DOI: 10.1016/j.fuproc.2014.10.005

Multilayer solar dryer



Drum dryer



http://www.gemcopelletmill.com/rotary-drum-dryer.html

Pyrolysis / Gasification

Biomass + air / oxygen / steam + **Heat**

Luque et al 2008, DOI: 10.1039/b807094f

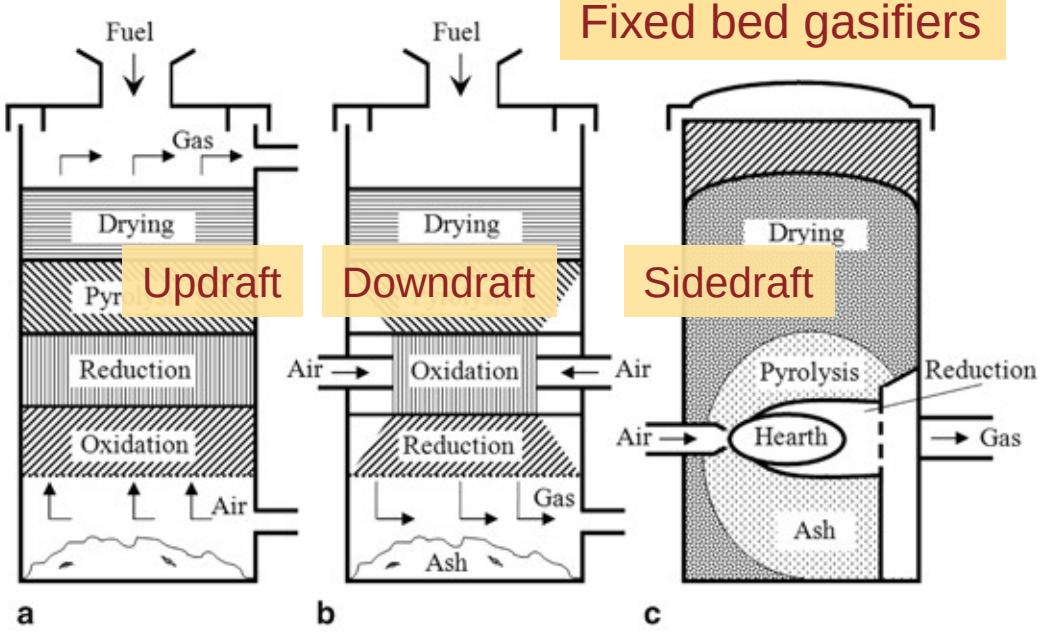
$$(1)\ CH_{1.49}O_{0.67}(s) + 0.33\ H_2O(g) \longrightarrow CO + 1.08\ H_2$$
$$(2)\ 0.52\ CO + 1.56\ H_2 \longrightarrow 0.52\ CH_4 + 0.52\ H_2O(g)$$
$$(3)\ 0.48\ CO + 0.48\ H_2O(g) \longrightarrow 0.48\ CO_2 + 0.48\ H_2$$
$$(4)\ CH_{1.49}O_{0.67}(s) + 0.29\ H_2O(g) \longrightarrow 0.52\ CH_4 + 0.48\ CO_2$$

Drying, pyrolysis, partial combustion, gasification

Products: **H_2 + CO** (Syngas), **CH_4**, tars (C_nH_n), char …

Syngas → **methanol**, etc.

Fixed bed gasifiers



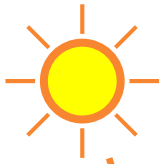
Abdollahi-Neisiani et al. doi: 10.1007/978-3-642-32735-3_10

Solar Gasification

High temperature:

concentrate sunlight

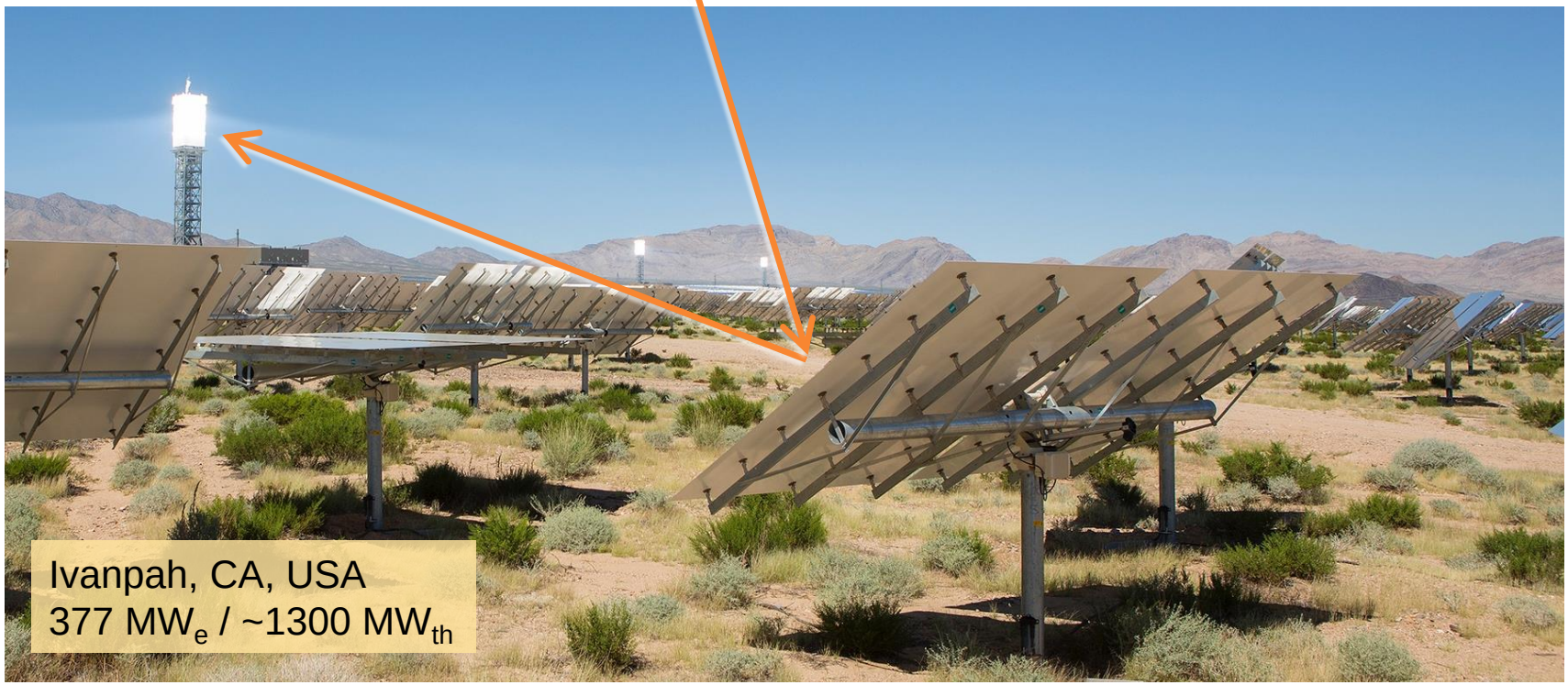
→ Solar tower



Tower technology

Concentration ratio: 500 – 2000

Temperature: 500°C – 1500°C



http://www.brightsourceenergy.com/

Solar Gasification Reactor

Drop-tube solar gasifier

Lichty et al. 2010

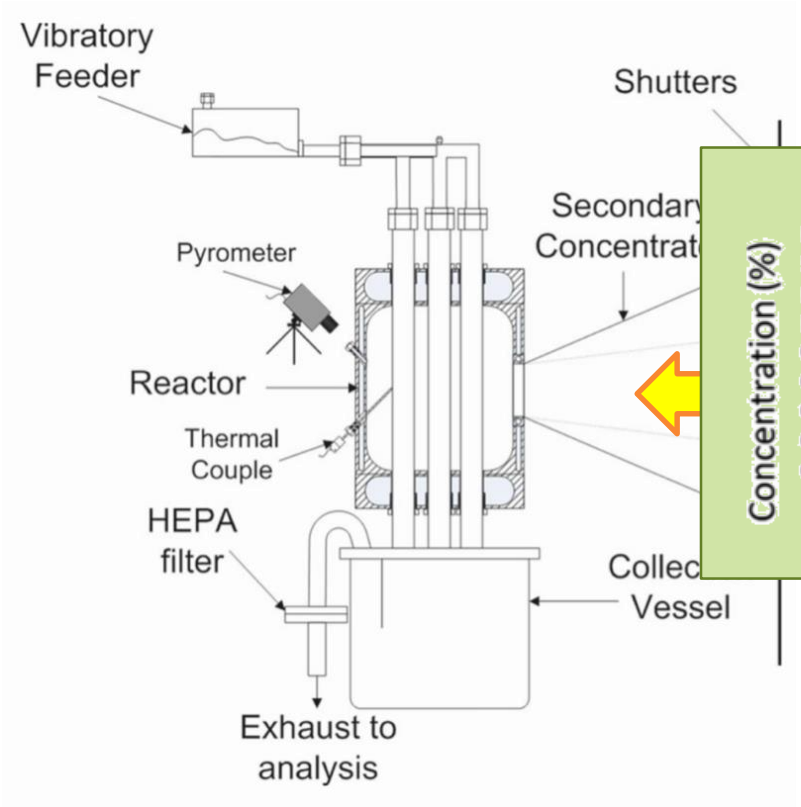
doi:10.1115/1.4000356

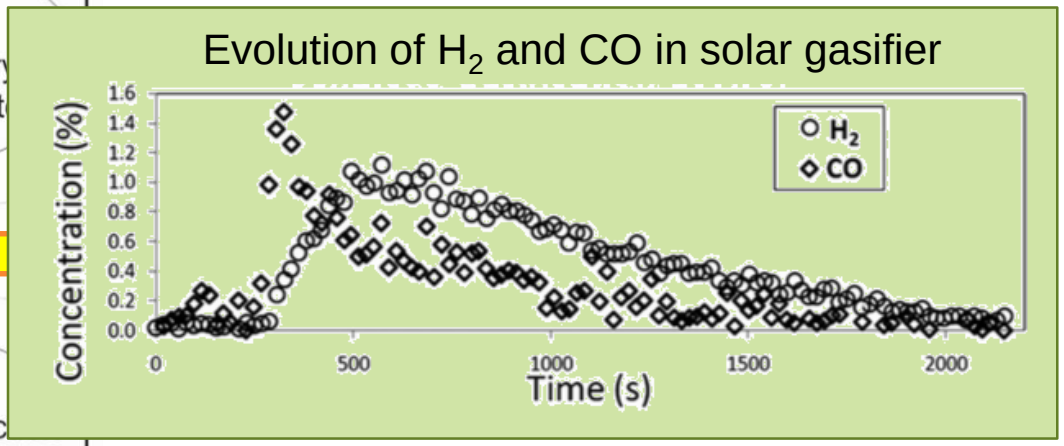
Concentration up to 2500 suns

Temperature up to 1380°C

Residence time: 4 s

Feed: Kentucky Bluegrass, corn stover





Conversion: 58% – **63%**

Product: **+29%** energy content

Solar Gasification Reactor

Fluidized bed solar gasifier

Müller et al. 2017

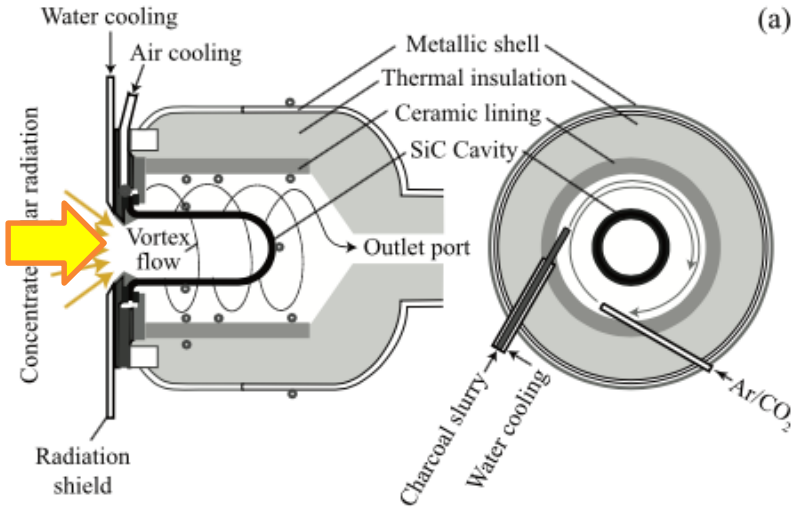
doi:10.1016/j.fuel.2016.12.036

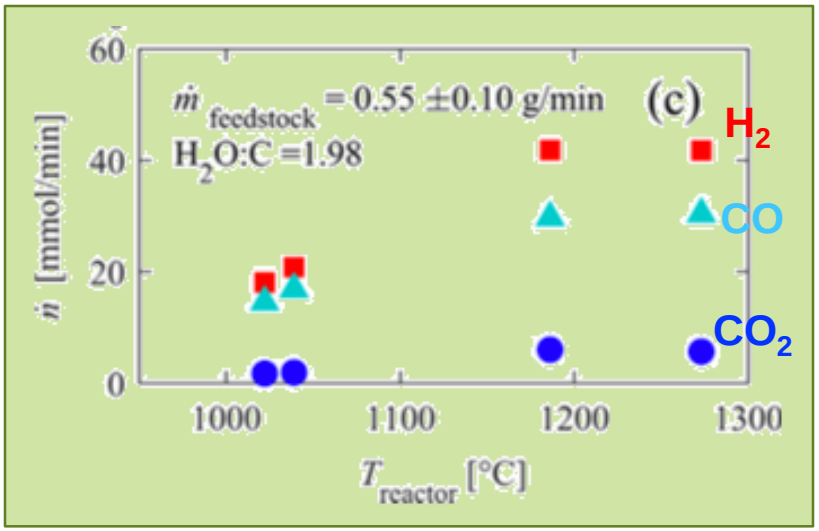
Concentration up to 3700 suns

Temperature up to 1270°C

Residence time: 5 s

Feed: charcoal





Conversion: up to **94%**

Product: **+35%** energy content

Solar Gasification with Molten Salt

Biomass pyrolysis / gasification in molten salt medium

Advantages:

- Alkali metal salts **catalyze the reactions**
- High **heat transfer**
- No combustion (**less CO_2** and **N_2**)
- Thermal **energy storage** (hot salt tank)

Adinberg & Epstein 2004

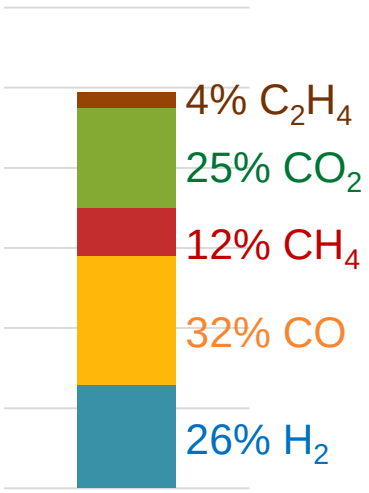
DOI: 10.1115/1.1753577

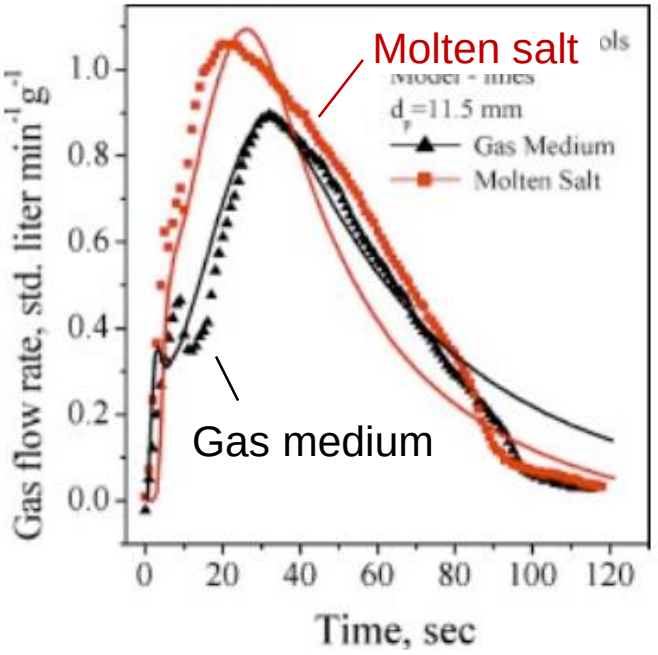
Feed: cellulose

Salt: Na_2CO_3 / K_2CO_3

Temperature: 1123 K

Conversion: 94%

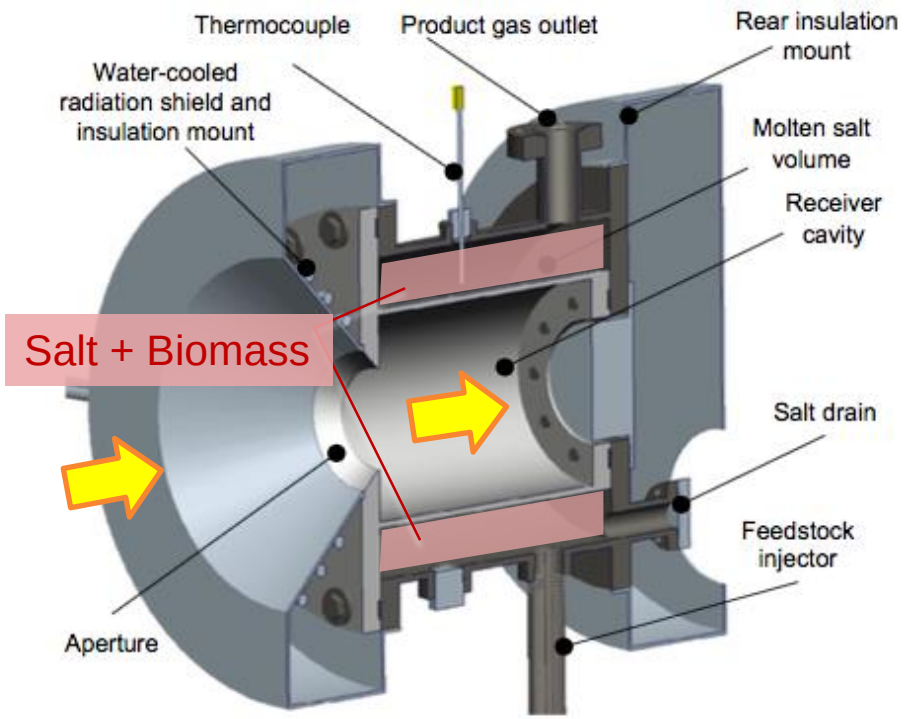




Molten Salt Solar Reactor

Hathaway & Davidson 2017

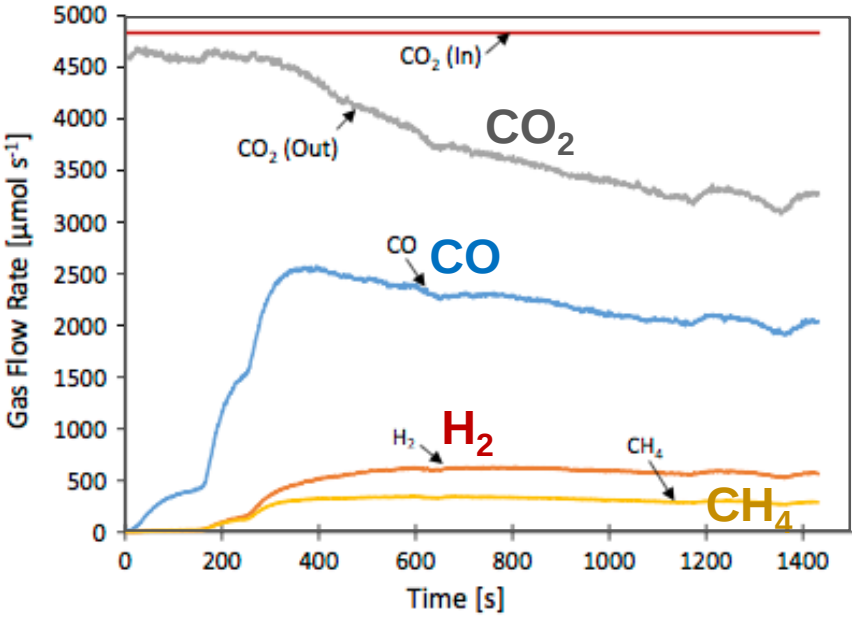
doi: 10.1016/j.solener.2016.12.032



Dry reforming: cellulose + CO_2

$$C_6H_{10}O_{5,(s)} + CO_{2,(g)} \rightarrow 7 \cdot CO_{(g)} + 5 \cdot H_{2,(g)}$$

Salt: Li_2CO_3 / Na_2CO_3 / K_2CO_3
Concentration 1500 suns
Temperature 1200 K



Conversion: 47%

Solar efficiency: 30%

Gasification in Super-Critical Water

SC Water Gasification (SCWG)

- Water as Carrier + Solvent + **Reactant**
- Complete conversion of organic matter
- **Moderate temperature**: solar heat
- Products at **high pressure**

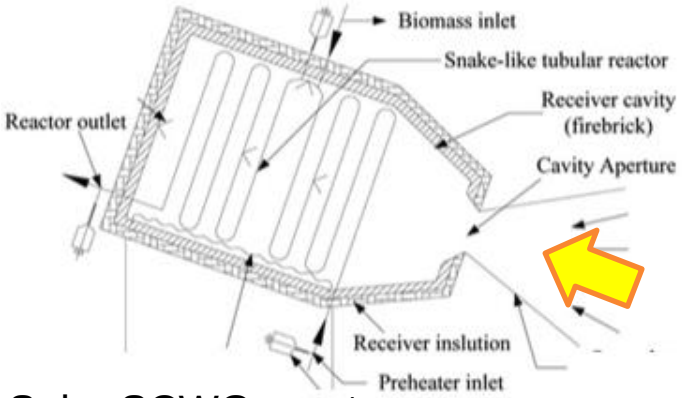
Critical point of water:

T_c = 374°C

P_c = 221 bar

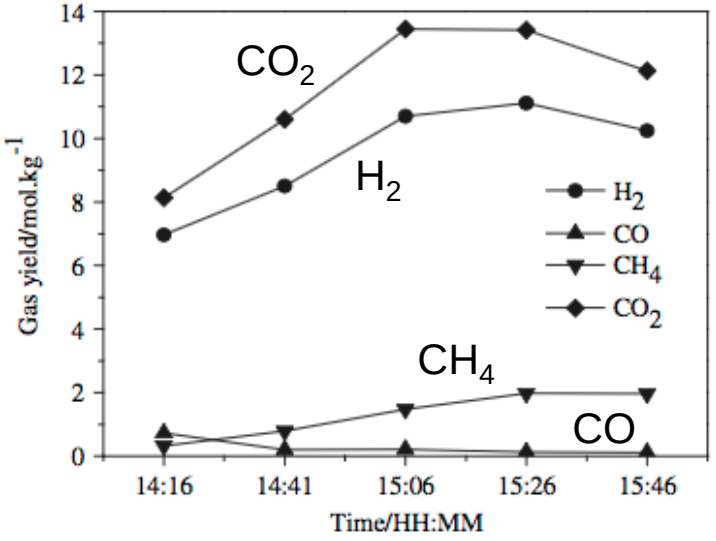
Chen et al. 2010

doi:10.1016/j.ijhydene.2010.02.023



Solar SCWG reactor

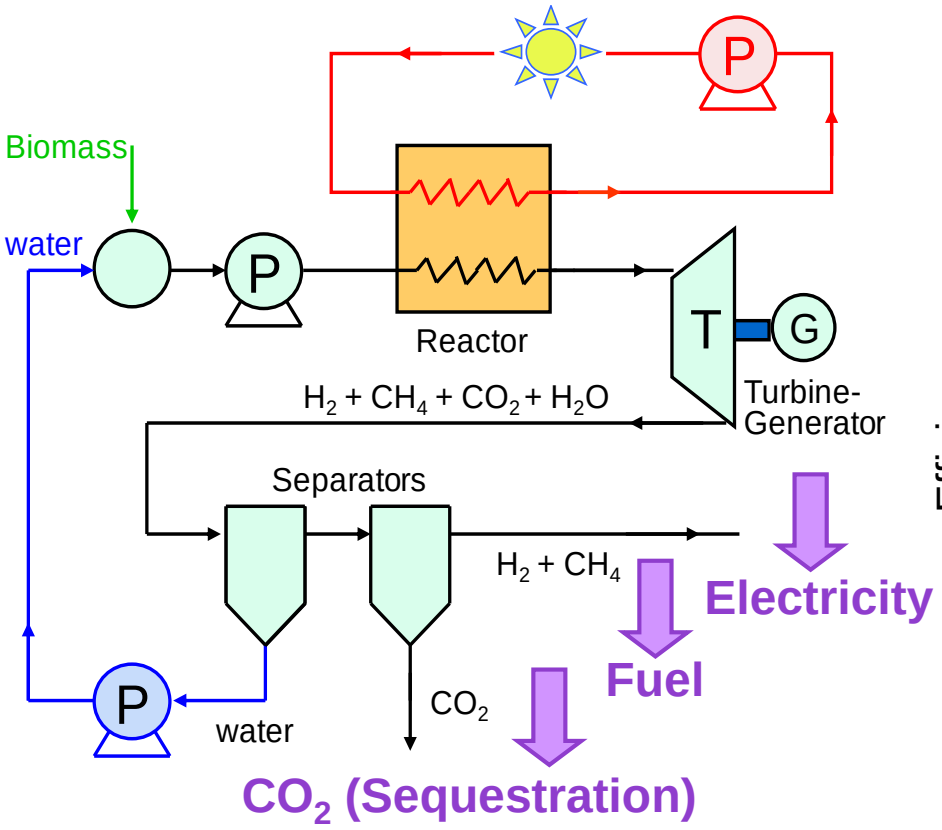
Feed: Corn meal
Temperature: < 600°C



SCWG of Biomass: Process

Ganany, Kribus et al. 2011

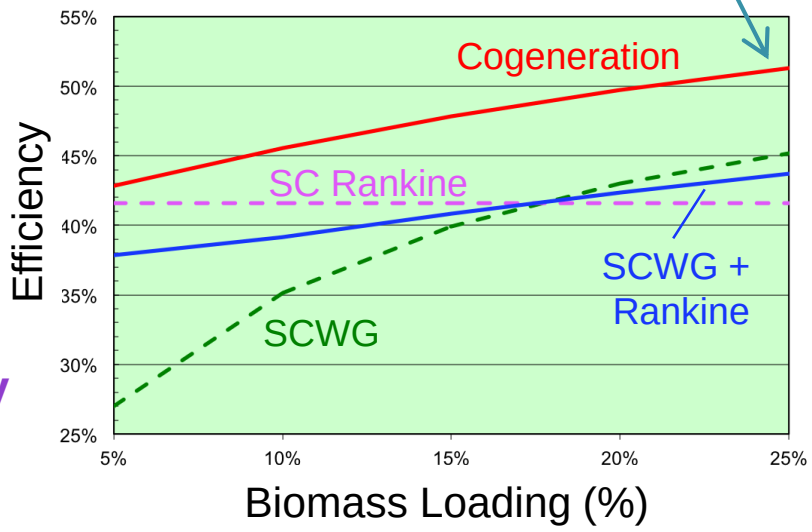
SolarPACES 2011, Granada



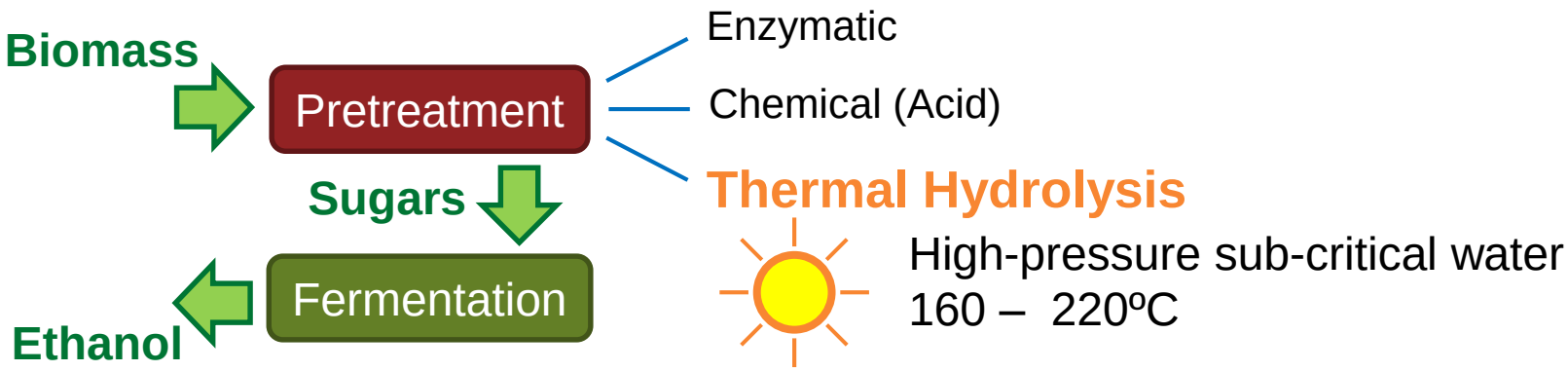
Thermal efficiency: **51%** !

→ Solar efficiency **~ 30%**

Feed: Glucose
Temperature: 600ºC
Triple stage turbine



Solar Thermal Hydrolysis of Biomass

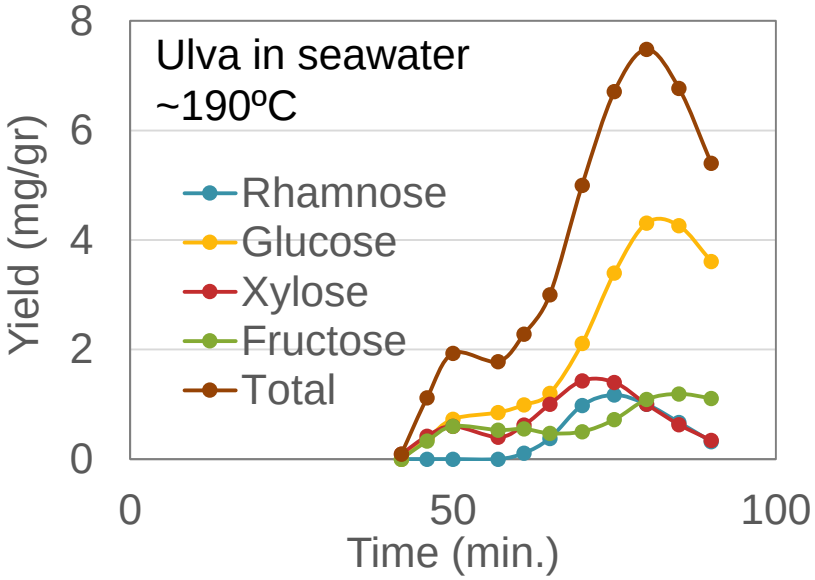


Greiserman, Epstein et al. 2017

Chaetomorpha in seawater
~170ºC

Total sugars:

6.1%



Conclusions

Solar drying – **Existing solutions**

Solar gasification (direct / molten salt / SC water)

High yield but **high temperature**

Solar hydrolysis – **Moderate temperature** but **low yield**

More work needed

Solar hydrolysis:

- Optimization of process parameters / catalysis
- Full plant analysis (upstream & downstream)

Solar gasification:

- Process engineering / cost optimization