SoCalGas A Sempra Energy utility®

Rule 1118.1
Beneficial Use Working Group - Biogas
Emerging Technologies

October 10, 2019, 1:30P.M.
South Coast AQMD Headquarters
Conference Rooms CC-3, CC-5, overflow CC-7
21865 Copley Drive Diamond Bar, CA 91765

SoCalGas | System of the Future[1]

Maximizing the value of SoCalGas' unique size and scale to deliver cleaner energy over time

Present → 2030 - 2050

Natural Gas	Renewable Natural Gas (RNG)	Liquified Natural Gas (LNG)	Distributed Energy (DE)	Hydrogen	Carbon Capture Utilization (CCU)
▪ Continued safety enhancement investments ▪ Natural gas needed for decades – provides affordability and addresses renewables intermittency	▪ Goal to deliver 20% RNG by 2030 ▪ Partnership with agriculture waste stream sectors for RNG production and pipeline delivery	▪ Deployment of LNG facility at port of Los Angeles/Long Beach for transportation sector (heavy duty and marine)	▪ Fuel cell deployment as wildfire mitigation measure ▪ Fuel cell development in transportation (heavy duty) ▪ DE for residential and commercial addresses renewables intermittency	▪ Power-2-gas ▪ Hydrogen vehicle fueling stations ▪ Hydrogen blending into pipeline system ▪ Collaborating with Engie, GRTgaz, GRDF and Energir	▪ Capture waste carbon dioxide ▪ Deploy in carbon-utilizing industries such as manufacturing

1) Timeline is illustrative only and not indicative of when, or if, certain events may occur or the order in which they may occur. Actual events and the timing thereof may differ materially.

Addressing California Policy Goals

RD&D Policy Drivers

GHG Emissions	• SB32 – Reduce CO_2 emissions 40% below 1990 levels by 2030 • SB100 – Zero carbon electricity by 2045 • EO B-55-18 – Carbon neutral economy by 2045 • AB3232 – Building decarbonization
Pipeline Safety	• CPUC General Order 112F • DOT CFR 49 Parts 191 – 193 • AB1900 – Biomethane quality standards
Local Air Quality	• Clean Air Act (CAA) – Air quality standards for NOx and PM • AB617 – Pilot communities for air quality improvements • Rule 1118.1 - Reducing emissions from non-refinery flares
Methane Emissions	• SB1383 – Reducing methane emissions from dairies and landfills • SB1371 – Reducing pipeline system leaks
Clean Transportation	• ARB Implementation Plan – Low NOx standard for trucks • AB8 – Development of 100 Hydrogen fueling stations • EO B-32-15 – Sustainable freight action plan • LCFS – Reduce carbon intensity of fuels 10% by 2020

Regulatory Charter for Research Development and Demonstration (RD&D)

The California Legislature enacted **Public Utility Code section 740.1** to establish the basis upon which RD&D programs for gas and electric corporations are authorized by the Commission:

Each project should also support one or more of the following objectives:

1) Environmental improvement.
2) Public and employee safety.
3) Conservation by efficient resource use or by reducing or shifting system load.
4) Development of new resources and processes, particularly renewable resources and processes which further supply technologies.
5) Improve operating efficiency and reliability or otherwise reduce operating costs.

Program Cycle 2019-2021 funding $43 million.

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Advanced Low Carbon Gas Technologies RD&D

Beneficial Biogas Use Utilization Pathways

Key Technologies

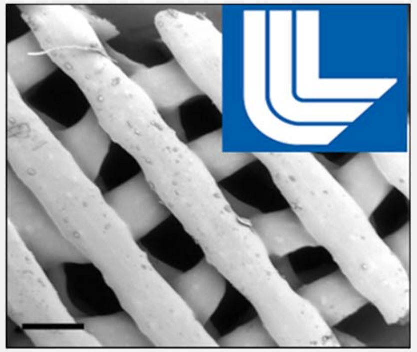
A. Advanced sorbents

B. Hydrothermal processing

C. On-site hydrogen generation

D. Power-to-gas, power-to-molecules

E. Co-production of hydrogen and carbon fibers

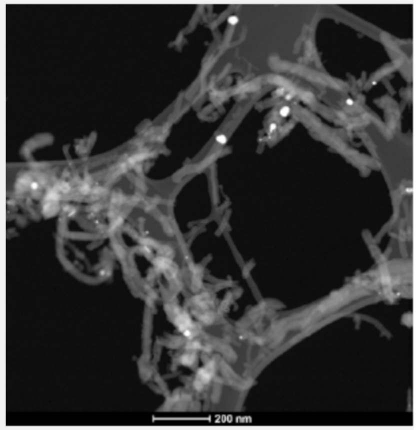


A

B

C

D



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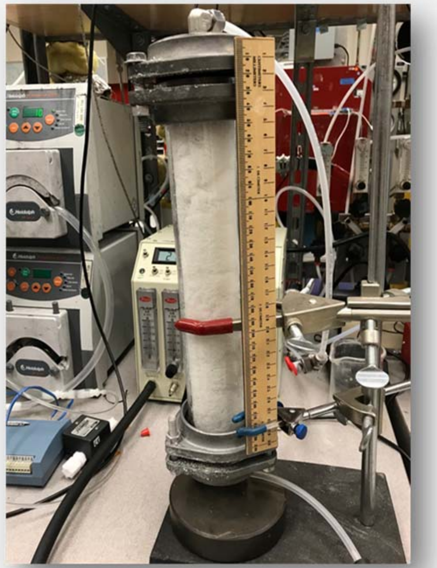
Gas Separation

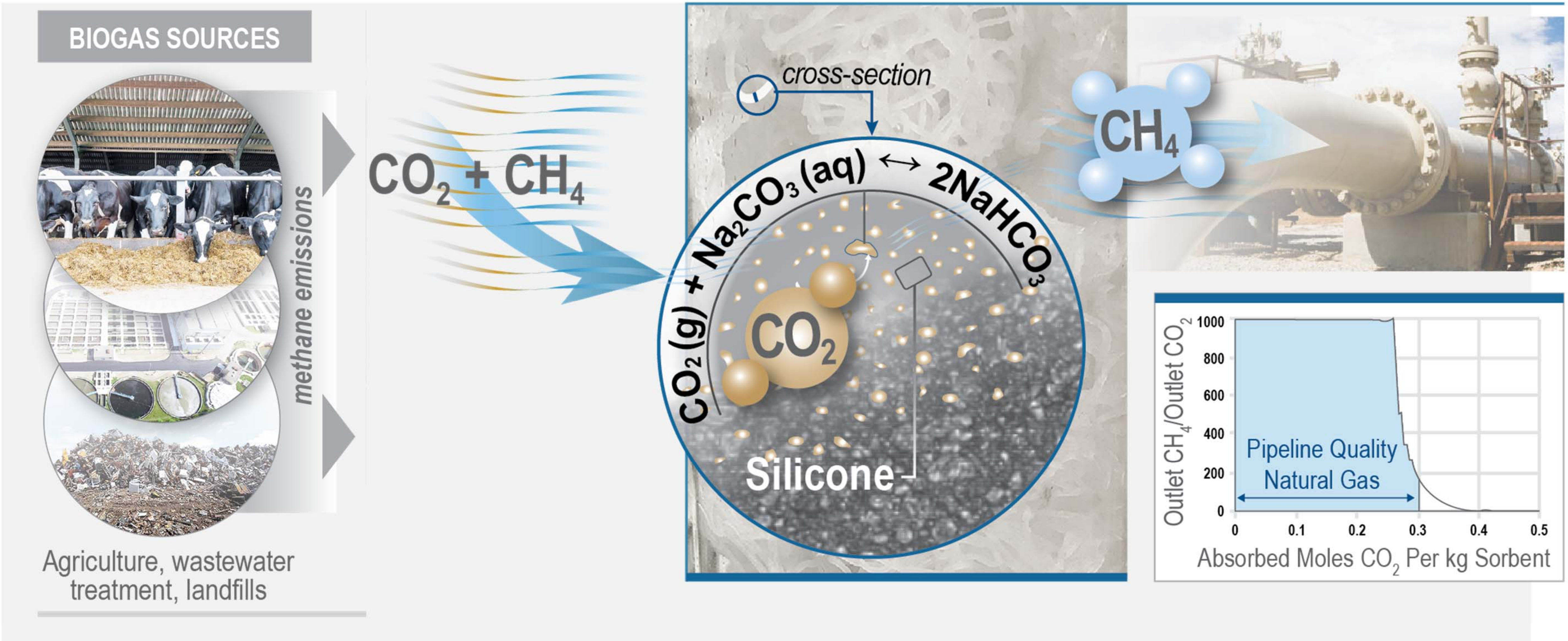
Composite Sorbents: Enabling Economical Biogas Upgrading

- LLNL is refining and demonstrating a new class of sorbents for capturing CO2.
- The sorbent materials combine the operational advantages of solid sorbents with the high CO2 selectivity of CO2 capture liquids.
- This offers a simple, robust, modular, and environmentally benign means to capture CO2
- This could, for example, enable producers of underutilized biogas to turn their waste into high quality biomethane—becoming energy producers rather than consumers.

Composite Sorbents Can be Printed, Extruded, or Pelletized (scale bar 200 µm)



Gas Separation (Cont'd)

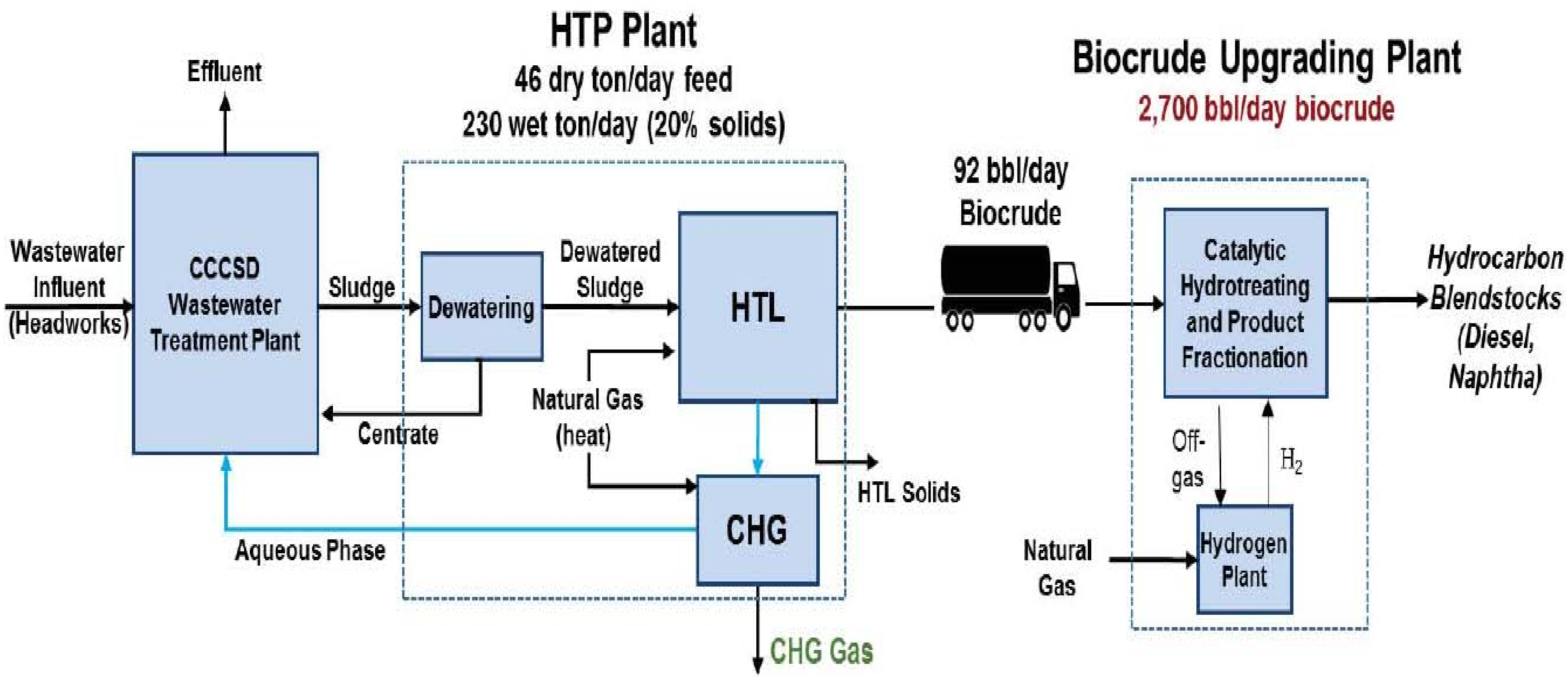


Hydrothermal Processing

- Hydrothermal Processing (HTP) uses temperature and pressure to convert wet organic matter to:
  - Biocrude oil via hydrothermal liquefaction (HTL)
  - Methane via catalytic hydrothermal gasification (CHG)
- Operates at 350°C and 200 bar
- Wet feed stock includes wood, biosolids, food waste, dairy waste, algae, etc.
- Highly efficient—captures more than 86% of feedstock energy and uses only 14% for process
- Energy yield 2x biological processes
- Temperature much lower than syngas processes
- Feedstock is completely converted—no solids left
- Converting waste products to energy has the potential to address landfill, food, agricultural and forestry waste challenges while creating renewable energy and reducing GHG emissions.

Genifuel dairy waste processing demonstration

HTP Process Model



HTP Output Products

Solids with Phosphorus

Bio Oil

Methane

Water

- The oil/gas production ratio can vary from 100% oil/0% RNG to 0% oil/100% RNG, depending on operator preference.

Hydrothermal (HTP) vs. Anaerobic (AD)

MEASURE	VALUE
▪ Footprint	HTP is 44% of AD
▪ GHG Reduction	HTP reduces GHG 3x as much as AD
▪ 20-year NPV Cost	HTP is 55% of AD Cost
▪ Energy Production	HTP produces 2x the fuel energy from AD

Low-Cost Hydrogen Generation

Solar Thermochemical Advanced Reaction System (STARS)

- "Chemical Process Chips": Microchannel reactors and heat exchangers
- 70% World Record Solar-to-Chemical Energy Efficiency
- Multiple R&D 100 Awards
- 25 years of development
- \$50M to develop by NASA and DOE, 32 Licensed Patents
- STARS' Modular H2 Generator produces H2 at an initial cost of < \$5/kg
- It will fall to under \$3/kg with low volume mass production

Power-to-Gas

Carbon utilization via methanation

Electrolysis with Methanation: $4H_2 + CO_2 \xrightarrow{\text{Biocatalyst}} CH_4 + 2H_2O + \text{Heat}$

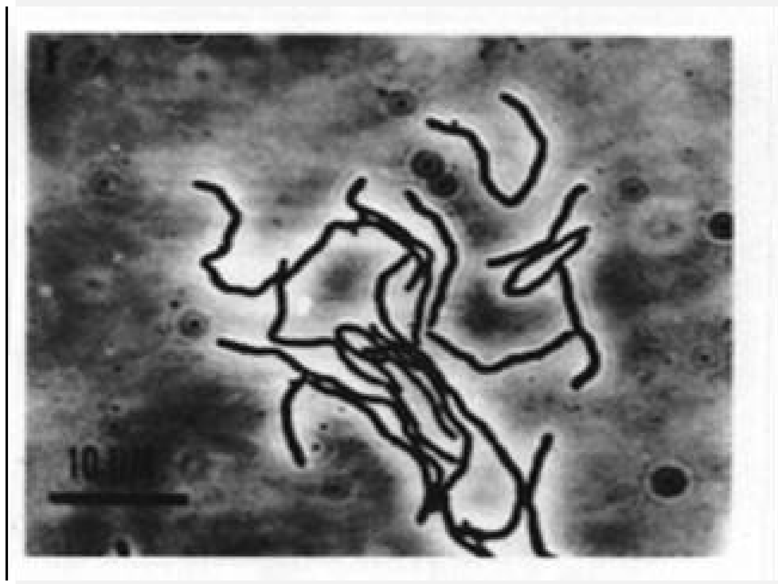
- Using the renewable H_2 and CO_2 in a downstream methanation process to produce renewable methane and water
- 700 L bioreactor contains biocatalyst that combines H_2 and CO_2 to produce pipeline quality methane
- Benefits of renewable methane
  - Enables higher penetration of renewable electricity
  - Recycles CO_2
  - Meets pipeline quality standards
  - Provides long-duration energy storage in the NG network
  - Upgrades waste streams containing CO_2
    - Ethanol, dairies, wastewater, breweries
  - Scale-able, non-toxic, self-replicating biocatalyst, low temperature systems

Rule of Thumb: 10MW$_e$ of electrolysis feeding a bioreactor can recycle 7500 tons of CO_2 per year

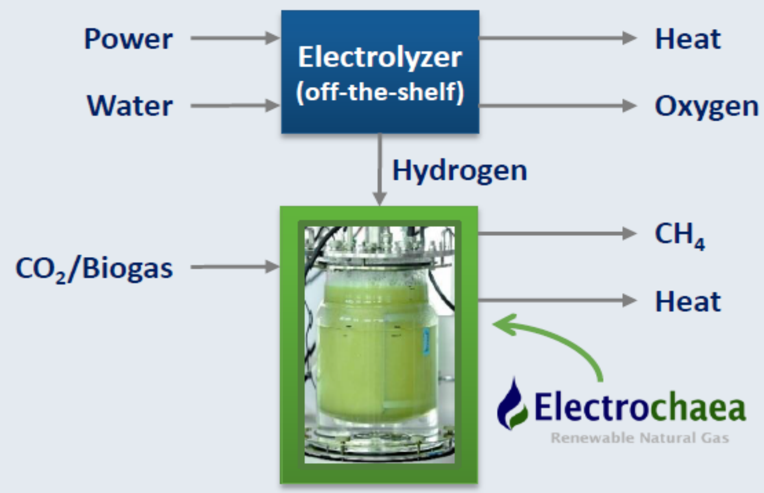
Power-to-Gas / Biocatalyst – Methanogenic Archaea

About the organism

- Self-replicating
- Found in extreme environments
- Thermophile up to 80°C (176°F)
- Selectively evolved, not genetically modified
- Anaerobic, but tolerates some O_2



System Design



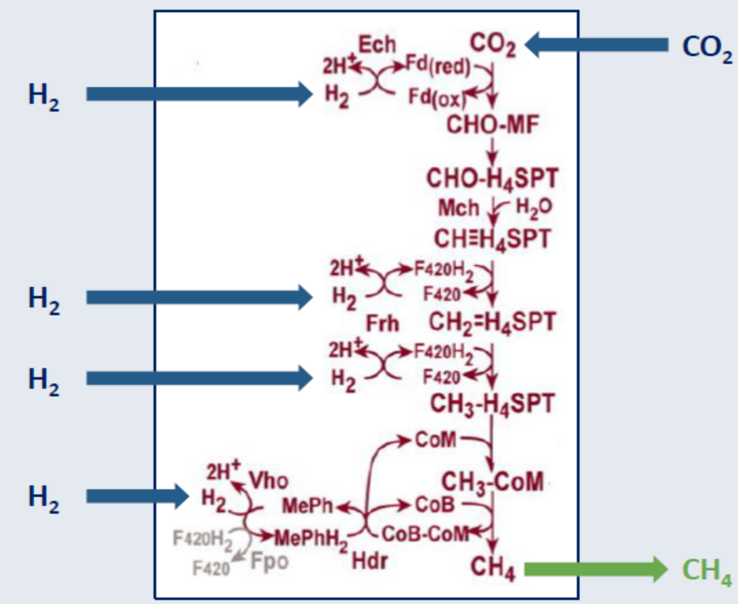
Inputs
- Water
- Low-cost or stranded electricity or H_2
- CO_2 from biogas, fermentation, or other sources
- Electrochaea's proprietary biological catalyst

Outputs
- Pipeline-grade methane for direct grid injection
- Oxygen for industrial or medical applications
- Heat for on-site use or district heating grids

Chemistry & Biochemistry

Chemical Reactions:

1) Electrolysis	$4H_2O \rightarrow 4H_2 + 2O_2 + Heat$	η=0.80
2) Methanation	$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O + Heat$	η=0.75
Net Reaction	$CO_2 + 2H_2O \rightarrow CH_4 + 2O_2 + Heat$	η=0.60



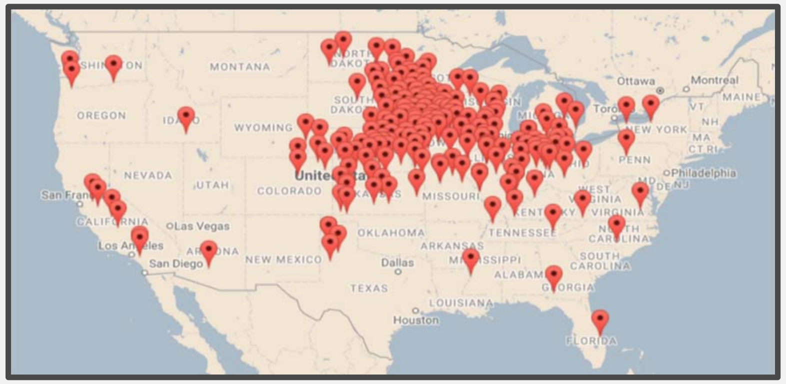
Power-to-Gas (Cont'd)

Rule of Thumb:

10MW$_e$ of electrolysis feeding a bioreactor can produce ~500 scfm (12,000 Nm^3 or 440 MMBTU per day/6 g/L-hr) of methane and recycles ~20 tons of CO_2 per day

Early Market CO_2 Sources – Plenty of Resource

- As of May 2018, the United States has over 200 operating refineries producing 15.8 billion gallons of ethanol per year (http://www.neo.ne.gov/statshtml/122.htm)
- Typical ethanol plant produces 50 Million gallons of ethanol per year and 150,000 metric tons of CO_2
- Each 50 MW of electrolysis (432 kg H_2/day) feeding a bioreactor can recycle 37,000 metric tons of CO_2
- Therefore, It would take 200 MW of electrolysis per typical ethanol plant to recycle all of the CO_2 into CH_4

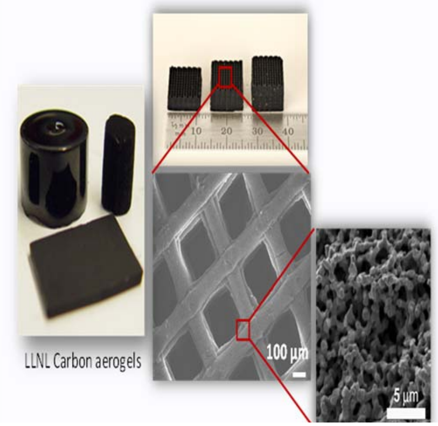


http://www.ethanolrfa.org/resources/biorefinery-locations/
Last updated: April 30, 2018

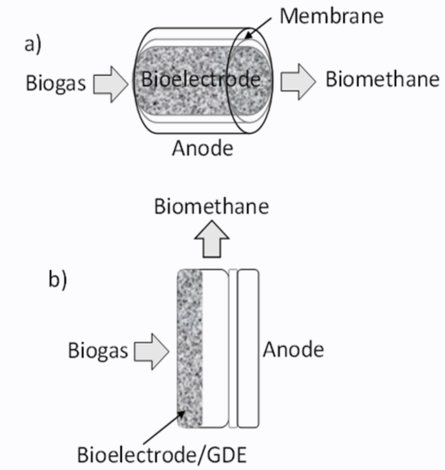
LLNL/Stanford Microbial Electromethanogenesis Flow Reactors for Biogas Upgrading

CO_2 and Electrons to Methane

- Lawrence Livermore National Laboratory and Stanford University are using *Methanococcus maripaludis* to convert carbon dioxide and water into methane.
- Hierarchically porous electrode with high surface area due to mesopores generated during carbonization, and macropores to ensure good fluid flow/mixing



Carbon aerogels and printed aerogels with hierarchical pore structures.



(a) flow through aerogel tube-based reactor design; (b) GDE stack-based reactor design.

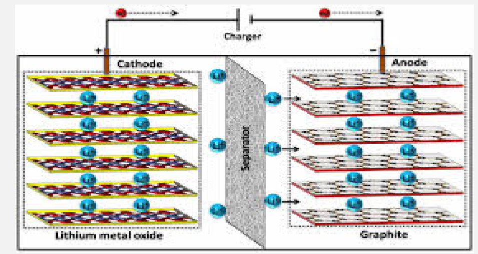
Hydrogen + Carbon Fibers

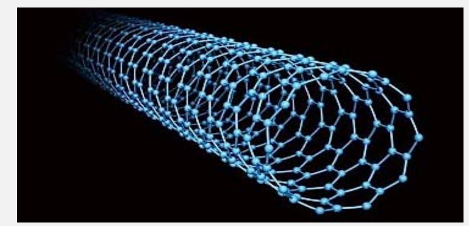
Carbon Capture and Utilization: H_2 + C Co-production

Methane Pyrolysis for Base-Grown Carbon Nanotubes and CO_2-free H_2

Partners: West Virginia University, C4-MCP, PNNL, DOE.

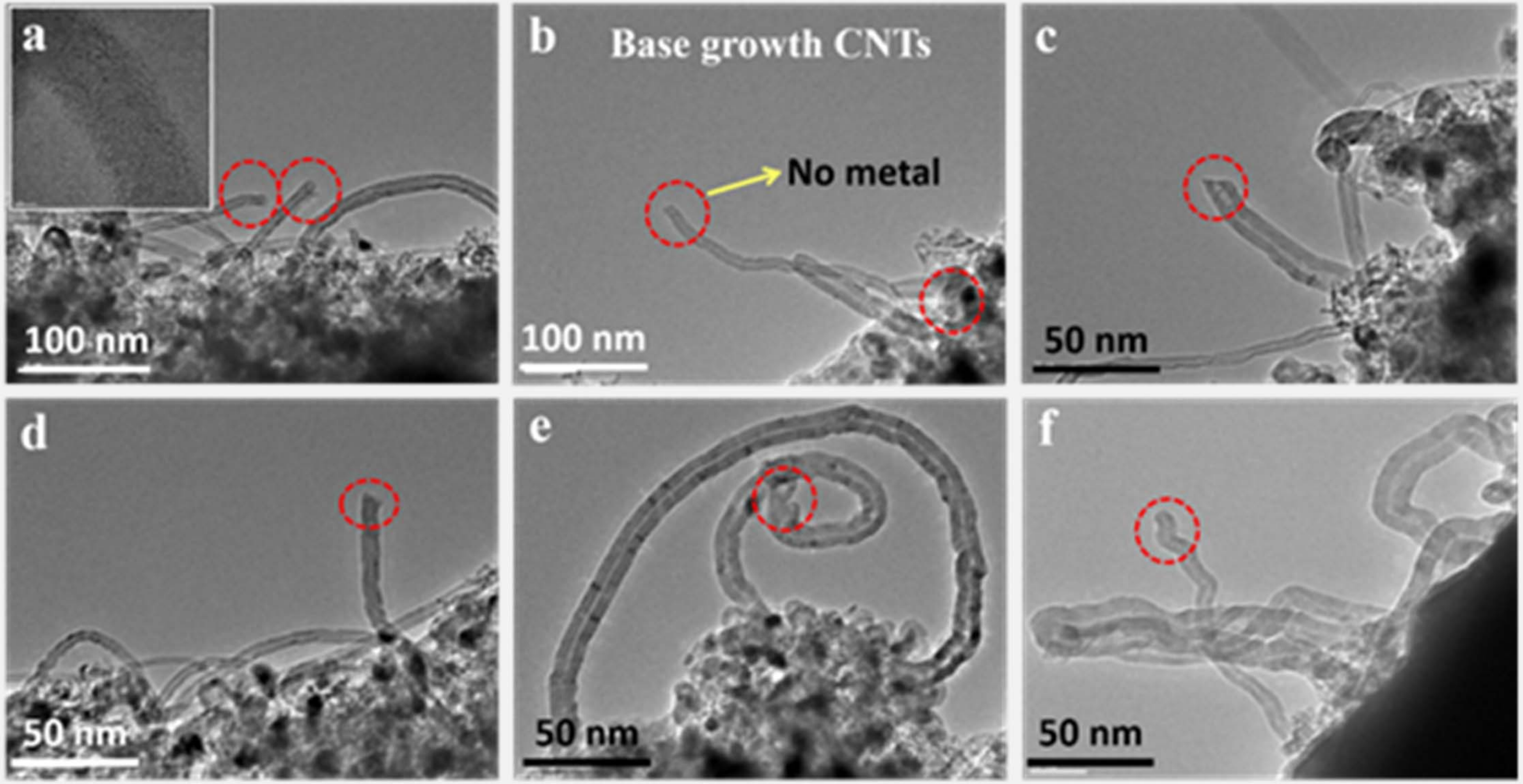
- A new process for producing CO_2-free hydrogen and solid carbon from natural gas
- Net production cost of H_2: < \$2/kg with the sale of valuable byproduct carbon.
- Carbon nanotubes produced via “base-growth” versus “tip-growth” mechanism, the conventional technology, offers potential for economic advantage (catalyst regeneration and purity)

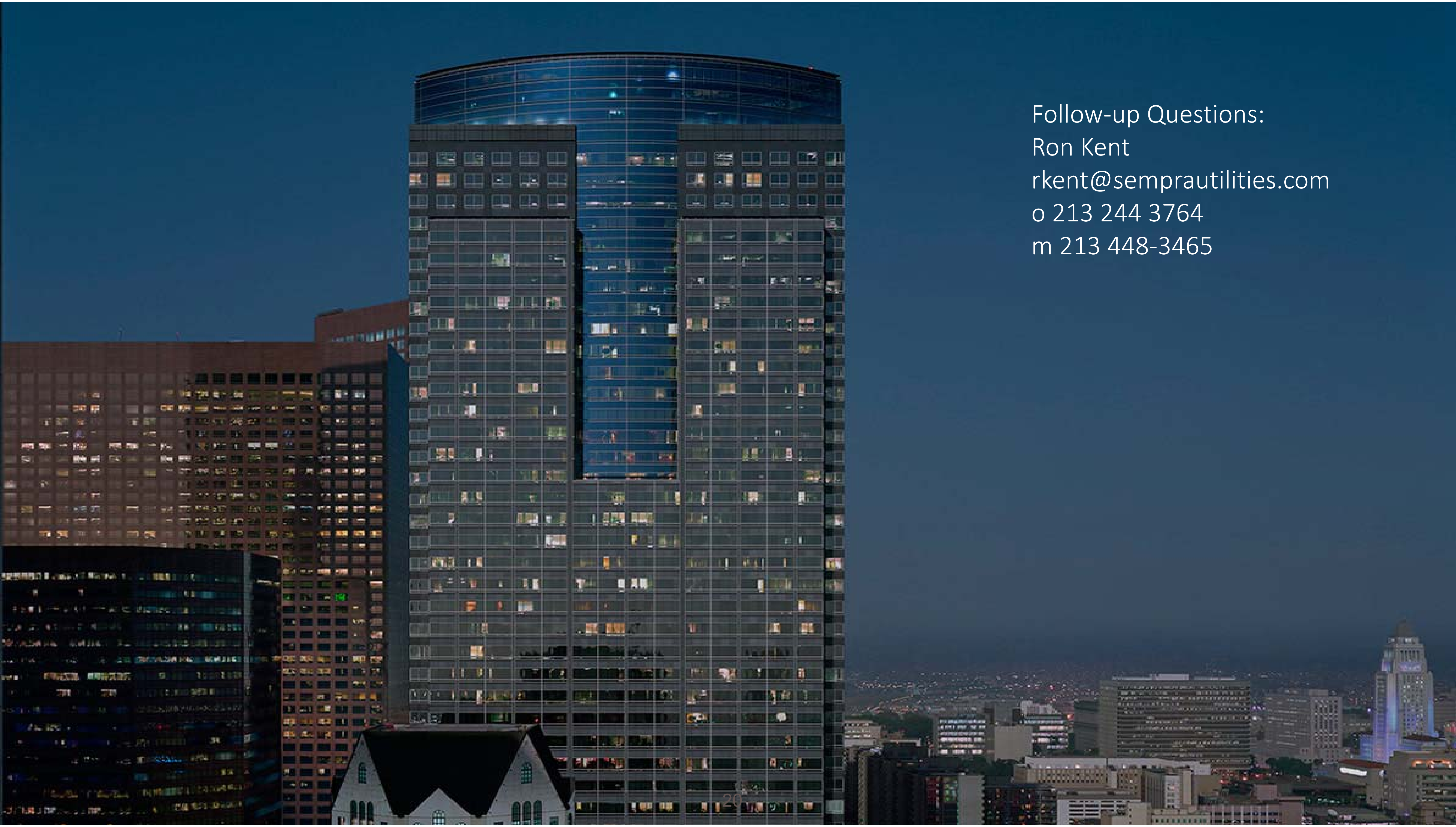




Hydrogen + Carbon Fibers

Carbon Nanotubes




Follow-up Questions:
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RNG Production and Market Barriers

SOUTH COAST AQMD RULE 1118.1 BENEFICIAL USE TECHNOLOGY ASSESSMENT WORKSHOP

Jim Lucas
Market Development Manager

October 10, 2019

Interconnection: Overview of Components

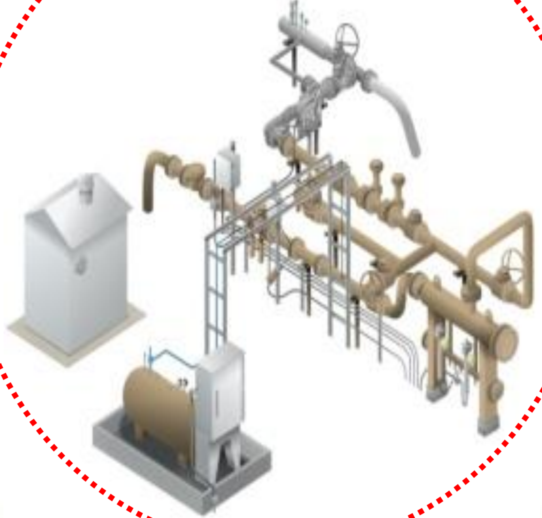
Two Primary Components of the Term "Interconnection"

("Interconnection" = "Point of Receipt" + "Pipeline Extension")

Customer Pipeline

RNG from biogas conditioning upgrading plant

"Point of Receipt (POR)"



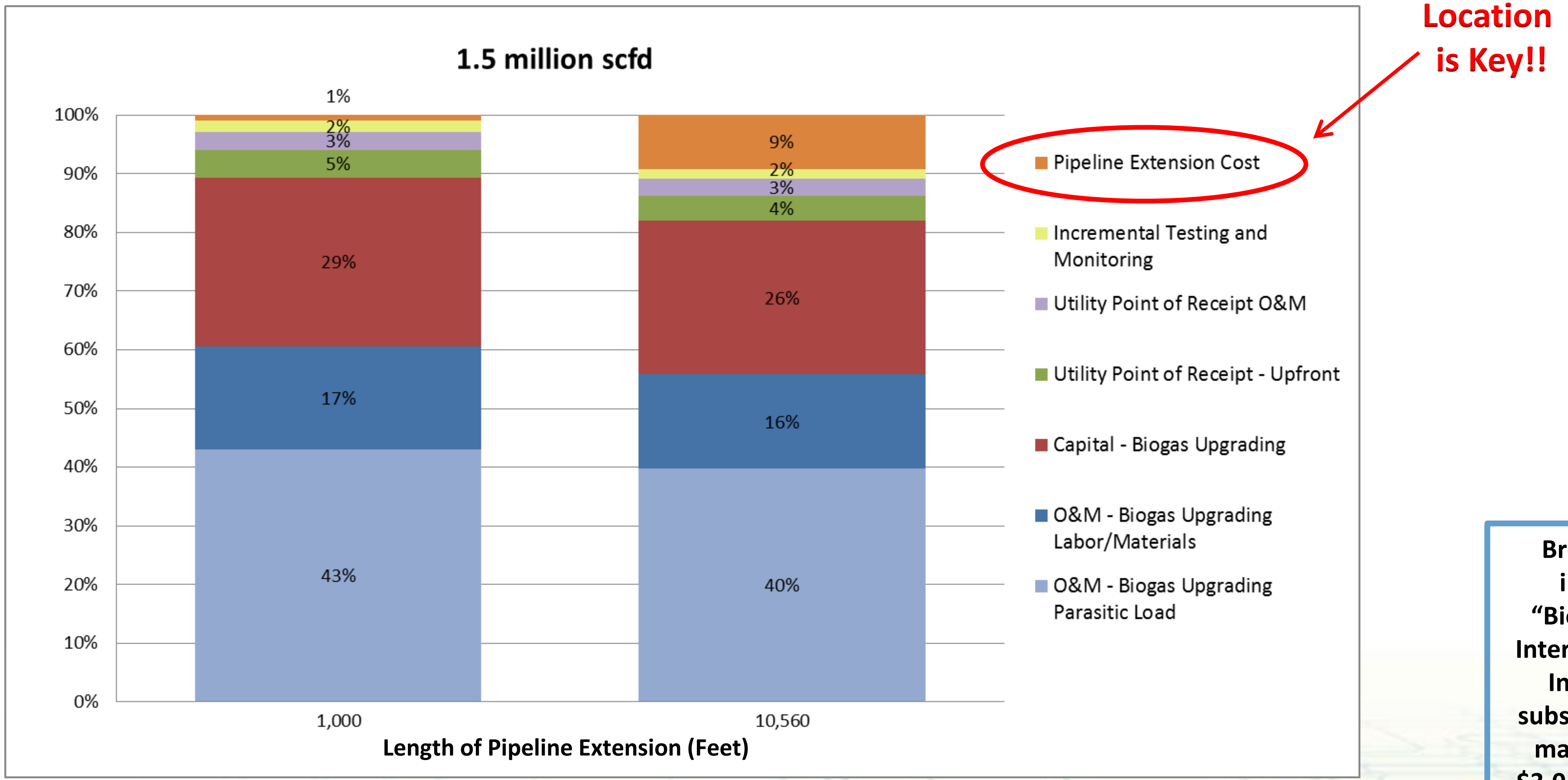
Utility Pipeline

"Pipeline Extension"

Interconnection Facilities are Funded by Interconnector and Owned/Operated by SoCalGas

Estimated Breakdown of Major Cost Components for Producing and Injecting RNG into the Pipeline

Estimated Breakdown of Lifecycle Costs to Produce and Inject RNG into the Pipeline {based on 1.5 million scfd of biogas for 15 years}

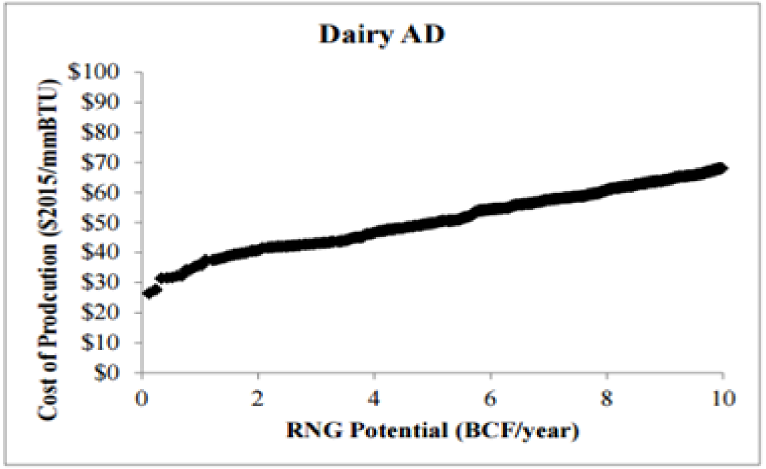


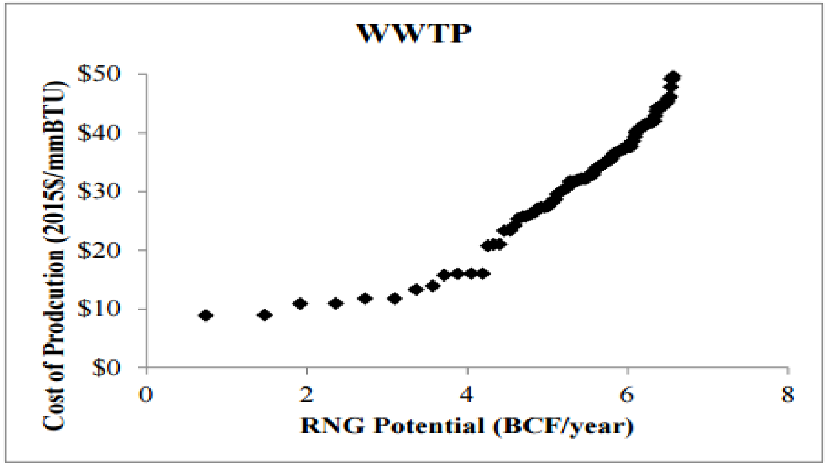
Breakdown includes "Biomethane Interconnection Incentive" subsidy of 50%, maximum of $3.0 million per project

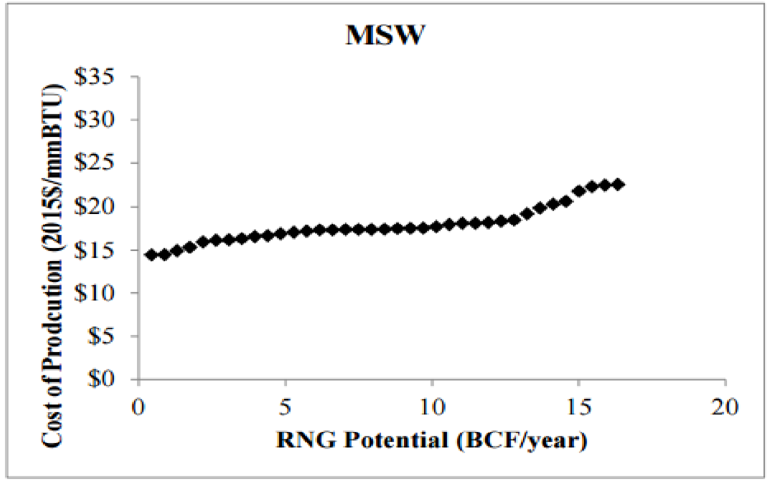
1) Pipeline Extension costs are based on installing pipeline in roads with curb/gutters.
2) Estimated costs assume testing for all 17 biogas constituents and includes the cost of the tests and associated labor.

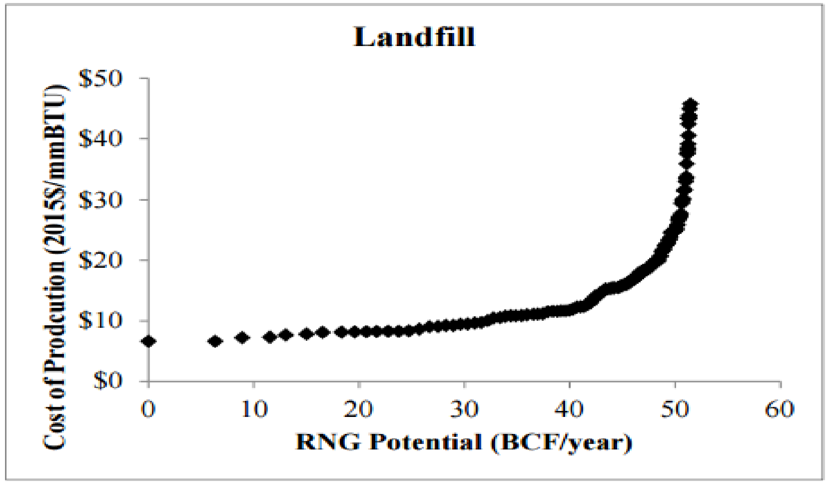
Cost of Renewable Gas Production in CA

RNG Production Cost Curves by Source of Feedstock









Source for RG Cost Curves: "The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute," Updated June 2016. Amy Myers Jaffe, Principal Investigator; STEPS Program, Institute of Transportation Studies, UC Davis – [pp 54-55 https://www.arb.ca.gov/research/apr/past/13-307.pdf]

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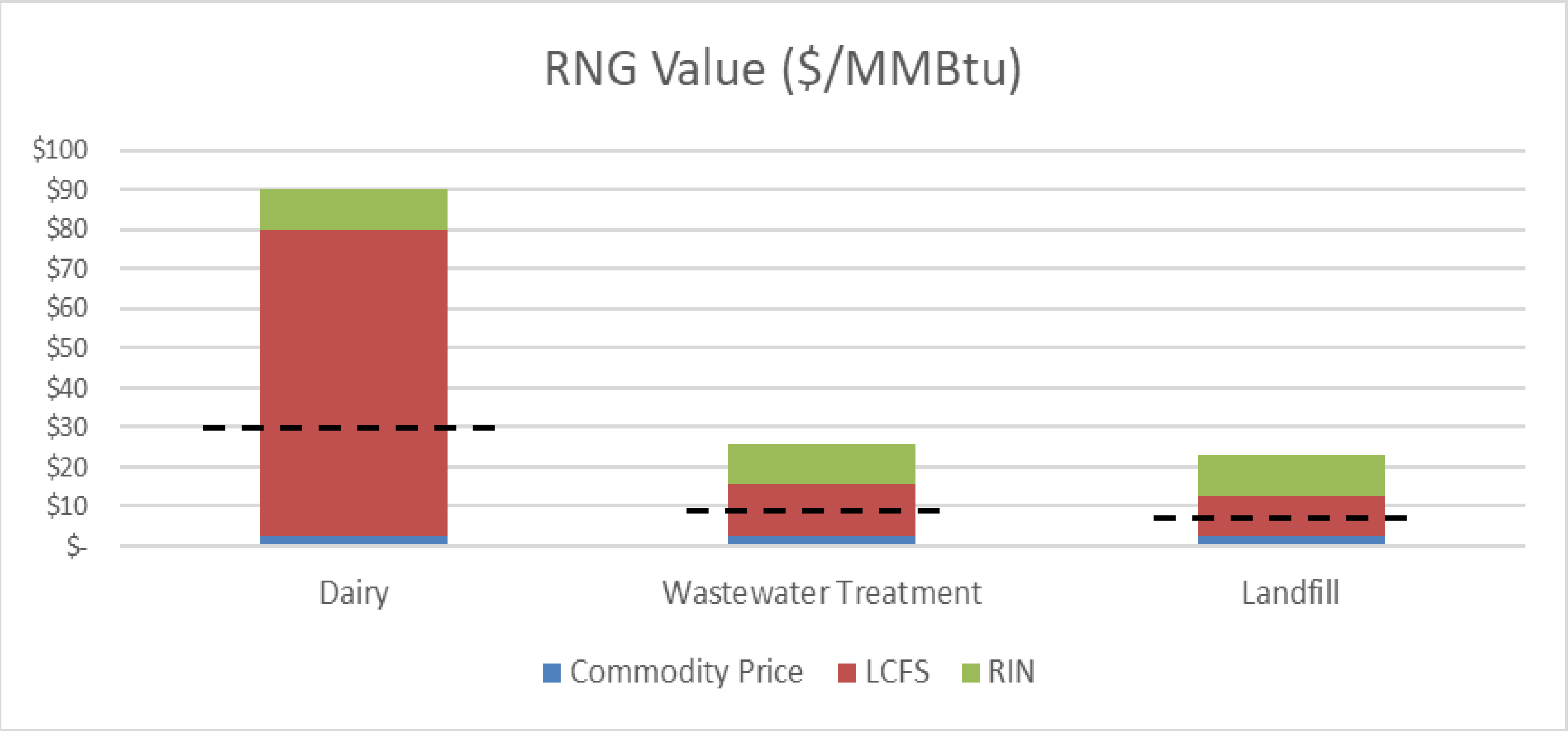
Today's Value of RNG in Transportation

- RNG can have significant value when used as a vehicle fuel in CA
- Typically this value can compensate for higher production costs, however environmental credit uncertainty limits sector growth



--- Estimated Low-End Production Cost

Prices as of 10/04/19

* 2019 Vintage D3 RIN's

** Assumes carbon intensity for Dairy biogas of -276 gCO2e/MJ, WWTP biogas of 30 gCO2e/MJ, and LFG of 45 gCO2e/MJ

*** Approximate Henry Hub Natural Gas Future Price – November 2019

http://progressivefuelslimited.com/Auth_RIN/PFL_RIN_Recap.pdf

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Challenges to Produce RNG

1) **Market Price of RNG**
   - The primary barrier for the RNG industry over the last decade is the unavailability of long term contracts at a purchase price higher than the cost to produce/inject RNG
     - If RNG long term contracts were available, numerous landfills and wastewater treatment plants would likely stop flaring and develop RNG to pipeline projects
   - Entities are not willing to enter into long term contracts to purchase LCFS and Renewable Fuel Standard (RFS2) due to future uncertainty of these markets

2) **Project Scale**
   - Minimum threshold is approximately 1.0 to 1.5 million standard cubic feet per day for favorable economics (including interconnection costs). Higher volumes generally needed for landfills
   - Small to medium scale biogas production facilities have historically not been economical. But with biomethane interconnection incentive and high credit prices things are changing

3) **Landfill Gas Quality/Composition** - many landfills have high-levels of nitrogen and oxygen (expensive to remove)

4) **Incentives/Subsidies -** Need incentive programs specific to RNG projects to bring down the costs

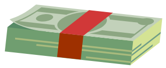
5) **Limited Growth of CNG Vehicles in CA**
   - CNG vehicle fuel market is becoming saturated with RNG, resulting in limited demand for additional/incremental RNG

Overview of SoCalGas Biogas Conditioning/Upgrading Services (BCS) Tariff

BCS Tariff Illustration

Customer Owned Biogas

Biogas Conditioning/Upgrading Services Facility
(SoCalGas Owned and Operated)



Customer pays SoCalGas a monthly BCS tariff fee for a turnkey solution

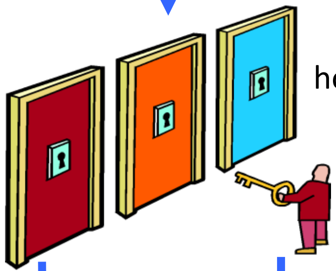
What is included in SoCalGas' turnkey solution?

- 100% of the upfront capital
- Biogas conditioning/upgrading facilities design
- Equipment and construction RFP
- Vendor selection and management
- Project/construction management
- Facility operation and ongoing maintenance
- Contract management

What is not included?

- Customer pays for utility costs (e.g. – kWh to operate the upgrading facility)

Customer Owned
Conditioned/Upgraded Biogas



Customer decides how to use conditioned/ upgraded biogas

Onsite Use – CNG or Generation

Interconnection for Pipeline Injection (Responsibility of Customer)

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