Carbon Sink LLC

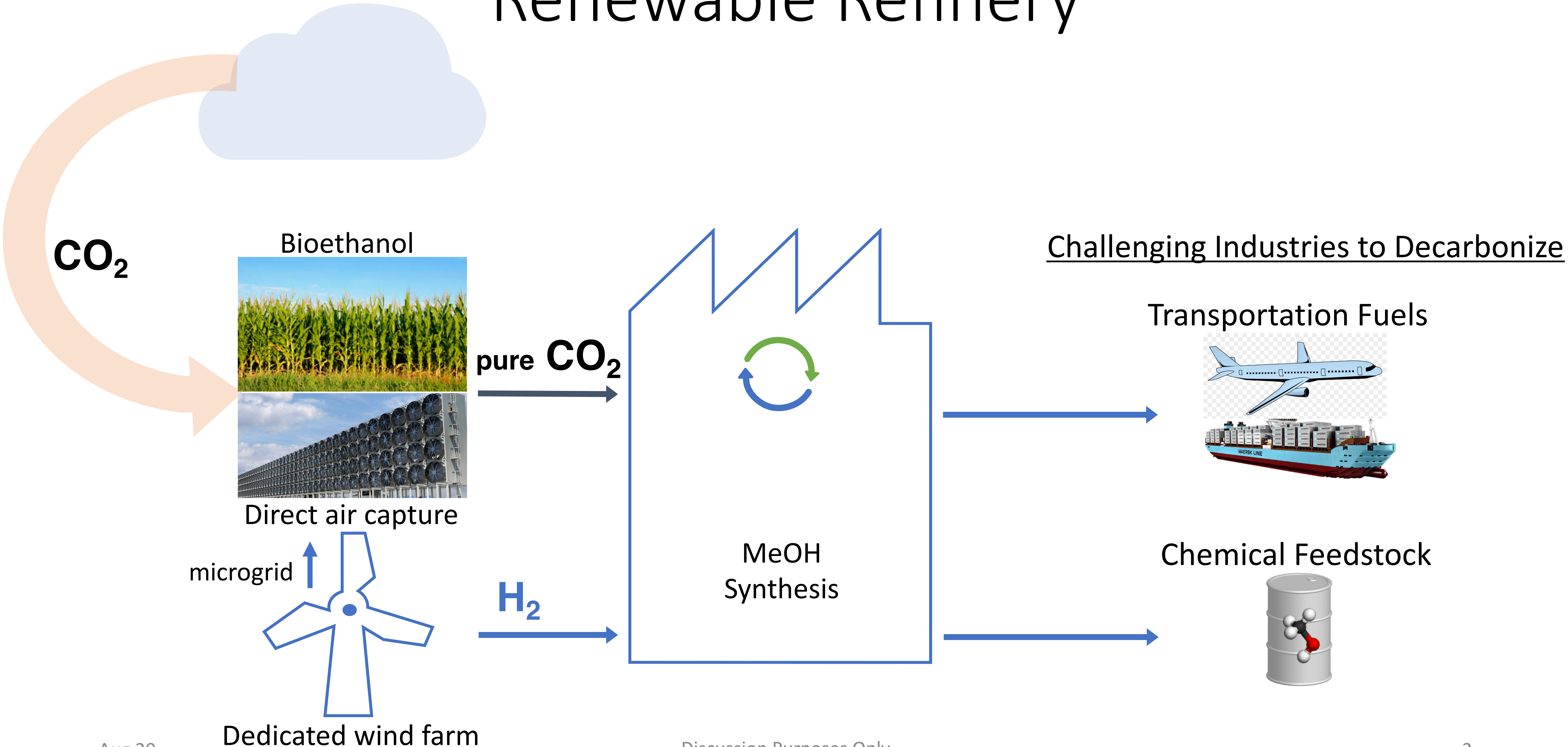
Renewable Refinery

Tapping Wind Resources for E-Fuels and Chemicals

For Discussion Purposes

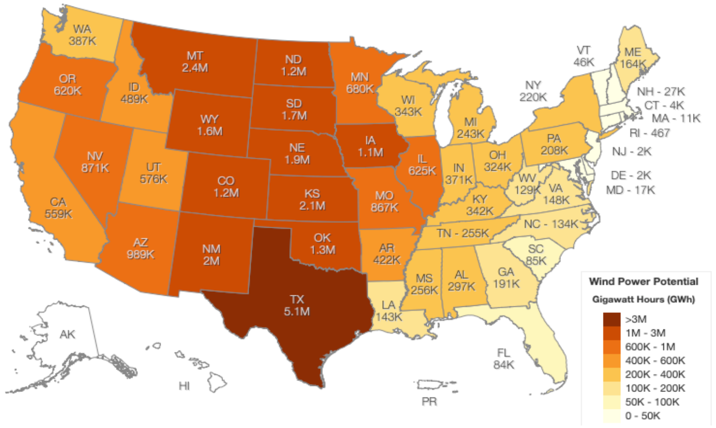
August 2020

Renewable Refinery

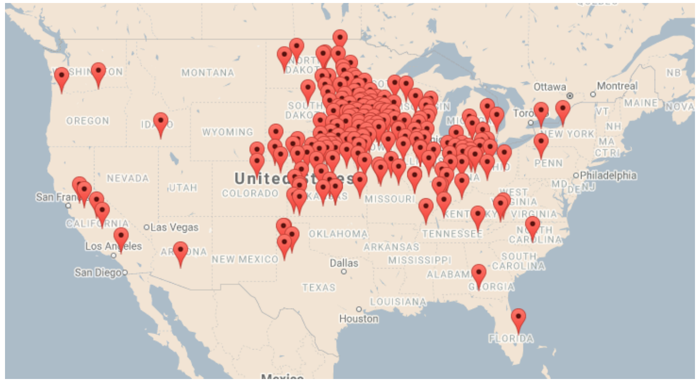


US Potential for E-Fuels & Chemicals

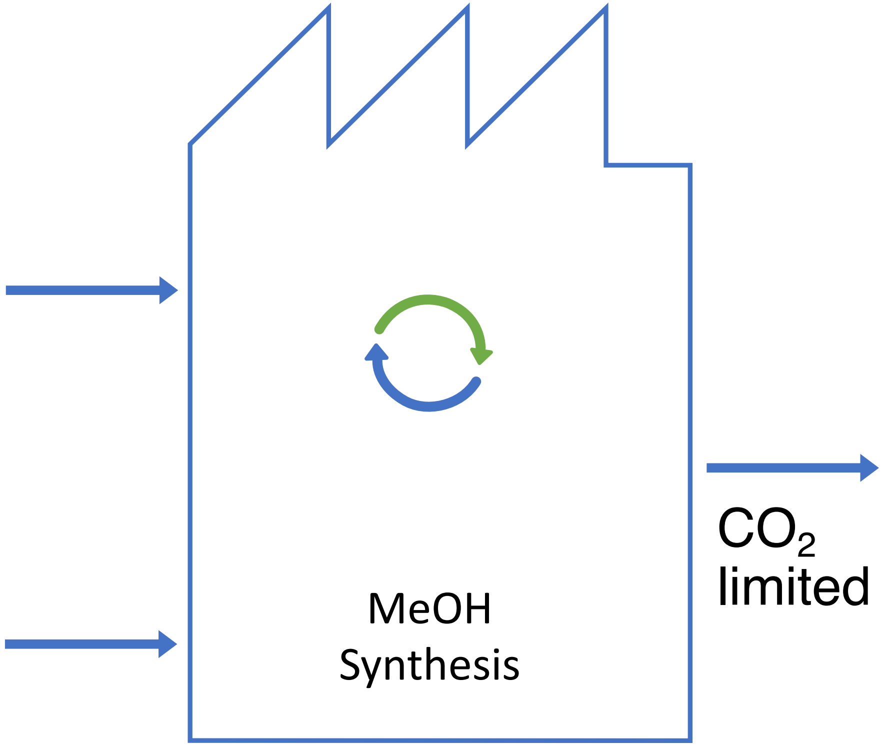
Total Potential Onshore Wind Generation: 32,787 TWH
(Total U.S. Electricity Demand: 4,118 TWH)



Source: AWS Truepower, NREL Annual Technology Baseline



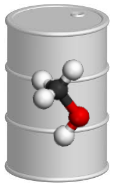
215 U.S. Bioethanol Plants
44 Million Metric Tons CO_2 Emissions



Utilizing readily available 44 MT CO2 from bioethanol plants

~ 25% of U.S. jet fuel demand (~5 billion gallons)

or



~30% world demand for methanol (30 million metric tons)

E-fuels and chemicals can supply all transportation and chemical needs when direct air capture is developed.

Carbon Recycling International: 1.4 t CO_2 per 1 t MeOh

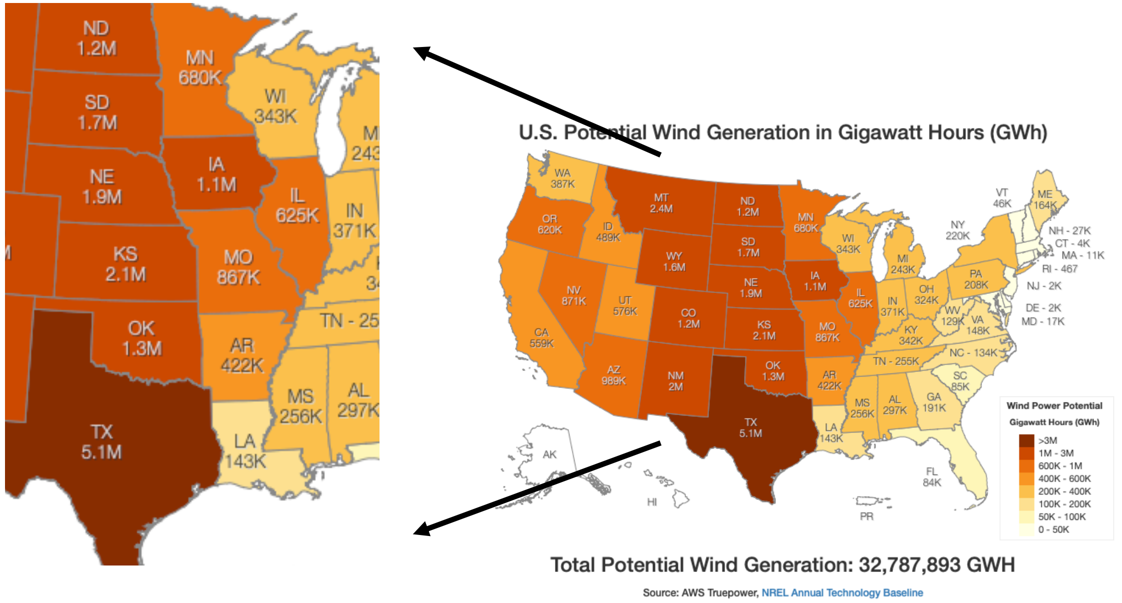
Carbon Sink LLC

Top Six Bioethanol Producing States, plus Texas

<u>75% Bioethanol Production in 6 States</u>

	Electricity Consumption	Potential Wind Generation	MISO	
(1) Iowa	51,213	1,100,000	Y	
(2) Nebraska	30,939	1,900,000	N	
(3) Illinois	142,654	625,000	Y	
(4) Minnesota	68,729	680,000	Y	Excess
(5) Indiana	104,217	371,000	Y	Wind
(6) South Dakota	12,865	1,700,000	Y	Potential
Total GWh	410,617	6,376,000		5,965,383 GWh

	Consumption	Wind Potential	Excess Potential	
Texas	424,528	5,100,000	4,675,472	GWh
		Total Excess Wind	10,640,858	GWh



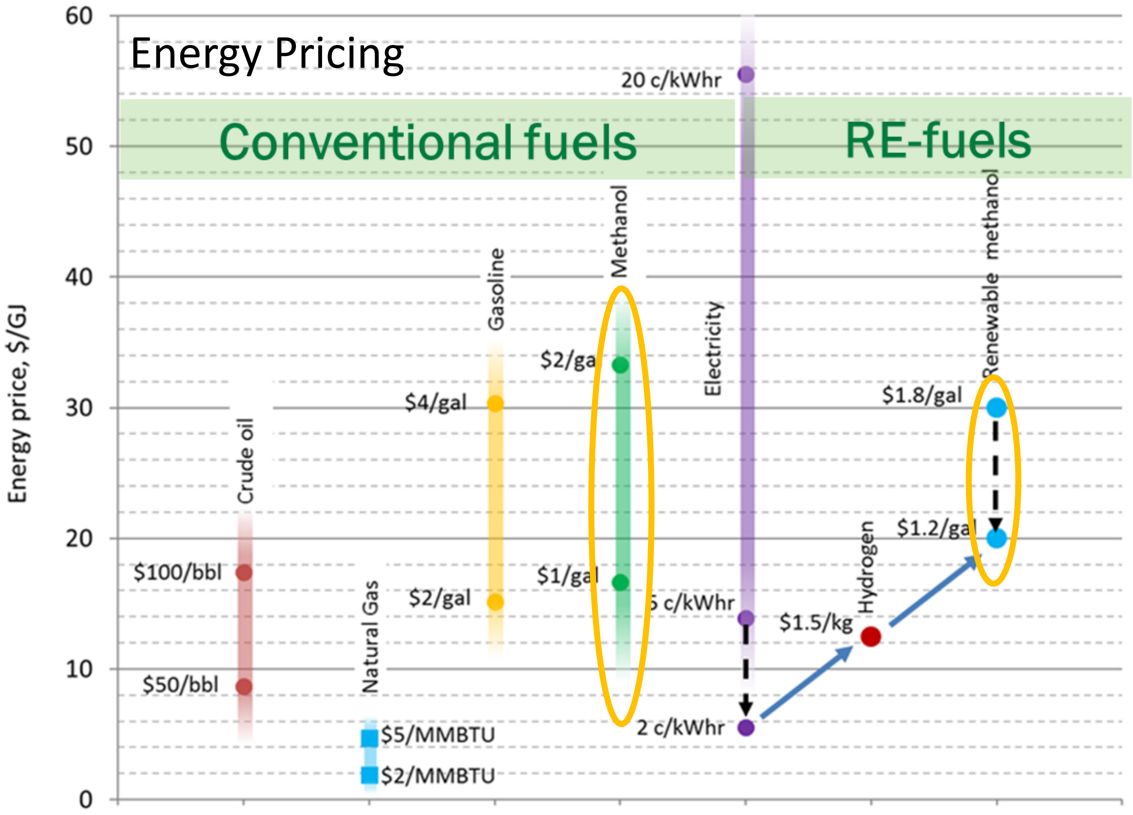
<u>Central Region of US has enough CO_2 emissions & excess wind to produce:</u>

~ 18% of US jet fuel demand

~ 22% of global methanol demand

Carbon Sink LLC

Can Renewable Fuels Be Cost Competitive?



price ranges for conventional fuels normalized by LHV

Critical cost contributor

M. Lyubovsky. J. Energy. Security 2017 (http://ensec.org/)

Inputs based on DOE targets for RE electricity, H_2, & CO_2

Renewable Methanol Synthesis: $3H_2 + CO_2 \rightarrow CH_3OH + H_2O$	
Cost of H_2 from advanced electrolysis at 2 c/kWh : 1.95 $/kg_H2	
H_2 contribution in MeOH	**1.1 $/gal**
Cost of captured CO_2 : 40 $/tonne_$CO_2$ = 0.04 $/kg_CO2	
CO_2 cost contribution in MeOH	**0.20 $/gal**
Extrapolating from existing fuel synthesis plants:	
Levelized plant costs (capital and O&M)	**0.50 $/gal**
cost projection for renewable MeOH	**1.8 $/gal**

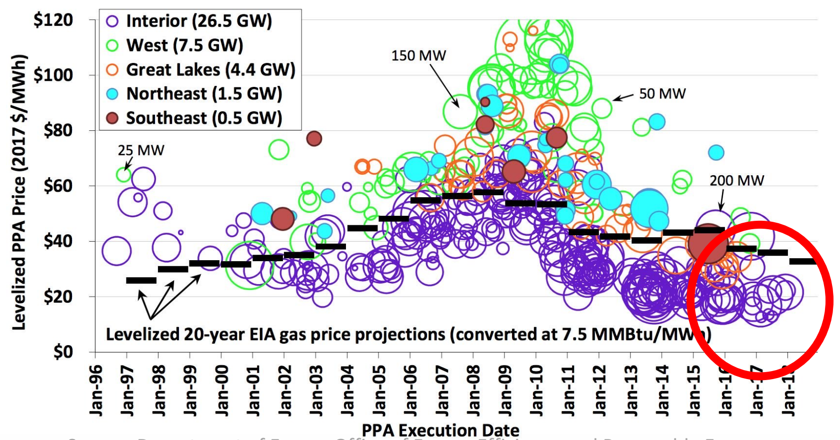
Key drivers relevant to renewable fuels synthesis:

- **Price & availability of renewable electricity**
- **Efficiency of chemical conversion processes**
- **Cost and performance of electrolyzers**
- **Cost of CO_2**

Carbon Sink LLC

E-Fuels and Chemicals Can Be Competitive!

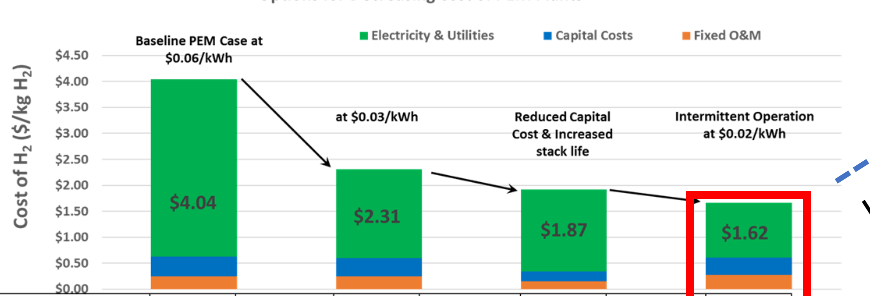
Wind PPA Prices Remain Very Low, and Are Competitive with the Levelized Fuel Cost of a Gas Plant



Source: Department of Energy Office of Energy Efficiency and Renewable Energy

wind < 2 cents

Lowering cost of renewable hydrogen



Capacity Factor (%)	97%	97%	97%	50%
System Cap Cost ($/kW)	$475/kW	$475/kW	$237/kW	$237/kW
Electricity Cost (¢/kWh)	$0.06/kWh	$0.03/kWh	$0.03/kWh	$0.02/kWh
Degradation Rate (mV/khrs)	1.5 mV/khrs	1.5 mV/khrs	1 mV/khrs	1 mV/khrs
Stack Lifetime (years)	7 years	7 years	10 years	10 years

rategic
nalysis Inc.

Cost of electricity is the major fraction of the renewable hydrogen cost

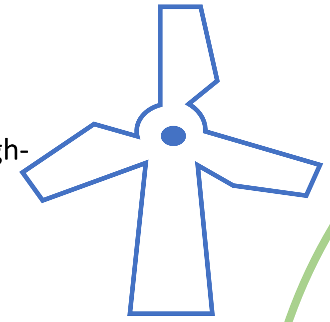
H2 < $1.95/kg

Renewable Methanol Synthesis: $3H_2 + CO_2 \rightarrow CH_3OH + H_2O$	
Cost of H_2 from advanced electrolysis at 2 c/kWh : 1.95 $/kg_H2	
H_2 contribution in MeOH	**1.1 $/gal**
Cost of captured CO_2 : 40 $/tonne_$CO_2$ = 0.04 $/kg_CO2	
CO_2 cost contribution in MeOH	**0.20 $/gal**
Extrapolating from existing fuel synthesis plants:	
Levelized plant costs (capital and O&M)	**0.50 $/gal**
cost projection for renewable MeOH	**1.8 $/gal**

Integration and Optimization Can Significantly Lower Cost of Renewable Liquid Fuels & Chemicals

Integrating and Optimizing of Key Technologies Can Produce a Competitive Renewable Refinery

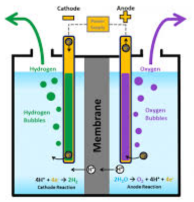
Wind improvements
- No voltage step-up and grid synchronization costs.
- Large scale deployment in high-quality wind regimes
- No long transmission and interconnect costs.



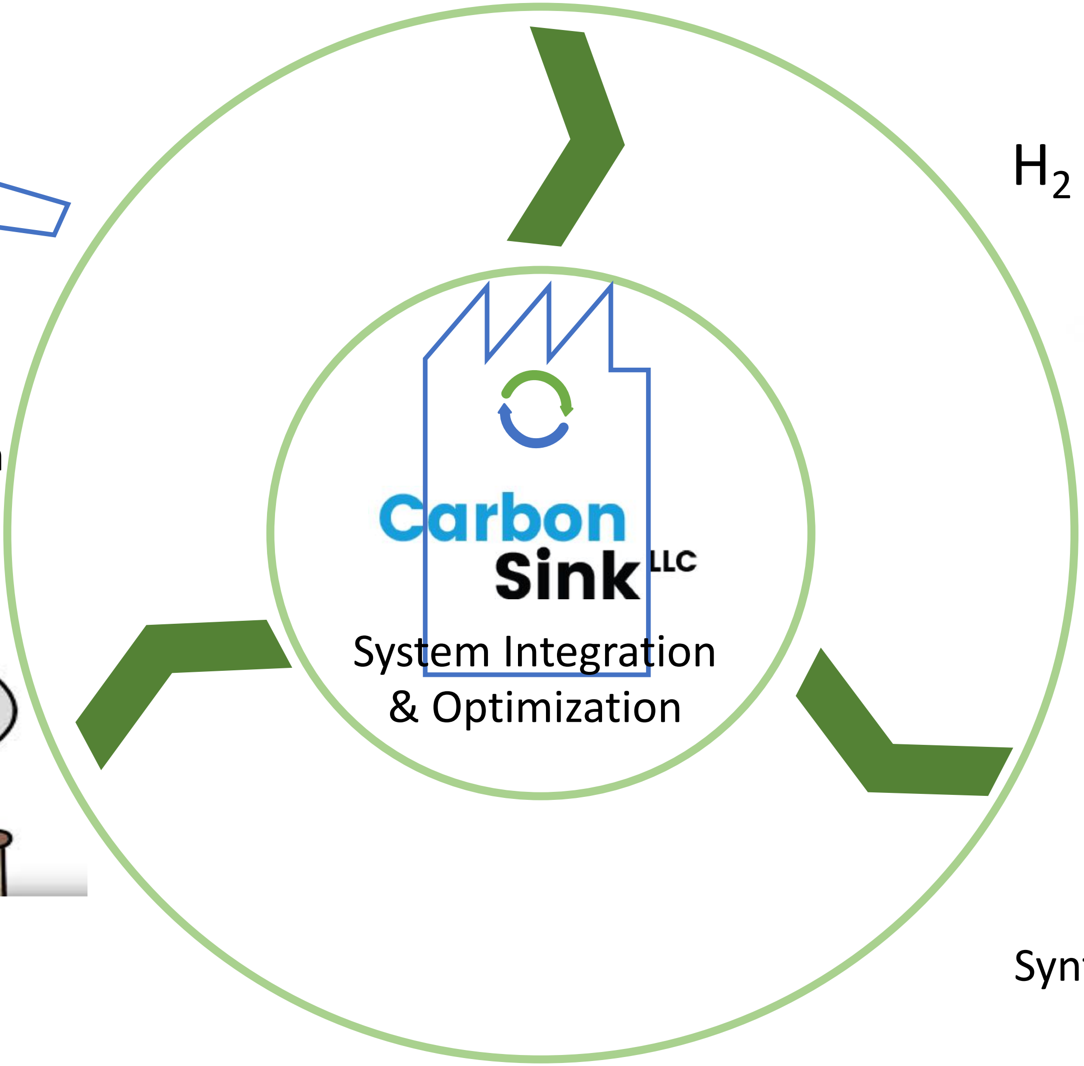
Dedicated Wind Farm

Electrolysis improvements
- Large scale electrolysis deployment
- Electrolysis independent of H_2 transport infrastructure
- Direct DC power source

H_2

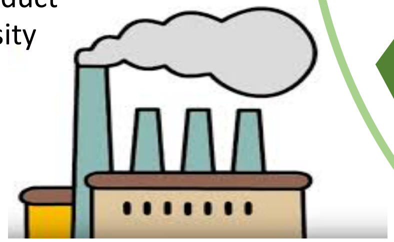


Electrolyzer



Bioethanol improvements
- Utilizing a waste CO_2 byproduct
- Reducing the carbon intensity of the bioethanol process

CO_2



Bioethanol

Synthesis improvements
- Large / modular construction
- Optimized for cost of production
- Non-volatile cost structure

MeOH Synthesis Technology

Additional Slides

Advantages of an Integrated Renewable Refinery

Competitive E-Fuels & Low Carbon Intensity Ethanol

- Low-cost wind – leveraging larger offshore wind designs for high-wind regimes
  - Non-grid connected integrated DC power & control systems
  - Integration with bioethanol plant reducing ethanol carbon intensity
  - Hydrogen storage for renewable grid support
- Low-cost electrolyzer/hydrogen
  - Direct DC power supply integration for greater efficiency
  - Large scale production of hydrogen & storage
- Lower carbon intensity bioethanol
  - Integration of renewable energy & bioethanol production
  - Minimal gas clean-up and handling
  - Automation for reduced operating costs
- Synthesis technology – Methanol and/or Fischer-Tropsch
  - Proven technologies
  - Market ready products