



## Mixed Alcohol Renewable Gas (MARG) Process Pilot Systems Development

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# Company Description

- Provider/developer of thermochemical systems for the conversion of biomass to power, fuels, and chemicals since 2007
- Commercial development efforts include two community-scale facilities
- Low-carbon renewables pathways including biomass-based hydrogen, synthetic natural gas, diesel, aviation fuels, chemical alcohols, and advanced carbon products
- Collaborations with public/private and national/international partners



# Project Purpose and Goals

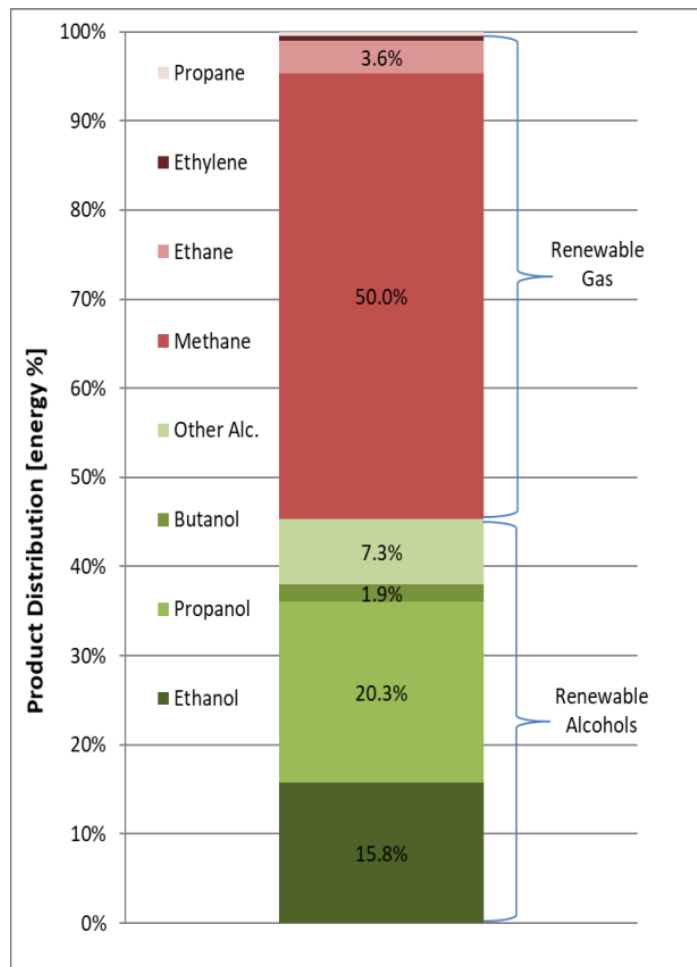
*Demonstrate production and separation technology that will convert forest biomass residuals to pipeline quality renewable gas and value-added byproducts*

1. Pilot the complete process from forest biomass to renewable gas
2. Verify the system stability and reliability with testing
3. Validate n<sup>th</sup>-plant commercial opportunity for the proposed process
4. Determine the environmental footprint and the low-carbon fuel pathway for products



*Synthesis, compression, gas storage systems for conversion of biomass to Renewable Gas and Alcohols*

# Why Alcohols and RNG?

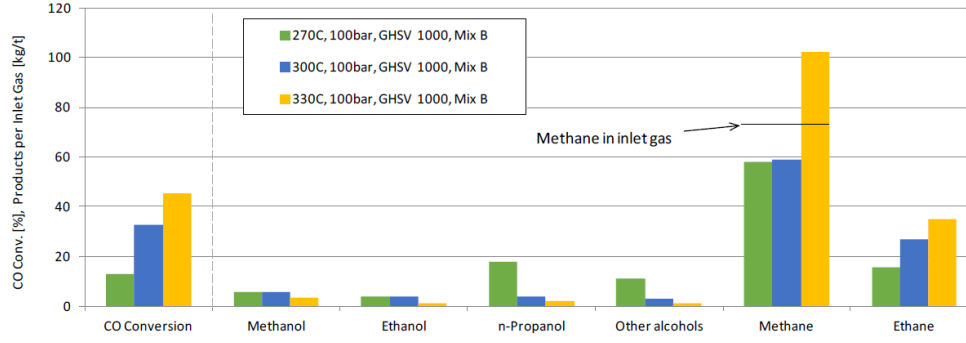
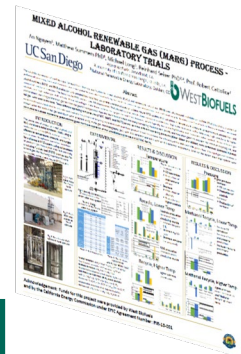


Desired mixture of upgraded syngas products from synthesis reactor  
(Source: West Biofuels/UCSD)

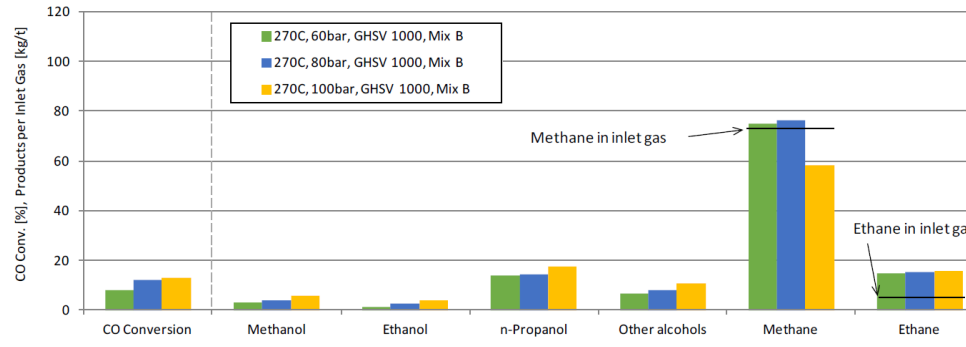
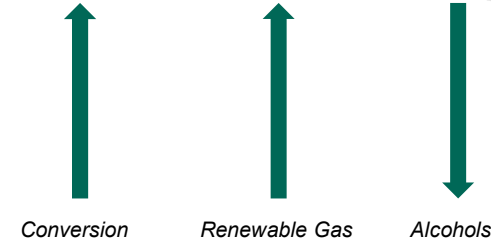
- Renewable Gas (RG)
  - West coast commercial viability: \$16/MMBtu
  - Current catalytic pathways: \$20-\$30/MMBtu
- Renewable Alcohols
  - Significantly greater value
  - Tail gas stream contains significant Methane and Ethane
- Co-production represents value-added pathway
  - Target product distribution indicates 240% greater revenue potential

# Tailoring of Alcohols to Renewable Gas Ratio

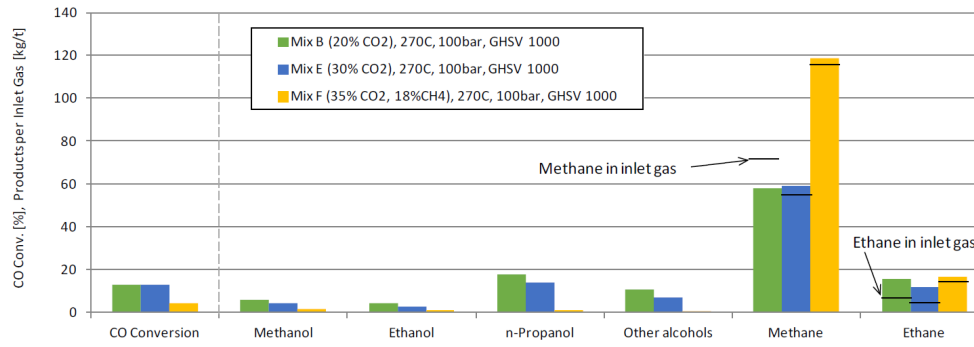
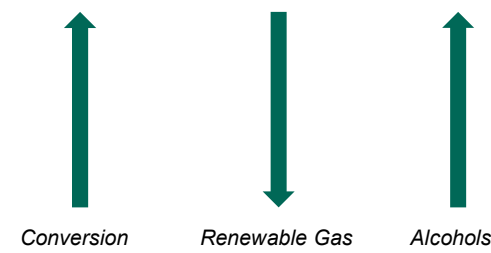
See MARG Laboratory Trials poster for additional details 



Temperature effects:

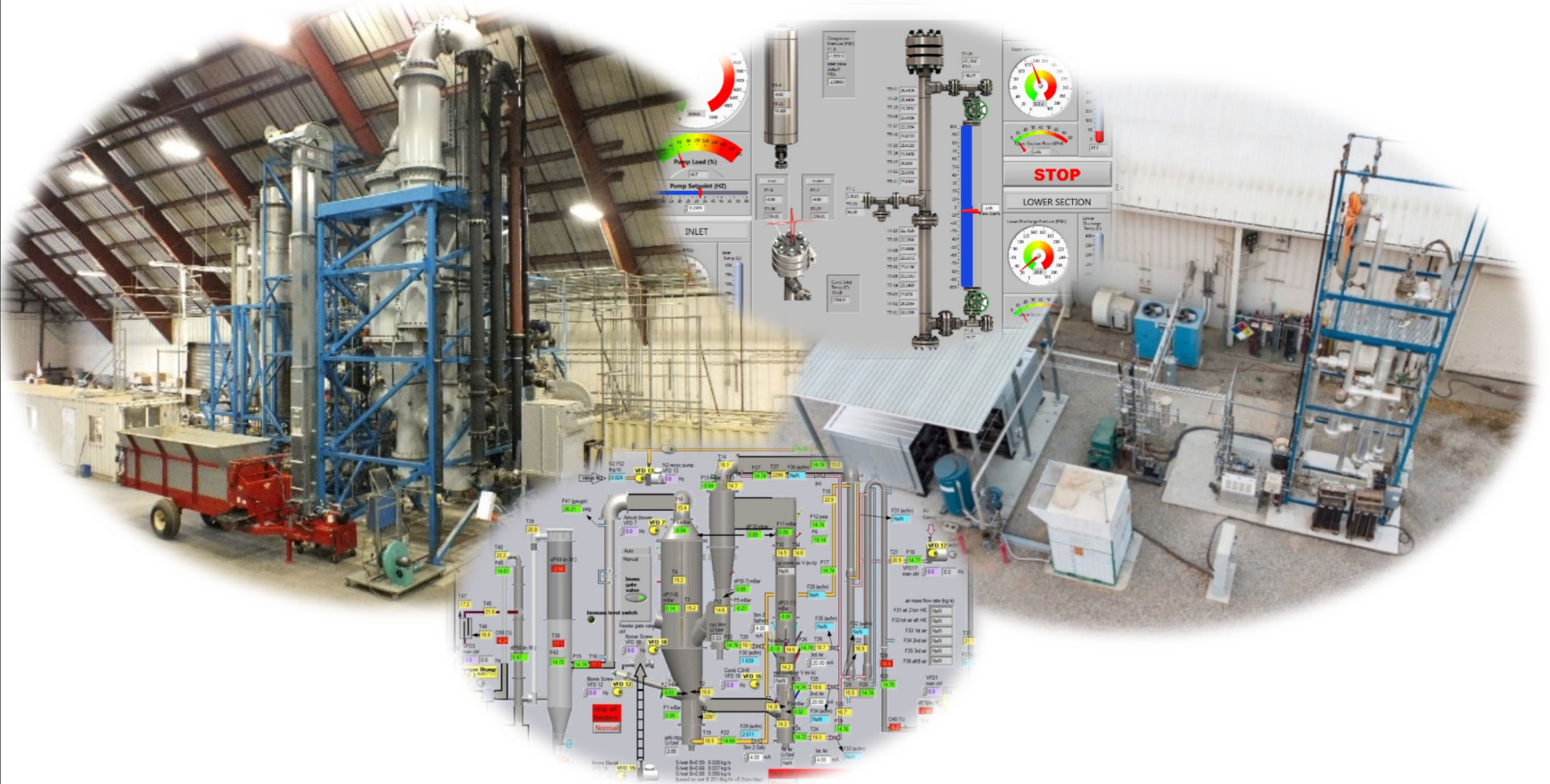


Pressure effects:



Simulated recycle effects:

- Recycle reduces alcohol production
- Recycle increases Renewable Gas production

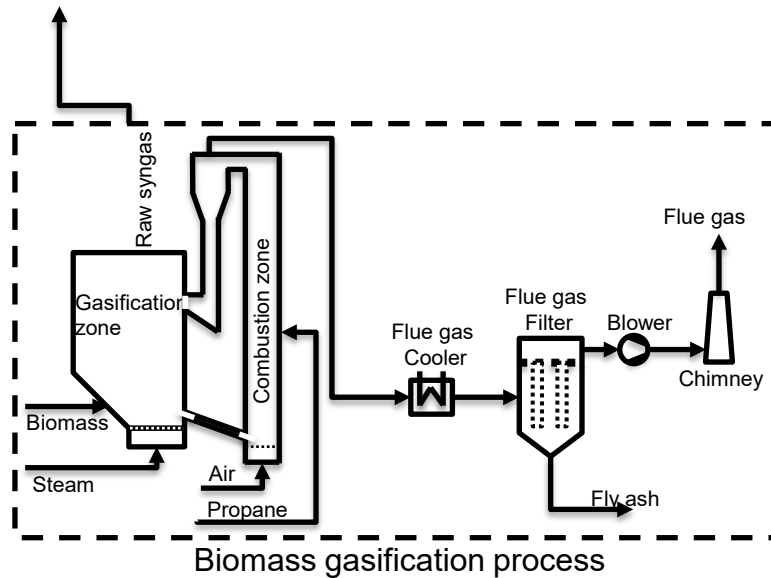


# TECHNICAL SYSTEM LAYOUT AND CAPABILITIES

# Biomass Gasification

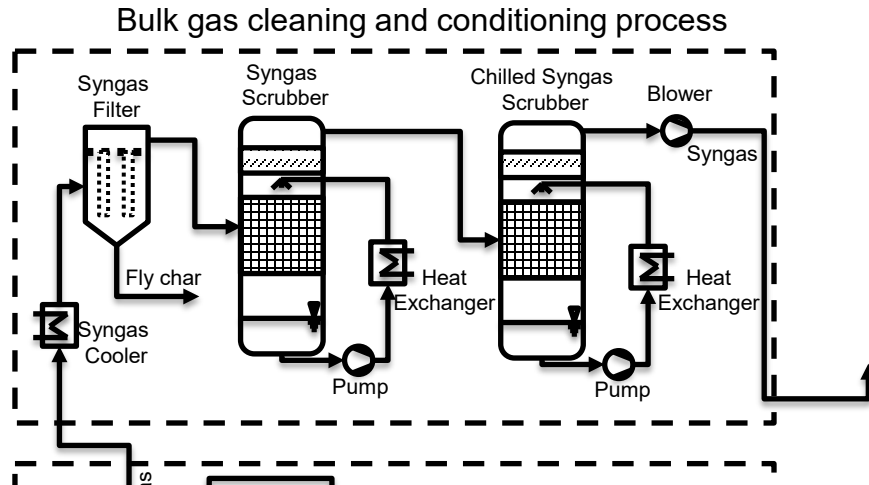


Syngas composition	dry vol%
H <sub>2</sub>	35%-40%
CO	22%-29%
CO <sub>2</sub>	20%-24%
CH <sub>4</sub>	9-12%
C <sub>2</sub> H <sub>4</sub>	2%-3%
C <sub>2</sub> H <sub>6</sub>	<1%

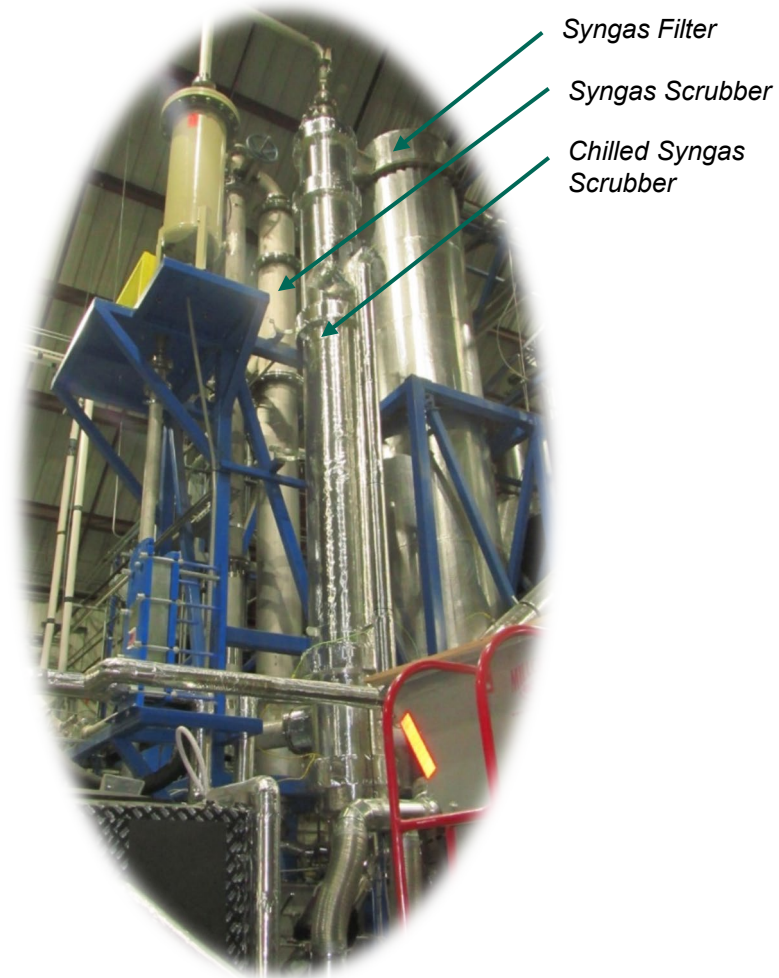


- 1MW<sub>th</sub> Dual Fluidized Bed Pilot System
- Commissioned in 2014 w/ proven operational history
- High quality syngas
  - High H<sub>2</sub>%
  - High CH<sub>4</sub>%
  - Low tars
  - No air separation unit requirement

# Bulk Gas Cleaning



- Syngas filter
  - Baghouse design w/ pulse jet cleaning
  - Removal of small entrained bed, char, and condensed tars
- Syngas scrubbers
  - Solvent: Rapeseed Methyl Esters (Biodiesel)
  - Warm scrubber: removal of bulk tars
  - Chilled scrubber: removal of water and light tars





# Gas Compression and Storage

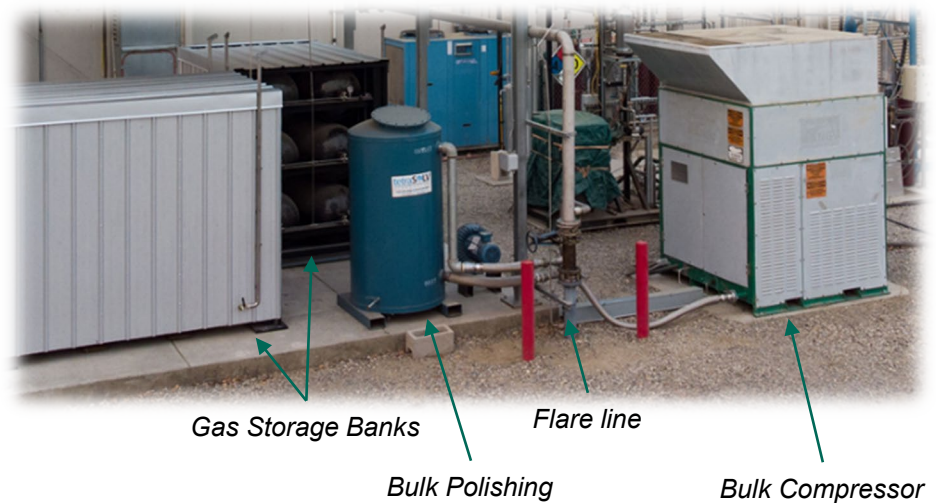
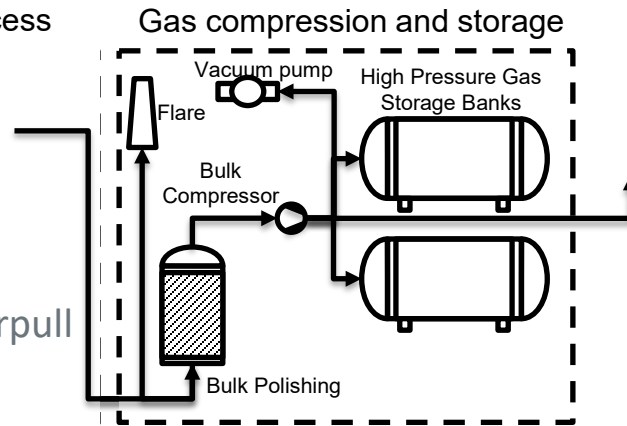
Bulk gas cleaning and conditioning process

- Gas compressor

- Capacity = 110 SCFM
- Pressure = 3600 PSI
- Capacity controlled via outlet feedback loop to exclude overpull from upstream equipment

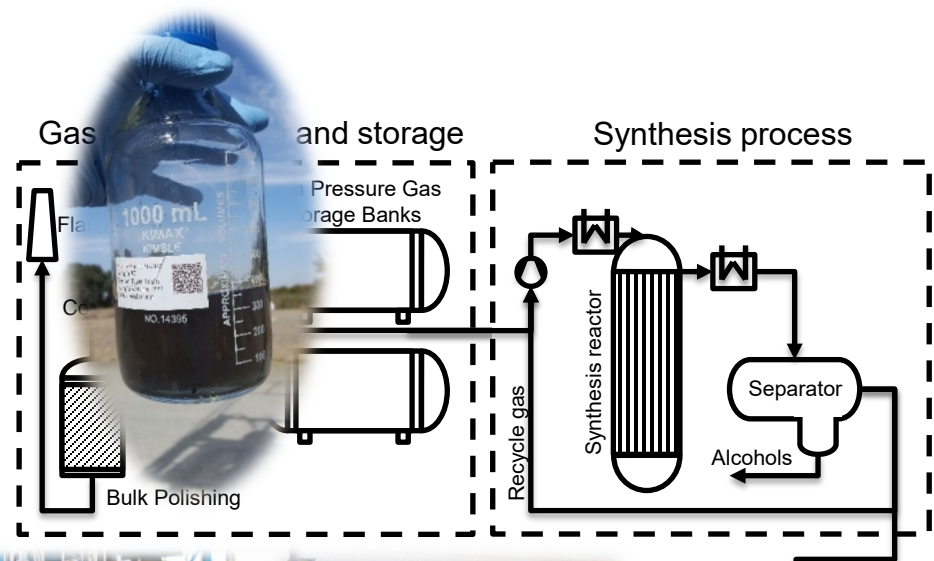
- High-pressure gas storage banks

- x2 banks of x6 563 L DOT cert. vessels
- Storage volume = 59235 SCF
- Pressure ratings (PSI)
  - Design = 3600
  - Proof = 5400
  - Burst = 10800



# Synthesis Reactor

- Design parameters
  - Temperature: 260 – 320 C
  - Pressure: <2500 PSI
  - GHSV: 1000
  - Capacity: 20 to 166 SLPM
  - Catalyst: Alkali-doped molybdenum sulfide (MoS<sub>2</sub>)
- Project related improvements
  - Precision Coriolis technology high-pressure flowmeter instrumentation package
  - Improved high-pressure liquids separator
- Product distribution variable by control of operating condition



Upgraded 2-stage separator

Synthesis reactor system

Species	vol%
H <sub>2</sub>	12-32%
CO	16-30%
CO <sub>2</sub>	20-30%
CH <sub>4</sub>	7-21%
C <sub>2</sub> H <sub>4</sub>	0-1%
C <sub>2</sub> H <sub>6</sub>	1-2%

# Separations

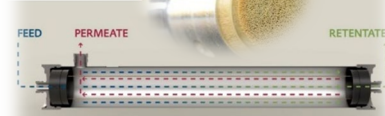
- Sulfur removal

- Sorption materials
  - Metal promoted carbon based
  - Mixed metal oxide based
- Lead-lag alternating series arrangement
  - Online sorbent replacement
  - Continuous fresh guard bed

## Hydrates for Gas Storage



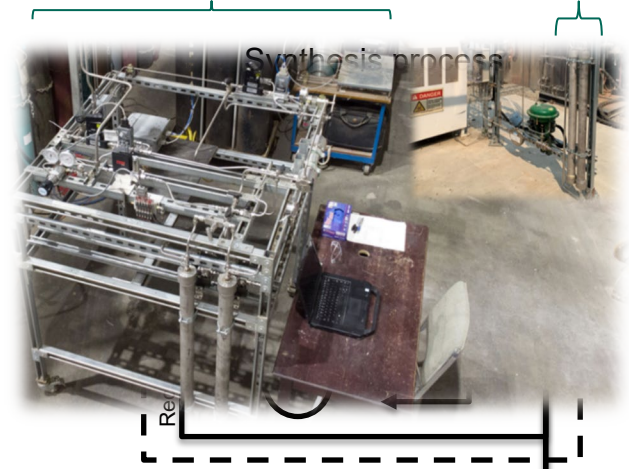
PSA material



Membranes

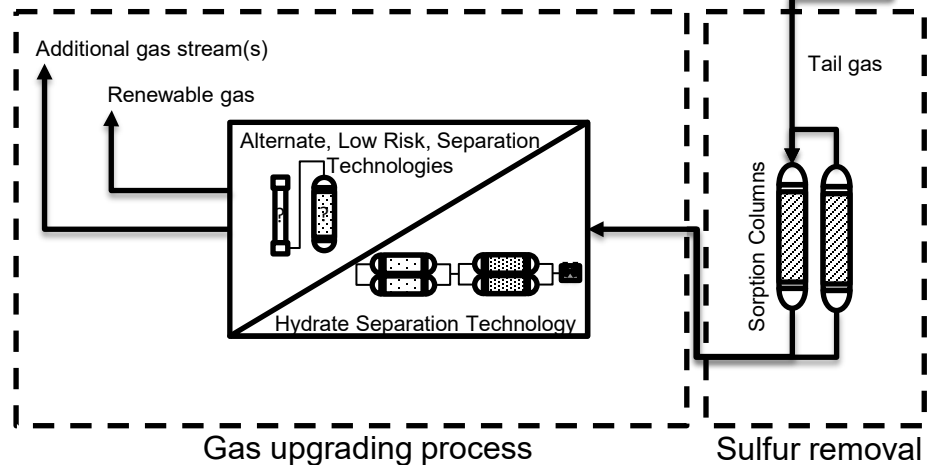
Gas upgrading development module

Lead-lag sulfur column arrangement

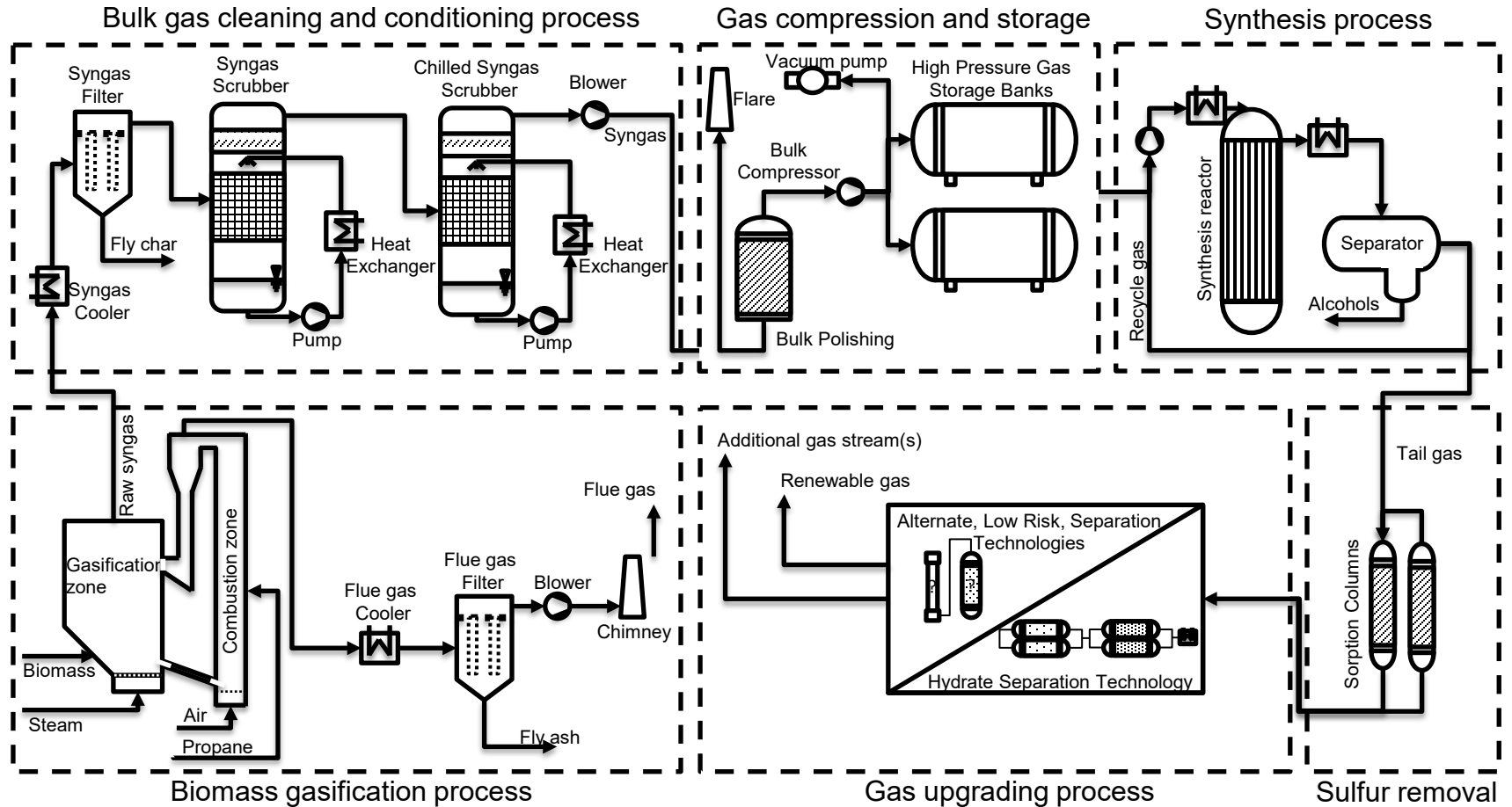


- Gas upgrading

- Gas Hydrates
  - Novel separation technology
  - Unknown economics
  - Early development, high risk
- Membranes
  - Commercially available, but still developing technology
  - Improved OpX over PSA
  - Potential poisoning by gas impurities
- Pressure Swing Adsorption
  - Commercially developed technology
  - Lowest CapX
  - Potential poisoning by gas impurities

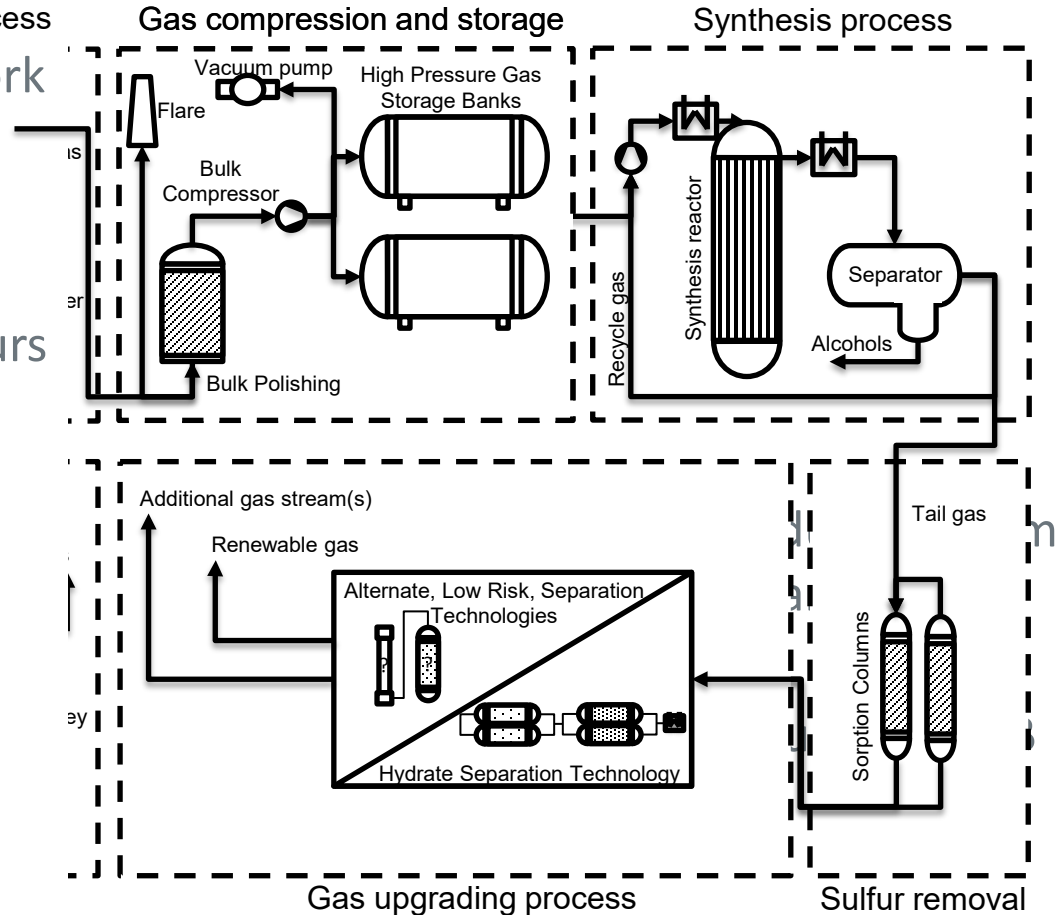


# Integrated Pilot System



# System Capabilities – De-coupled Experimental Capabilities

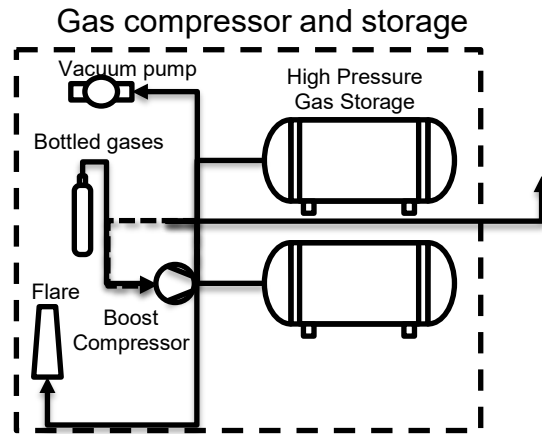
- Bulk gas cleaning and conditioning process
- Synthesis and upgrading work can be performed without the need for gas production operations upstream
- Storage capacity = >150 hours of run time
- Metering and control instrumentation shared



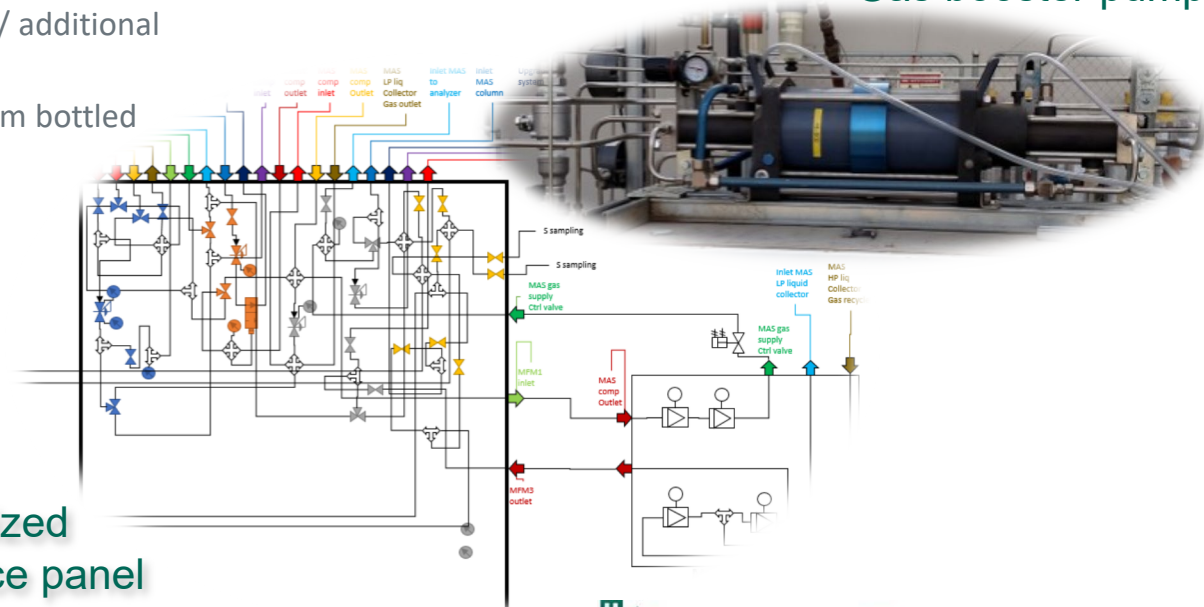
Biomass gasification process

# System Capabilities – Flaring, Evacuation, Boosting, and Blending

- Flaring of contaminated/waste gases
- Evacuation via vacuum system ensures complete removal of previous gases
- Boosting of gas pressures
- Designer gas blending
  - Modification of captured syngas with increased concentration of desired species
  - Doping of captured syngas w/ additional gases
  - Blend mixture generation from bottled gases

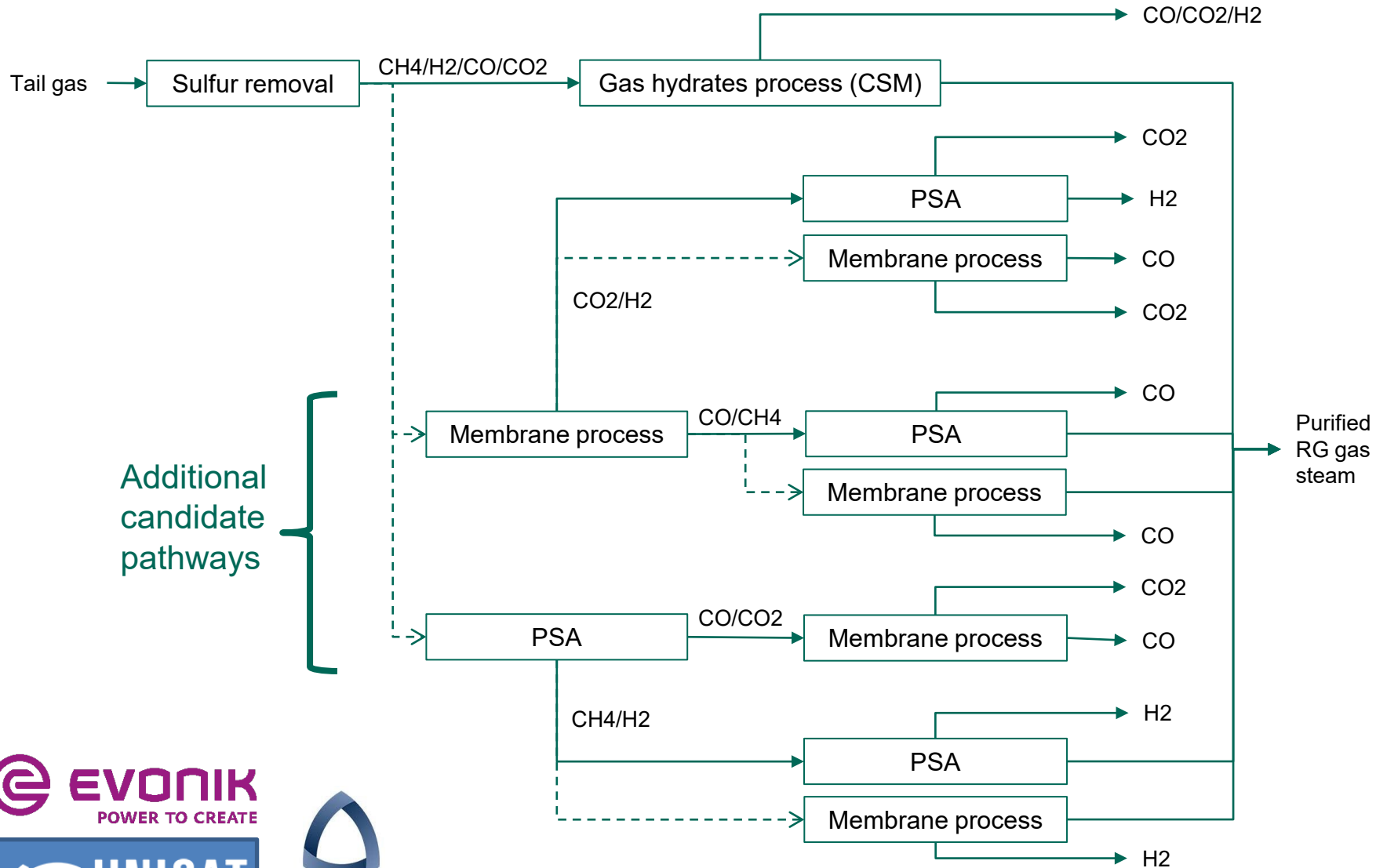


Gas booster pump

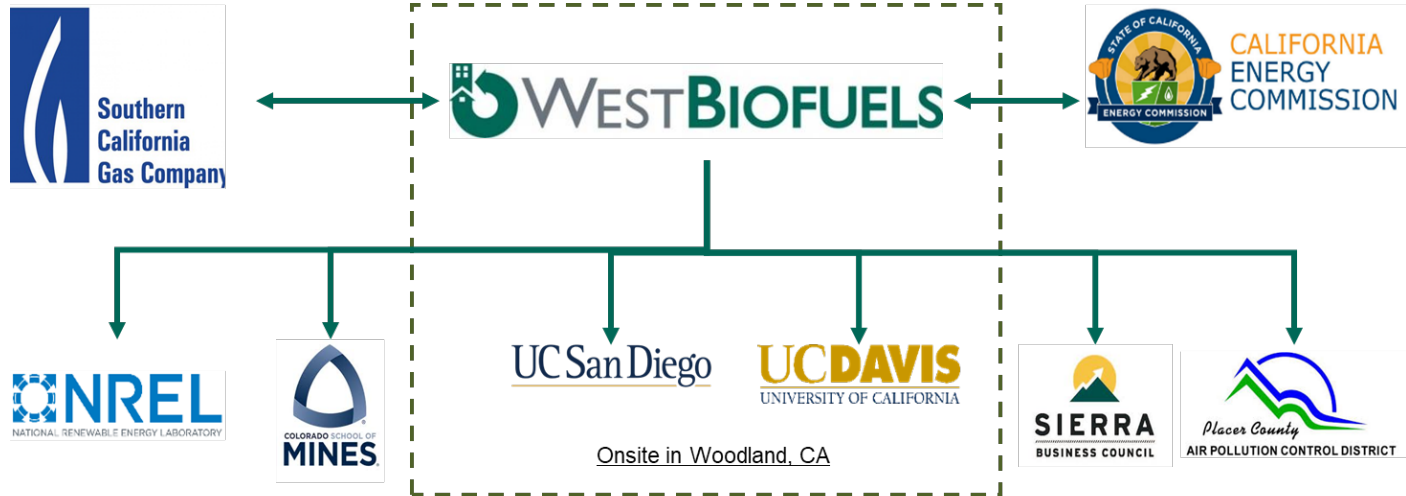


PFD of centralized system interface panel

# Gas Separation Technologies Mapping



# Thank You



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