Processing of Gaseous Waste Streams to Renewable Fuels and Chemicals

John N. Kuhn

Associate Professor

Chemical Engineering

RES&SC 2017

USF UNIVERSITY OF SOUTH FLORIDA

ACKNOWLEDGMENTS

Funding sources (biogas conversion):

- FESC
- Hinkley Center for Solid and Hazardous Waste Management
- T2C-Energy LLC *
- Dept. of Energy (DE-SC0015221)
- Florida HighTech Corridor
- NASA / FSGC

*

Funding sources (CO_2 conversion):

- National Science Foundation (CBET-1335817, IIP-1743623, and EEC-1560303)
- NASA / FSGC

Collaborators:

- Prof. Babu Joseph (USF & T2CE*)
- Prof. Venkat Bhethabotla (USF)
- Matt Yung (NREL)

* Disclosure, USF and T2C-Energy LLC

WASTE-TO-ENERGY (WTE)

OFMSW (~25% of 350E6 metric tons*/ EREF**)

Separation

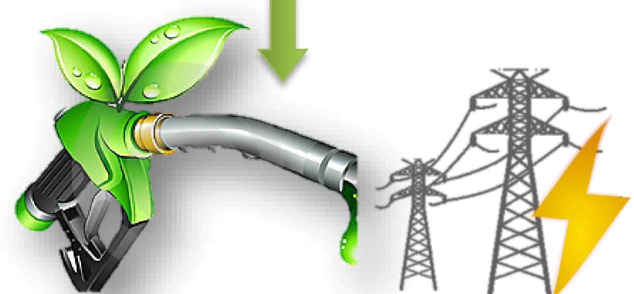
Chemical Processing

Gas Recovery

LFG

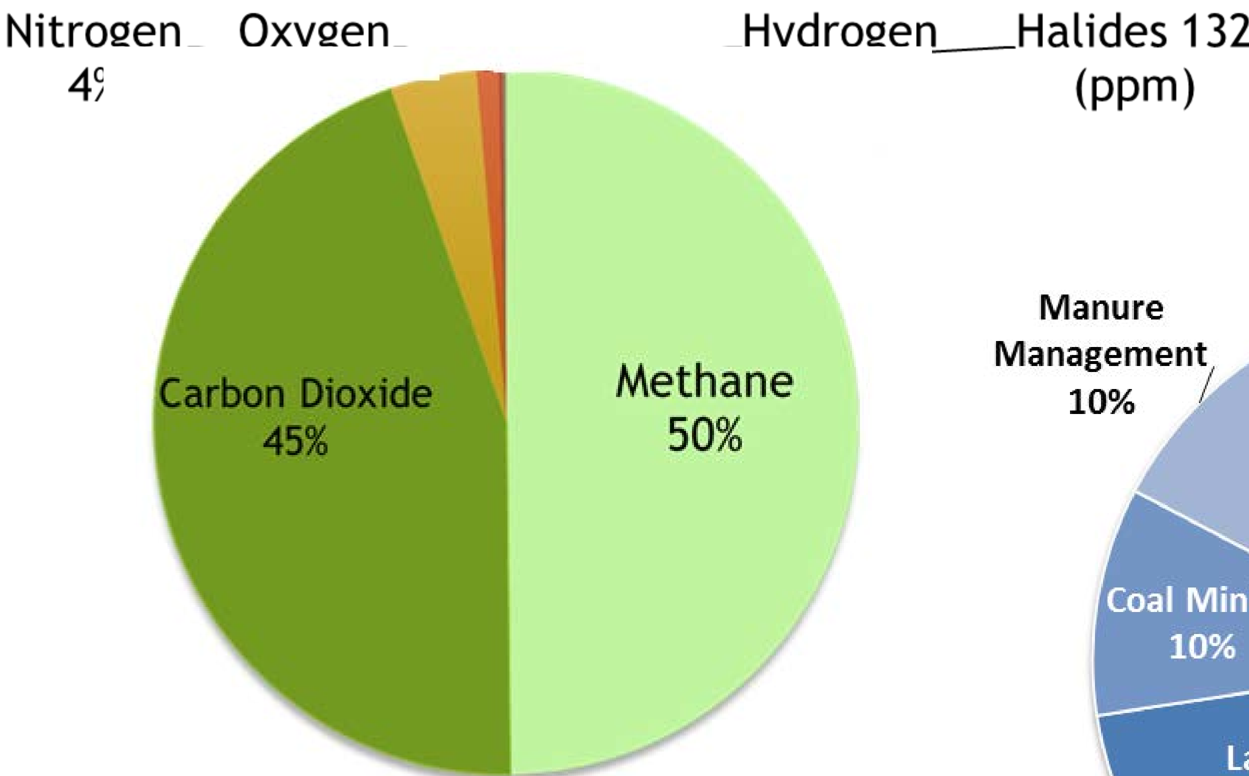
Chemical

Processing

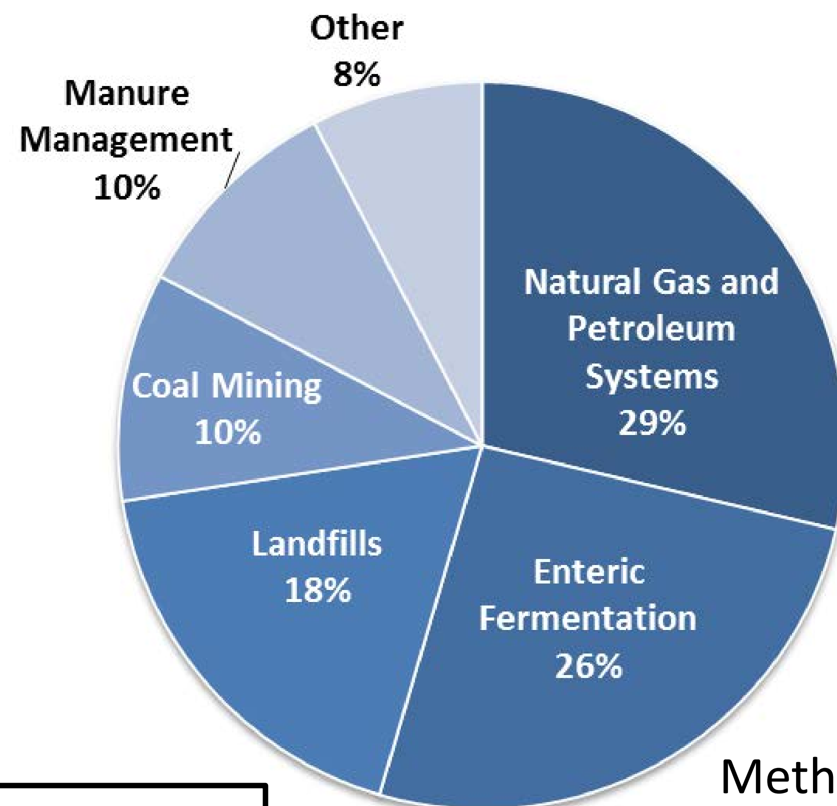


*another 87E6 tons that is recycled and composted / ** 40% higher than EPA

Potential & Problems of LFG



Safety



Methane emissions in 2013

Energy

Environment

EPA/EIA

Impact of LFG

- In 2013, US generated a total of 250 million tons of trash (4.4 lbs/person/day) most of which went to landfills.
- The average amount of LFG emitted per year is $83m^3$/ton MSW (6.5 cu. ft./person/day)

  - *"Of the 2,400 or so currently operating or recently closed MSW landfills in the United States, more than 550 have LFG utilization projects. EPA estimates that approximately 540 additional MSW landfills could turn their gas into energy, producing enough electricity to power nearly 716,000 homes"*

Sources: EPA, IEA, DOE

LFG Conversion Processes

Option	Strengths	Weaknesses
Flaring	• Cheap • Easy	• Wastes valuable resources
Electricity (CHP)	• Widely adopted • Decreases waste landfilled	• Competes with cheaper options • Low product value
Compressed natural gas (CNG)	• Easily Scalable • Produces pipeline quality fuel	• High equipment and operation costs • Competes with cheap alternatives
Liquid fuel production	• Value-added product	• Technology still under development

Opportunity

NEED FOR HYDROCARBON FUELS

Plastics *

- 8300 million metric tons plastics produced to date
- 6300 million metric tons plastics discarded as waste to date
- Of waste, 9% recycled, 12% incinerated, and 79% landfilled
- 12,000 million metric tons anticipated by 2050 (landfilled or in env.)
- Only 4 million metric tons of bio-based biodegradable
- ~13 % of U.S. MSW is plastics in 2013 (before recycling)**

Energy-Dense Liquid Hydrocarbon Fuels (i.e., Diesel)

- 100 million bbl crude oil used worldwide per day (~25% in U.S.)
- Equates to 4500 million metric tons per year
- Need for diesel expected to increase (US refineries focused on gasoline)
- Waste industry represents 4% of US diesel consumption (3% for ag)
- Diesel and jet fuel harder to replace to gasoline

* Geyer at al, Science Advances 2017 ** US EPA

Economic Potential of LFG

	Flaring	Electricity	CNG	Liquid Fuel*
FCI (MM $)	1.0	9.4	9.6	9.1
OP-EX (MM $/yr)	0.06	1	4	1.4
Revenue (MM $/yr)	-	3.5	6.2	4.7
NPW (MM $)	-1.1	-0.5	1.2	6.3
DCFRR (%)	-	13	14	28

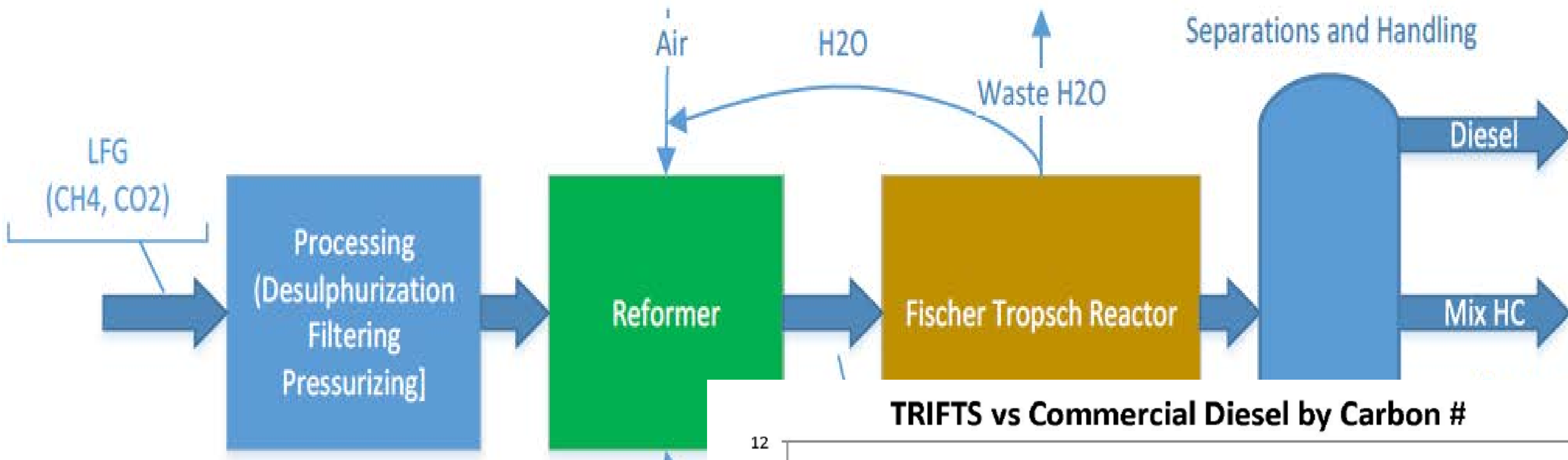
Techno-economic analyses of various LFG-to-energy technologies.

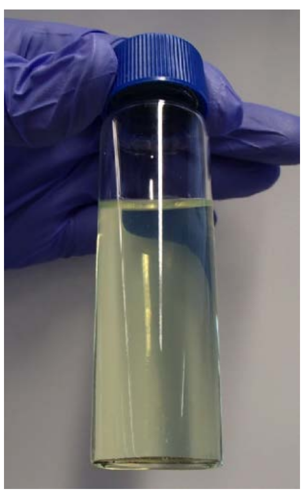
Assumptions:

- 2500 SCFM LFG flowrate
- No subsidies
- Liquid fuel assumed as diesel and sold at wholesale ($1.63/gal)
- Further analyses yielded a breakeven price for diesel of $0.96/gal

USF Thesis 2016, Ryan Kent and *Devin Walker (personal communication)

Process for Catalytic Fuel Synthesis

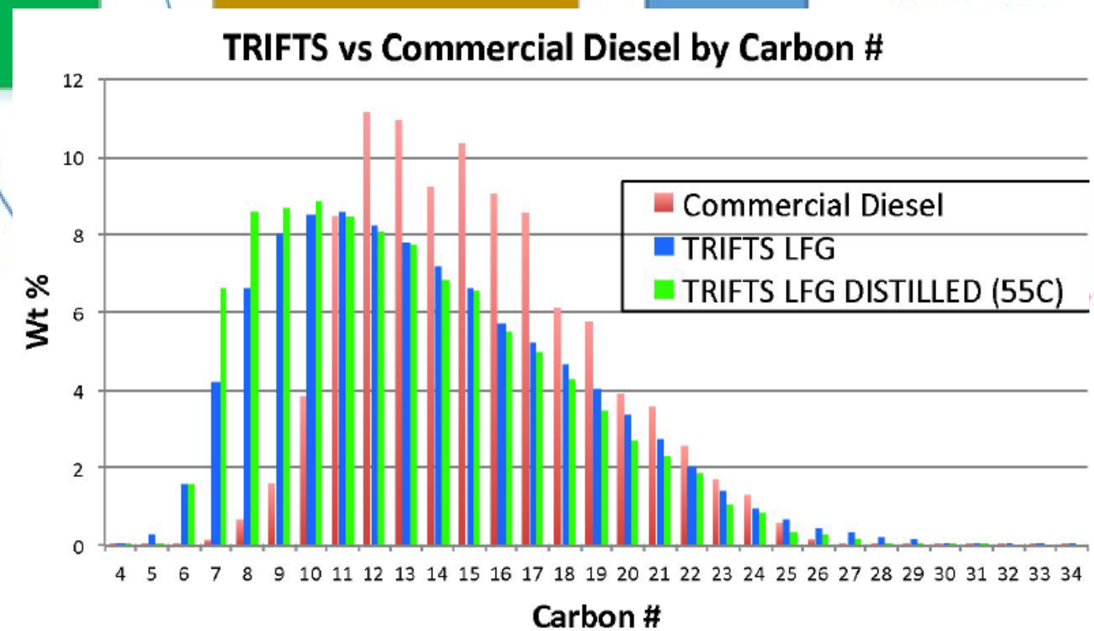




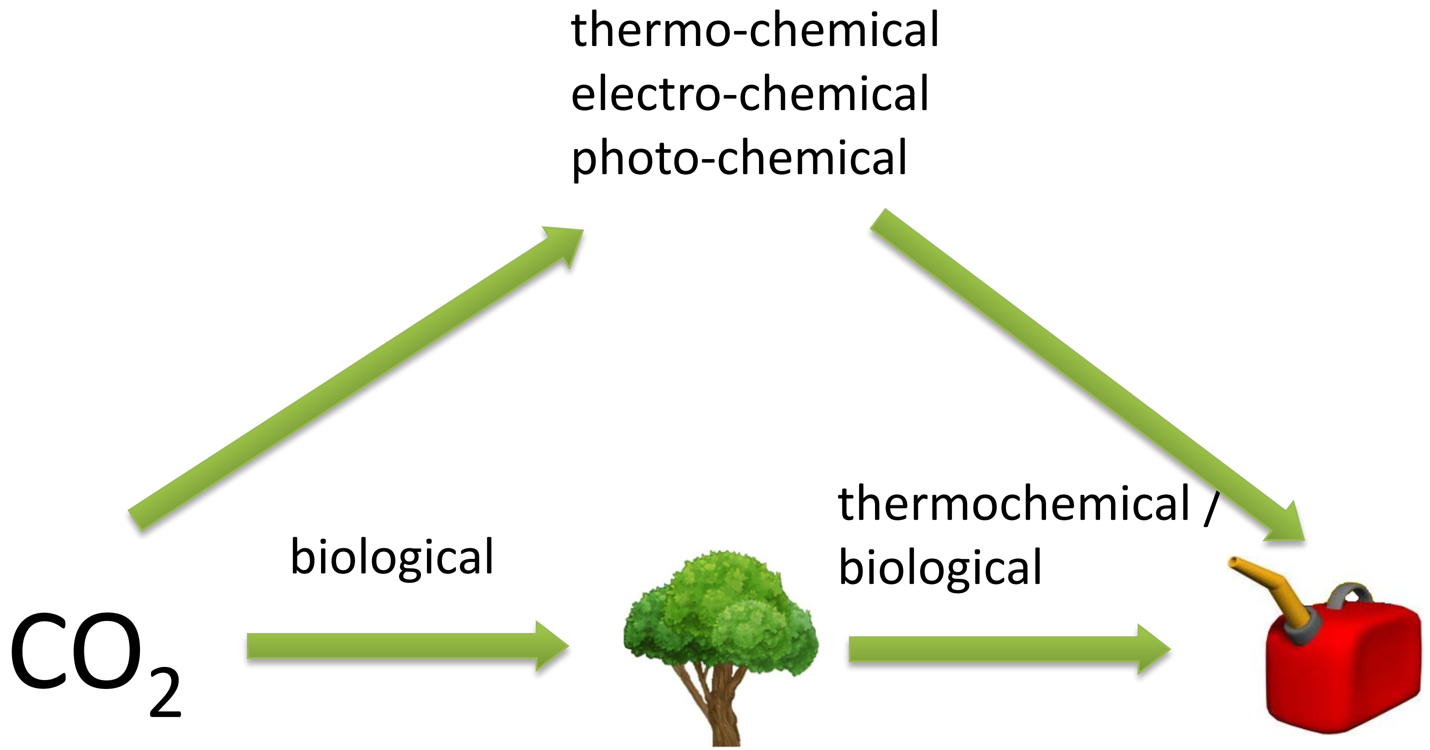
- Fuel derived from LFG
  - Drop-in fuel
  - Low sulfur
  - Low aromatics

- Catalysts are key

- 40% LFG energy recovery in liquid fuel



Taking out the Bio...



CO_2 AVAILABILITY

- Total emissions: 32.2 Gt of CO_2 in 2013 and projected to 45 Gt in 2040 (2015 Key World Energy Statistics / EIA)

120 Mt → Re-utilized in industry
81.5 Mt → Carbon Capture & Storage (CCS)

201.5 Mt < 0.65 % of 2013 CO_2 emissions

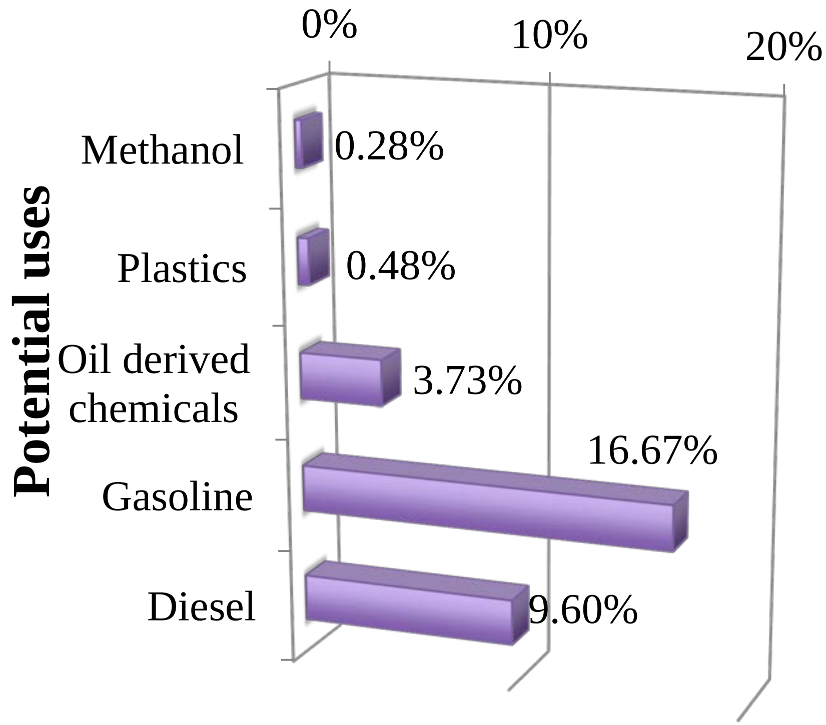
* 81.5 Mt -> estimated capacity

CCS active projects -> 28.4 Mt of CO_2

Capture: $ 36 – 80 /ton

Storage: $ 15 /ton

Stability concerns



Emissions reduction by CCU

Our review: Daza & Kuhn *RSC Advances* 2016

Efficiency of CO_2 Conversion

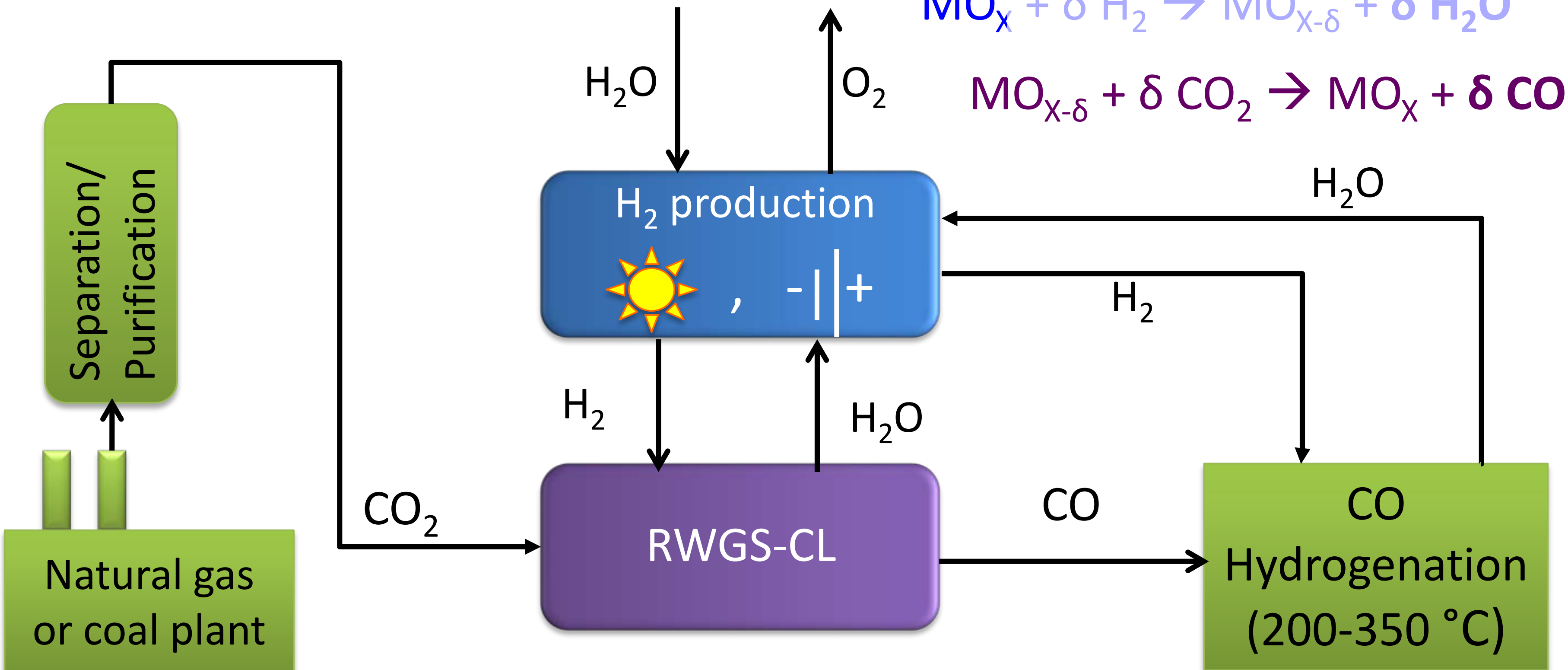
Technology	Estimated current efficiency (%)	Estimated potential efficiency (%)
Self contained Alg		2.39
Regulated bioma		3.10
Algae oil + residu biomass conversi (augmented proce		3.68
Direct photosynth CO_2 conversion to fuel		5.46
CO_2 extraction & thermochemical	4.19	7.92

CO_2 conversion through
Reverse Water Gas Shift Reaction
$CO_2 + H_2 \Leftrightarrow CO + H_2O$

CO to fuels with Fischer-Tropsch (FTS)
$(2n+1)\ H_2 + n\ CO \rightarrow C_nH_{(2n+2)} + n\ H_2O$

Mallapragada et al. I&ECR, 2013

CO_2 TO FUELS



60% of CO_2 emissions come from natural gas and coal burning plants (or air separation)

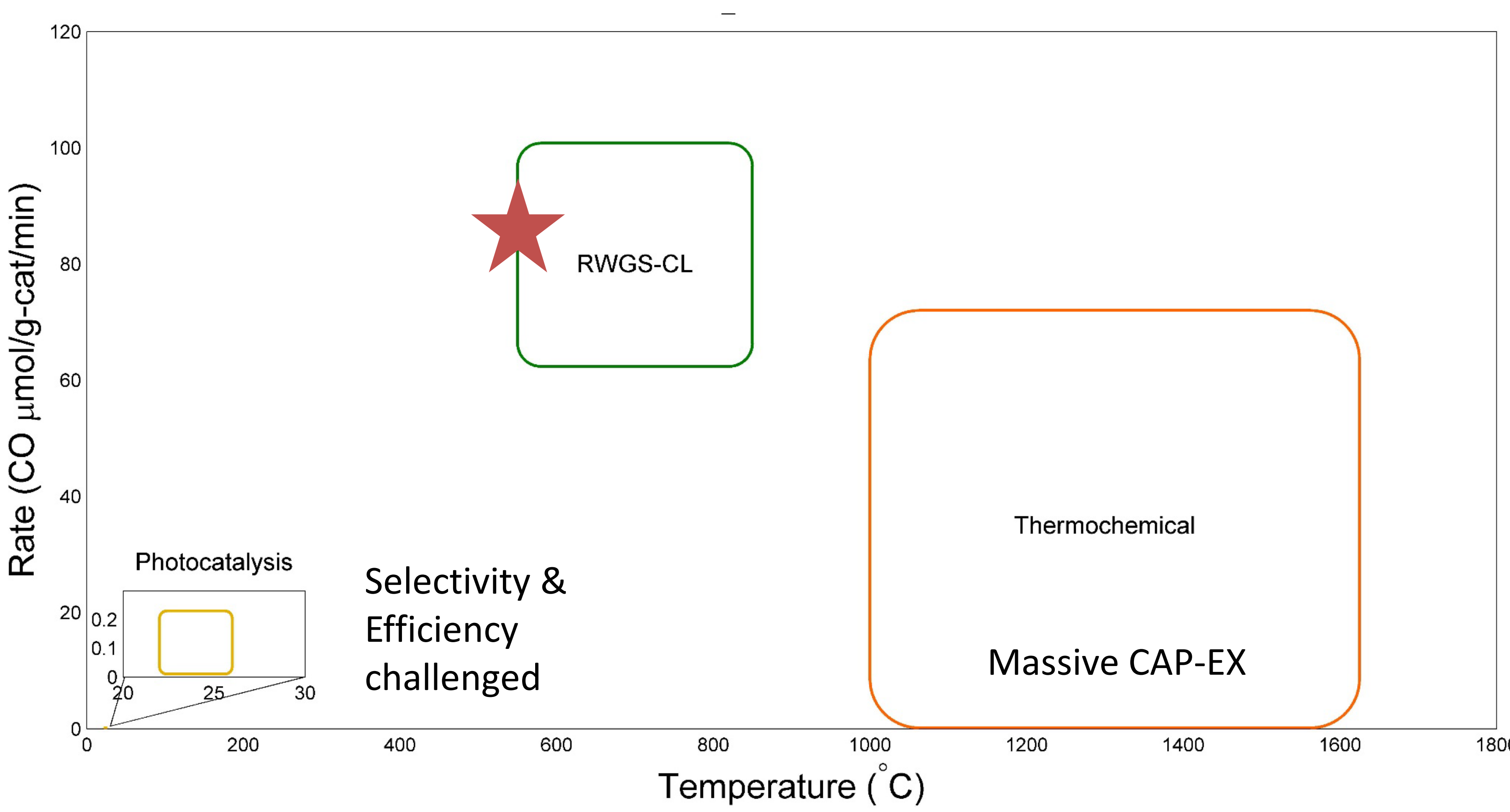
reverse water gas shift-chemical looping (RWGS-CL)
(~10% more efficient than RWGS*)

Liquid fuels or methanol (bep: $4.36/gge)

Daza … Kuhn, *I&ECR* 2014

*Wenzel et al *AICHE Journal* 2016

CO_2 CONVERSION COMPARISON



Processing of Gaseous Waste Streams to Renewable Fuels and Chemicals

John N. Kuhn
Associate Professor
Chemical Engineering

RES&SC 2017

University of South Florida