Converting CO_2 and Water into Hydrocarbons

Brad Brennan, PhD

Chief Science Officer

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Dimensional Energy

Dimensional Energy

- Founded in 2016 as a Cornell University spinout
- Focus
  - Reactors
  - Catalysts
  - Advanced Materials
  - Integration

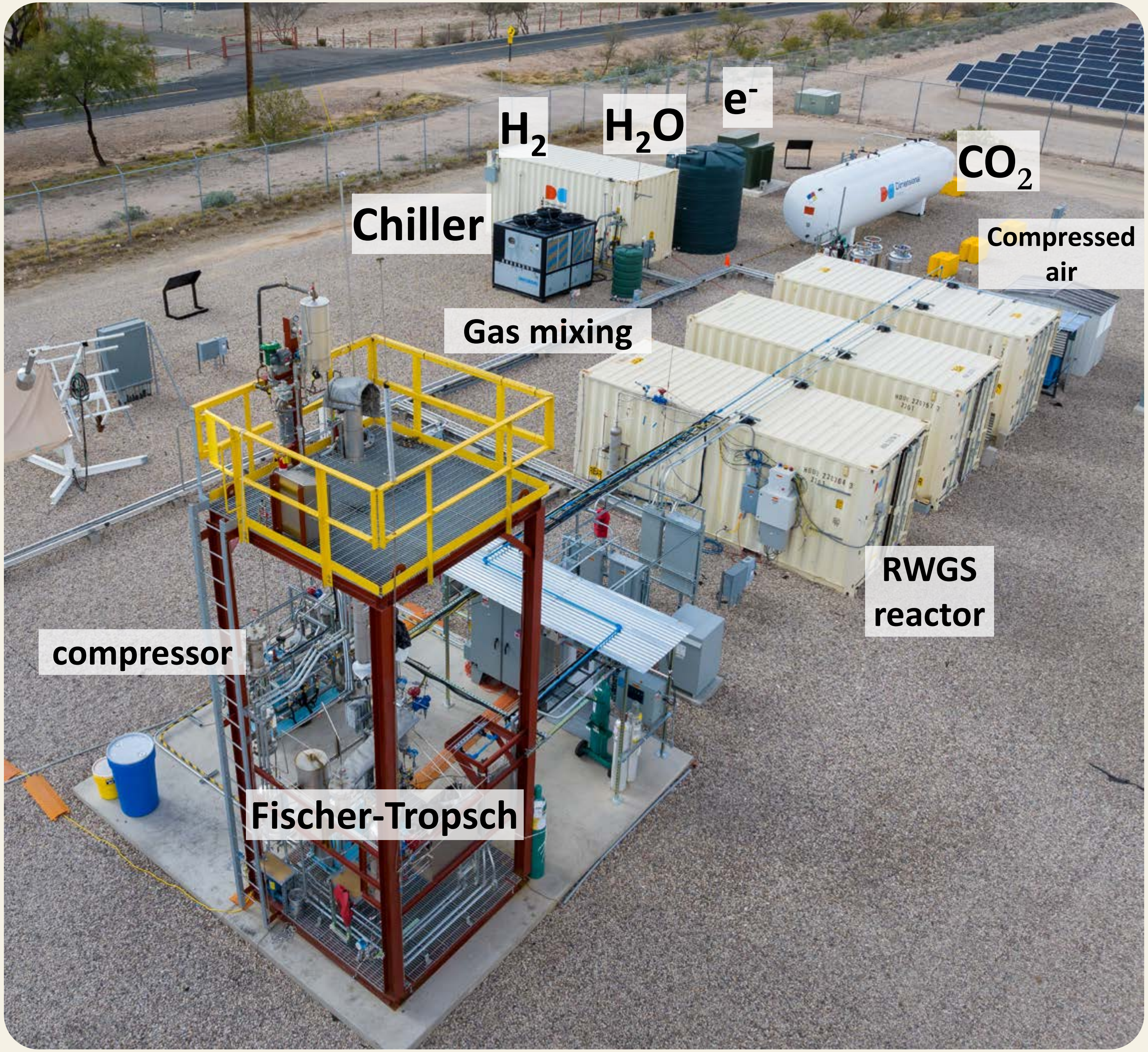
- Currently ~30 employees with ~50% as Scientists/Engineers

- Broadly interested in converting CO_2 into hydrocarbons

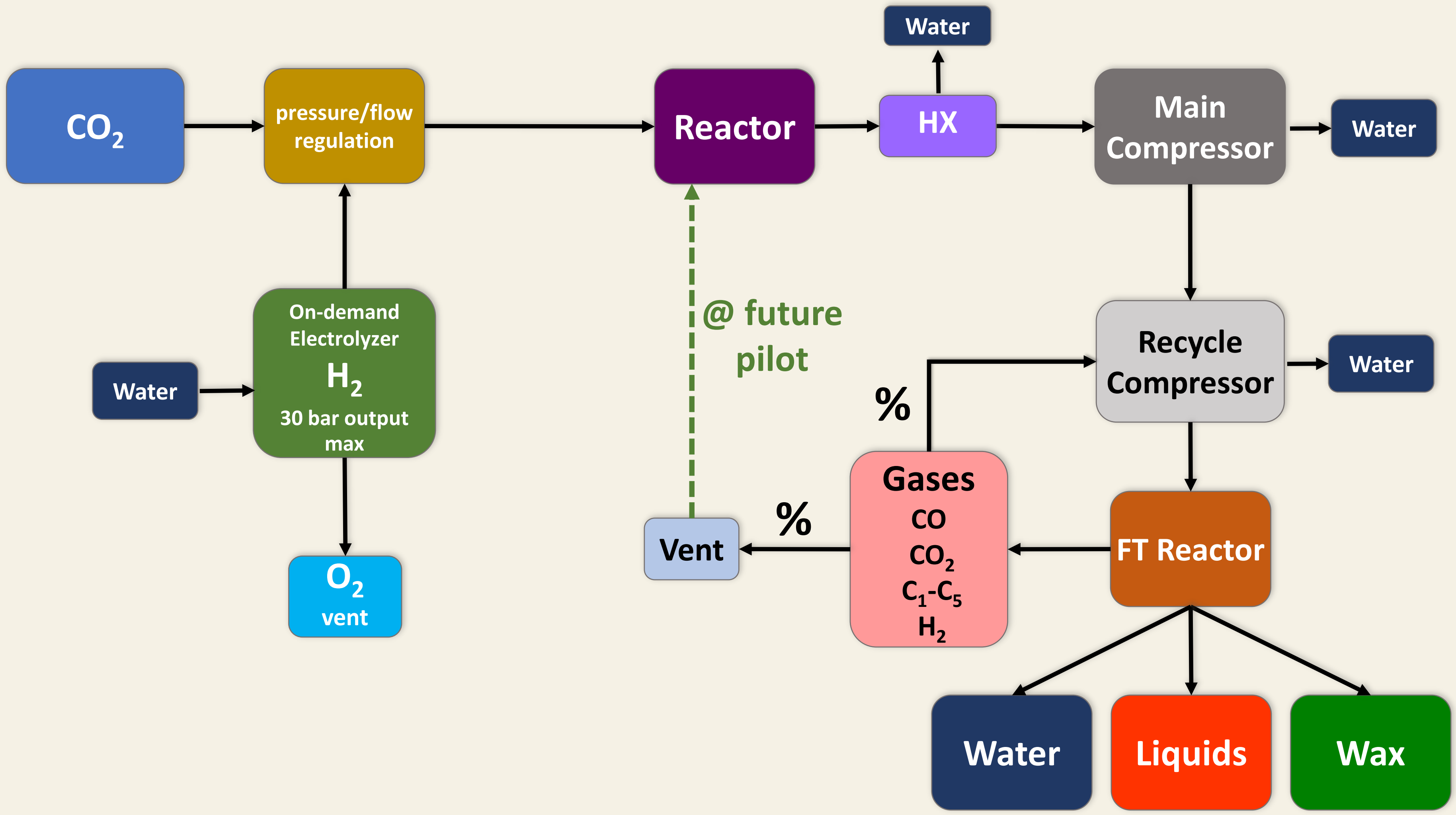
- Pilot Plant (2022) integrates CO_2-to-hydrocarbons technologies
  - $H_2O \rightarrow 2H_2 + O_2$ Electrolysis
  - $CO_2 + H_2 \leftrightarrow CO + H_2O$ Reverse Water Gas Shift (RWGS)
  - $CO + H_2 \rightarrow -(CH_2)_n- + H_2O$ Fischer-Tropsch

Pilot Plant – Tucson, AZ

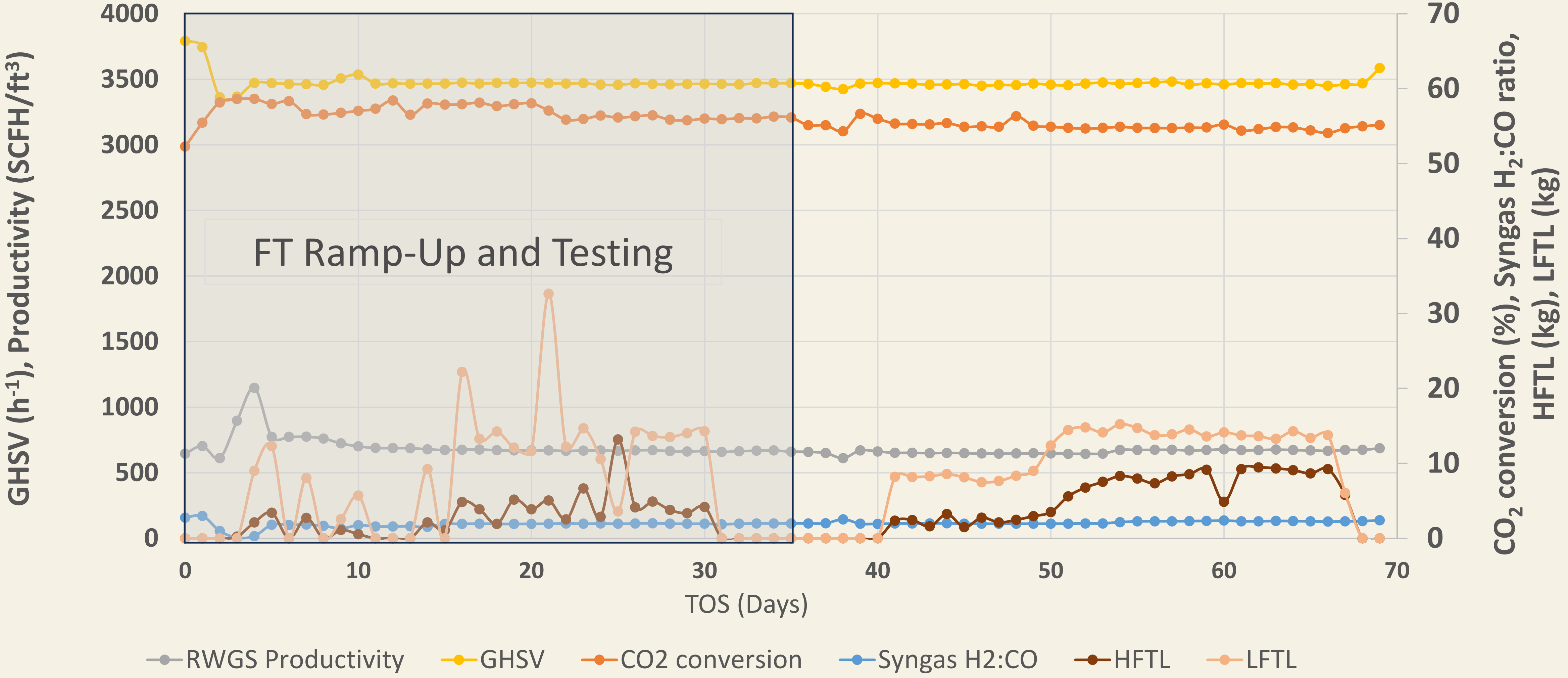
- Sept 2022 start
- ~12 employees
- 24/7 operation
- > 5000 operating hours
- > 500 kg hydrocarbons so far



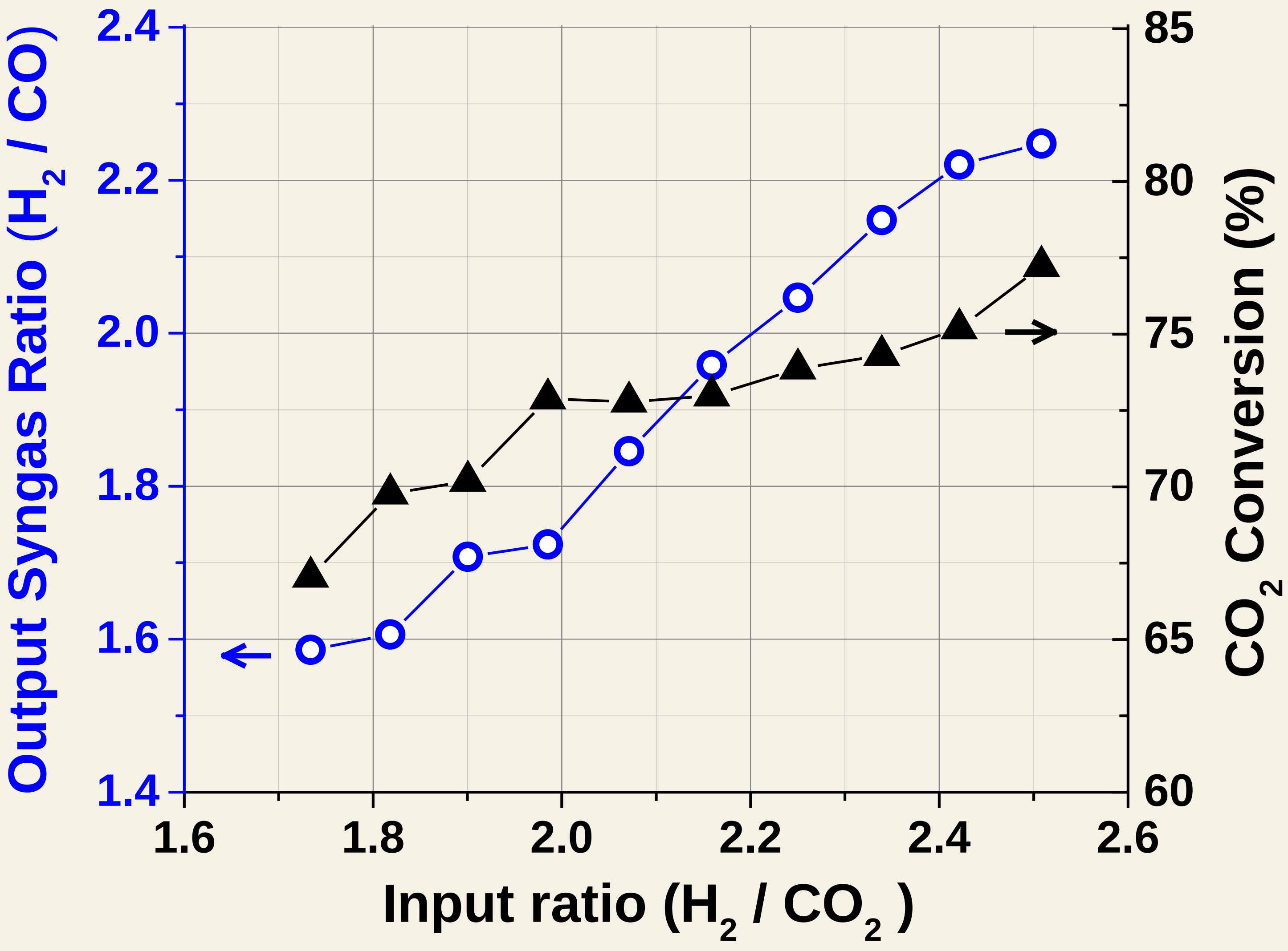
Fischer Tropsch Pilot Plant process flow



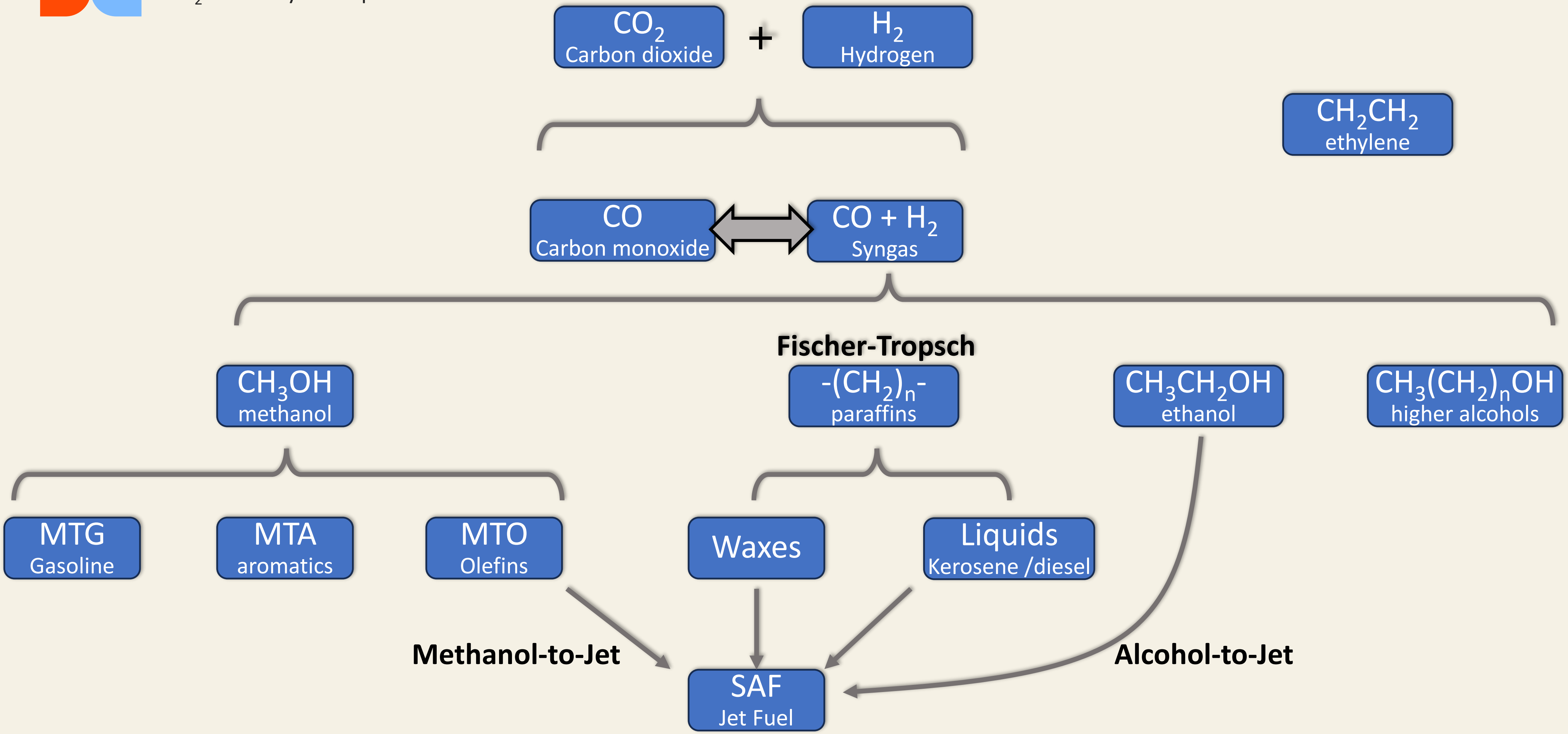
Pilot Plant Performance



- CO_2 conversion ~55% @ 850°C
- GHSV of 3500 hr^{-1}
- > 99% Selective for CO
- Zero Coking after > 2000 hours
- Tunable automated H_2:CO ratio
- Tuning of hydrocarbon chain length


Output Syngas Ratio (H2 / CO)
2.4
2.2
2.0
1.8
1.6
1.4
CO2 Conversion (%)
85
80
75
70
65
60
1.6
1.8
2.0
2.2
2.4
2.6
Input ratio (H2 / CO2)

@ 950°C



CO2
Carbon dioxide
+
H2
Hydrogen
CH2CH2
ethylene
CO
Carbon monoxide
CO + H2
Syngas
Fischer-Tropsch
CH3OH
methanol
-(CH2)n-
paraffins
CH3CH2OH
ethanol
CH3(CH2)nOH
higher alcohols
MTG
Gasoline
MTA
aromatics
MTO
Olefins
Waxes
Liquids
Kerosene /diesel
Methanol-to-Jet
Alcohol-to-Jet
SAF
Jet Fuel

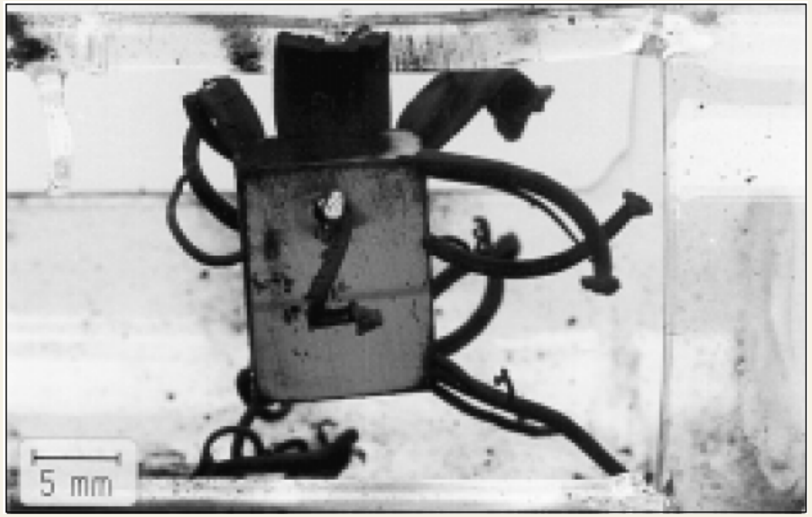
Reactor Alloys

- Unwanted catalytic properties

- Required properties @temp/pressure
  - Temperature constraints
  - Phase Transitions
  - Creep Strength
  - Thermal conductivity

- Hydrogen embrittlement

- Corrosion
  - Hydrogen embrittlement
  - Metal dusting
  - Carbon formation
  - steam



Important chemical reactions

- CO Reduction

  Bosch Reaction

$$H_2 + CO = C + H_2O$$
$$\left(\Delta H^0_{298} = -131.3\ \text{kJ/mol};\ a_{C_1} = K_1 \frac{P_{CO} P_{H_2}}{P_{H_2}}\right)$$

- Boudouard

$$2CO = C + CO_2$$
$$\left(\Delta H^0_{298} = -172.4\ \text{kJ/mol};\ a_{C_2} = K_2 \frac{P_{CO}{}^2}{P_{CO_2}}\right)$$

- Carburization $M + C \rightarrow M_{23}C_6$ / M_7C_3 / M_3C M=metal
- Dusting (iron) $3Fe + C \rightarrow Fe_3C \rightarrow 3Fe + C$ meta-stable decomposition
- Carbonyl formation $Ni + 4CO \leftrightarrow Ni(CO)_4$ ΔH^o_{298} = -147 kJ/mol

  $Fe + 5CO \leftrightarrow Fe(CO)_5$ ΔH^o_{298} = -116 kJ/mol

Thermal management is vital

- Production
  - Electric
  - Burning fuels
  - Microwave
  - Magnetic inductive

- Transport
  - Steam
  - Thermal fluids

- Use
  - Power generation
  - Pre-heating / removing heat from chemicals
  - Reactors

- Storage
  - Sensible heat
  - Latent heat
  - Thermochemical

Thermal integration is necessary for cost / efficiency

High temperatures and corrosion require new materials

Manufacturing heterogeneous catalysts is a technology-enabled art-form

Tableting

1. Prepare catalyst via precipitation, etc
2. Mix all components together as powder
   ie. Catalyst, binders, support
3. Compression into die @specific pressure to form pellet
4. Heat treatment

Extrusion

1. Mix support, binder, and lubricants as powder
2. Extrude through die @specific pressure/temp
3. Heat treat support @specific temp
4. Impregnate catalyst materials
5. Active catalyst prep steps

Alternative routes

- **3D printing**
- Sol gel
- CVD / PVD / Sputtering / Plasma

Heterogeneous Catalyst Issues

Manufacturing

- Preparation
  - Impurities
  - Phase (bulk and surface)
  - Dopants
  - Effects of Recipe

- Materials specs
  - Sufficient strength
  - Pressure buildup
  - Adequate pore sizes

Operation

- Reaction selectivity (and change over time)

- Corrosion
  - Attrition / mechanical degradation
  - Loss of materials (gaseous decomposition)

- Degradation
  - Sintering / loss of active sites or surface area
  - Chemical phase change
  - Coking
  - Chemical deactivations
    - Carbides
    - Carbonyls
    - Reacting with catalyst support

Heat Exchangers

- Uses
  - Feed / Effluent
  - Effluent / Steam
  - Steam / Feed
  - Water cooled
  - Solid / Gas

- Issues
  - Operational temperature ranges (differentials)
  - Temperature limits
    - Materials and assembly connections
  - High Pressure limits
  - Corrosion / Fouling

- Solutions
  - New Materials (ceramics require new methods)
  - New manufacturing methods
  - Coatings

https://www.energydais.com/titan-metal-fabricators/shell-and-tube-heat-exchangers-9270
http://www.fbmhudson.com/shelltube-heat-exchangers/

Some Solutions

- Materials choice
  - Doping
  - Composites
  - Specific phase
  - Modified material
  - Coatings

- Method of making material / system
  - Modified conventional
  - Exotic
  - 3D printing

- New process schemes
  - Chemical routes
  - Reactor designs

Need this…

…to scale to this

Shell Pearl GTL Plant - *Qatar*

Assumptions of Power-to-X system using *Fischer Tropsch*

- \$0.04-\$0.05 / kWh electricity
- \$60-\$100 / ton CO_2
- \$400-\$600 / kW electrolyzer
- 20 yr project life

- 1,000 barrel/day (42,000 gal/day) = **\$4.25 / gal SAF**
- 10,000 barrel/day (420,000 gal/day) = **\$3.48 / gal SAF**
  - \$0.035 / kWh
  - \$50 / ton CO_2
  - \$200 / kW electrolyzer
  - No subsidies

Thank You

and our funders

ARPA-E

SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

Feel free to contact me

Brad@dimensionalenergy.com