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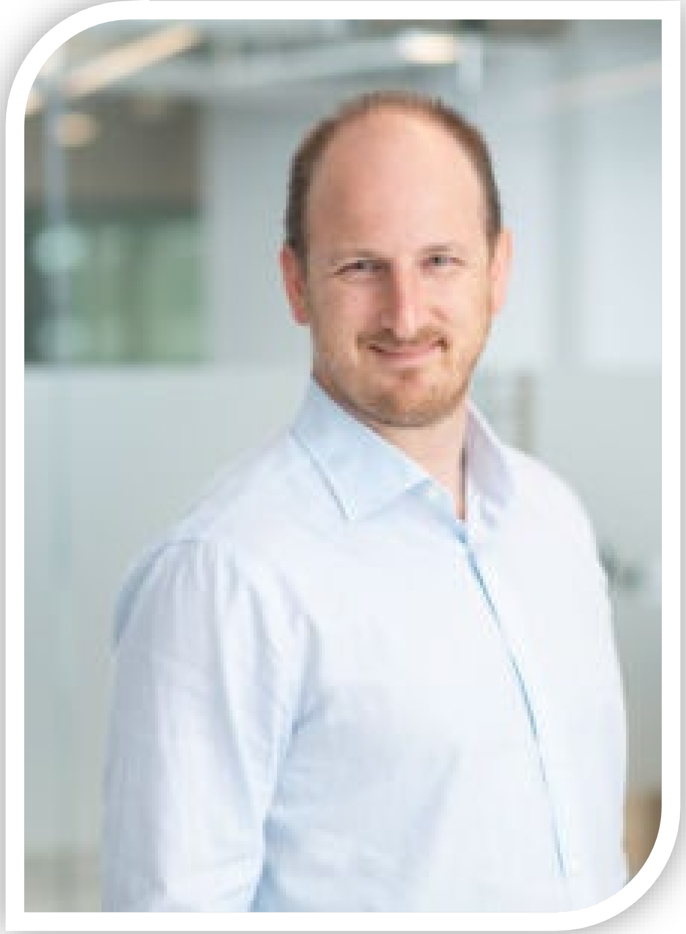


Developer Spotlight

Raycho Spilkov

Vice President – Development, Vanguard Renewables


Vanguard
RENEWABLES
Changing the Way the World Views Waste.

Who is Vanguard Renewables?

- Nationwide leader in organics-to-renewable energy
- AD developer, owner, operator
- 185 food waste partners and growing
- Projected >150 dairy farm partners
- Projected >15 bcf of RNG produced annually

Organics Depackaging

- One of our Organics Recycling Facilities (ORFs) can process up to 250 tons of packaged material per day
- Many codigestion projects going forward will feature an ORF

We're Excited to Work Together to Make Minnesota's Agriculture, Food & Beverage, and Energy Industries More Sustainable


Thank You!
Vanguard
RENEWABLES

Developer Spotlight

Stephen Dvorak, PE

President

DVO, Inc.

DVO
renewables at work

Anaerobic Solutions

High-Efficiency, 3rd-Gen AD for Global Agriculture

American company, based in Wisconsin

- DVO was founded in 1989 by Steve Dvorak, P.E.
- Packerland digester in 1985 – still operating today

DVO

Our first digester (patented)

- Gordondale Farms, WI, September 2001
- Today, DVO is the USA market leader, operating at +130 sites in 24 U.S. states
- International operations include Canada, Chile, South Africa, United Kingdom, China, South Korea, Serbia, India & Australia

DVO

Today…

- DVO processes manure from 400,000 dairy cows every day,
- Which is about 13.2 million gal/day (50,000 M^3/day) of manure.
- DVO also processes hog waste, chicken litter, food wastes and municipal organics.
- >30,000 MMBtus of renewable energy is produced daily.

DVO

2-Stage Mixed Plug-Flow

- Guaranteed consistent retention time of influent wastes = greater biodegradation of TS
- More biogas per ton of TS = more revenue potential
- Superior odor & pathogen destruction
- Optional N, P & K separation from liquid effluent after digestion
- Better quality of separated fiber solids
- More thermally efficient = > CI score

DVO DVO

Renewable CNG

When used as a transportation fuel to replace diesel or gasoline, renewable CNG (or RNG) earns additional credits – an attractive revenue option.

Separated fiber solids – valuable, & versatile

- High-quality Animal Bedding
  - Pathogen Reduction
  - Somatic Cell Count/Herd Health
  - Clean Cows
- Fertilizer
- Peat Moss Replacement
- Off-site sales
- Particle Board products

DVO

Pathogen destruction

Potentially harmful pathogens such as e-coli and salmonella are reduced in the digested waste – often to the point of “none-detected.”

- An answer to concerns about spreading raw, unprocessed farm wastes on fields,
- Via DVO’s “Guaranteed Retention Time”… unlike older AD designs, every unit of waste is retained in the vessel for a specific amount of time. Nothing is removed too soon, or too late, resulting in a *higher level of biodegradation of organic wastes.*
- Post-AD pasteurization is optionally available.

Land application

Liquid Fertilizer, inorganic nutrients

- N, P and K are not destroyed by the digester. Instead, they are transformed to an inorganic state that is already “plant-available,” and now can be land-applied to a growing crop.
- By restoring these valuable nutrients to the land, less artificial fertilizers need to be employed.
- DVO owners report up to 100% increase in yield for alfalfa, using digested liquid fertilizer.
- pH Increase
- Lessened Likelihood of Runoff
- Liquid can be pivot-irrigated

Requirements for successful AD systems

- Guaranteed retention time for the entire waste stream (for higher efficiency and pathogen destruction)
- No stratification of solids in-vessel
  - Constant temperature
  - Full dispersion of bacteria population
- Ability to handle multiple waste streams
- Ability to handle a wide range of waste streams (including poultry, hog, ethanol, food wastes & FOG), and
- Ability to handle both high and low solids concentrations

Questions to ask when selecting a digester…

- simple & practical operation
- Low maintenance
- Cost per Btu produced
- Btus produced per unit of Waste
- Ability to accept different % solids, and waste streams
- Number of systems in operation (experience & track record)
- System’s parasitic load (% of kW produced)
- Quality of separated solids & liquid effluent
- Third party data / performance verification

Reputation

- In the USA more agricultural wastes (by both number of installations and total volume) are processed in DVO digesters than any other,
- 97% of all DVO digesters ever built are still in operation,
- We are fortunate to see regular repeat business.

Phosphorus Recovery (PR)

Ammonia Recovery (AR) (patented)

DVO

Thank You.

info@dvoinc.com

INFO@DVOINC.COM CHILTON, WI USA 920 . 849 . 9797

Developer Spotlight

Noah Carlson

Application Engineer

BIOFerm Energy Systems

BIOFERM™

COMPANY OVERVIEW

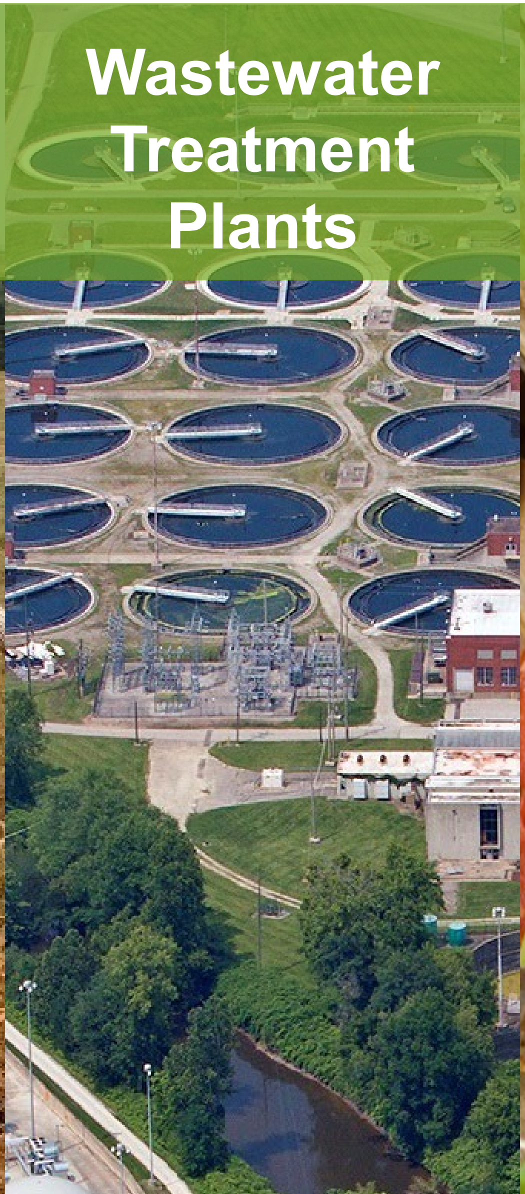
Noah Carlson,
Application Engineer

COMPANY PROFILE

- **Headquartered** in Madison, WI
- **Established** in 2007
- **Technology provider for:**
  - Gas Upgrading
  - Anaerobic Digestion
  - Solar
- **Other services:**
  - Biogas & Solar Engineering
  - Consulting
  - Technology
  - Plant Operation & Maintenance
  - Financing
- **Experience** building hundreds of international projects

BIOFERM™

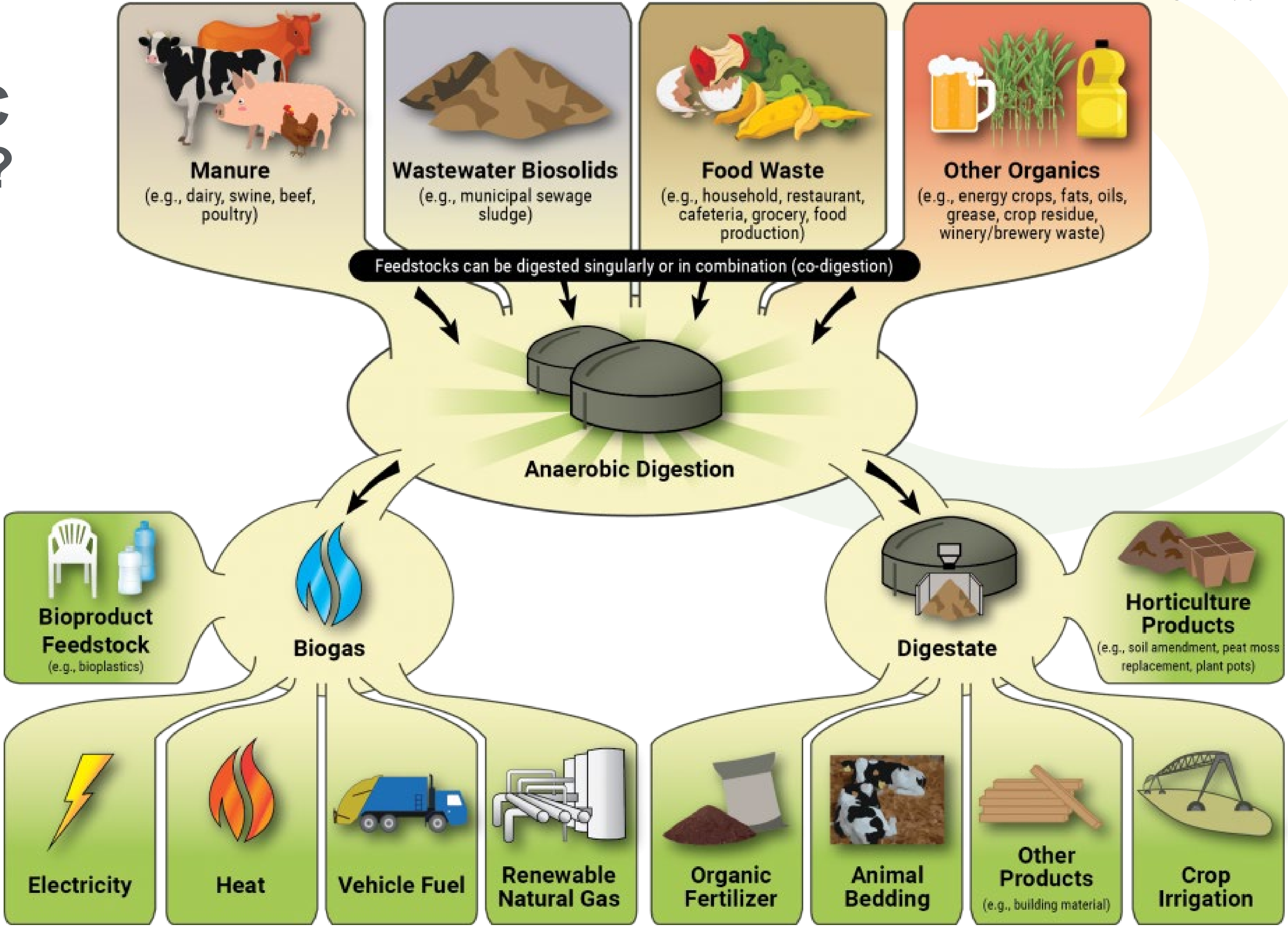
BIOGAS SOLUTIONS ACROSS ORGANIC WASTE SECTORS



WHAT IS ANAEROBIC DIGESTION?

Anaerobic digestion (AD) is a process through which bacteria break down organic material in the absence of oxygen.

Image courtesy of EPA



BIOFERM™

COMPREHENSIVE AD TECHNOLOGY

- **FERMADOR** Continuously Stirred Tank Reactor (CSTR)
- **FERMIGMA** Plug Flow Reactor (PFR)
- **FERMIGMA Small-Scale** CSTR or PFR
- **FERMITIGO** Dry Fermentation

BIOFERM™

FERMADOR CASE STUDY:
ROSENDALE DAIRY

Location: Pickett, Wisconsin

Waste Stream: 350 tons/day dairy manure from 8,500 cows

Capacity: 1.4 MW_{el}

Technology: 2 FERMADOR tanks

Operational: Since 2013

Offsets: Avoided release of 44,602 tons of CO_2 per year & provides electricity to 1,107 homes/year

BIOFERM™

FERMIGMA CASE STUDY:
CITY OF AKRON & KB BIOENERGY

Location: Akron, Ohio

Waste Stream: 15,000 tons/year of biosolids

Capacity: 1.8 MW_{el}

Technology: 3 FERMIGMA plug-flow digester & 3 FERMADOR complete mix digester

Operational: Commissioned in 2013

Offsets: Provide electricity to 932 homes/year, heat 878 homes/year

FERMIGMA SMALL-SCALE AD CASE STUDY:
ALLEN FARMS

Location: Oshkosh, Wisconsin

Waste Stream: 6,200 tons/year dairy manure from 136 cows

Capacity: 64 kW_{el}

Technology: 2 FERMIGMA small-scale digesters

Operational: Since 2012

Offsets: Avoided release of 2,312 tons of CO_2 & provides electricity to 50 homes/year

FERMITIGO AD CASE STUDY:
UNIVERSITY OF WISCONSIN-OSHKOSH

Location: Oshkosh, Wisconsin

Waste Stream: 8,000 tons/year of food waste, yard waste, & crop residuals

Capacity: 370 kW

Technology: 4 fermenters

Operational: Since 2011

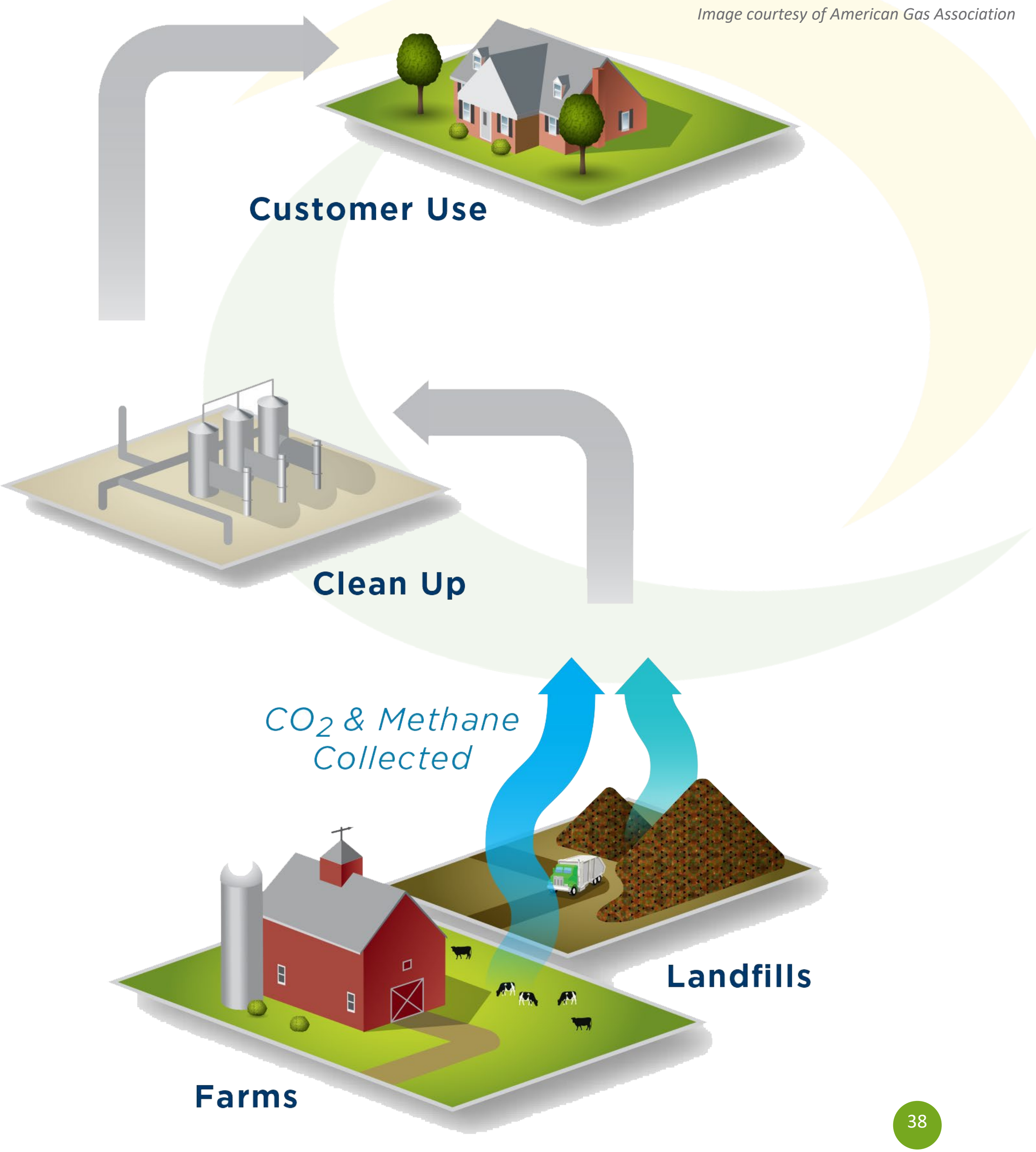
Offsets: Avoided release of 9,641 tons CO_2, provides electricity to 220 homes/year

BIOFERM™

WHAT IS RNG?

- Renewable natural gas (RNG) is pipeline-quality gas that is fully interchangeable with conventional natural gas.

- RNG is essentially methane from biogas that has been processed to high purity standards.



BIOFERM™

BIOVIS COMPREHENSIVE EPC GAS UPGRADING PRODUCTS

PSA
(1 & 2-Stage)

Membrane

Biological
Desulfurization

Hydrogen Sulfide
Removal

VOC Removal

BIOFERM™

BIOVIS P1200 1-STAGE PSA CASE STUDY:

SEABOARD ENERGY

Location: Guymon, Oklahoma

Completion: Commissioned July 2017

Capacity: 1,200 scfm biogas from covered lagoons for 5.5 millions hogs/year

Raw Gas: 68% CH_4, 24% CO_2, 1.5% N_2 , 0.4% O_2, 4,000 ppm H_2S

Performance: Exceeds ET pipeline requirements

BIOVIS P500 1-STAGE CASE STUDY:
WISCONSIN DAIRY FARM

Location: Green Bay, Wisconsin

Completion: Operational since early 2021

Capacity: 500 scfm biogas from anaerobic digester for 3,500+ dairy cows

Raw Gas: 60% CH_4, 40% CO_2, >1,500 ppm H_2S

Performance: Exceeds ANR pipeline requirements

BIOFERM™

BIOVIS P2500 2-STAGE CASE STUDY:

DANE COUNTY LANDFILL

Location: Madison, Wisconsin

Completion: Commissioned April 2019

Capacity: 2,500 scfm landfill gas

Raw Gas: 56% CH_4, 34% CO_2, 6.6% N_2 , 0.3% O_2, 3,000 ppm H_2S

Performance: Exceeds ANR pipeline requirements

COMBINED RENEWABLE ENERGY

Anaerobic Digester + Gas Upgrading + Solar Energy System

BIOFERM™

YOUR RENEWABLE ENERGY PARTNER

- One Stop Shop
- Proven Technology & Experienced Team
- Quick & Efficient Deployment
- Industry-Leading Performance Guarantee & Warranty
- Financing Options
- Completely Integrated System

QUESTIONS?

INFO@BIOFERMENERGY.COM

BIOFERMENERGY.COM

Audience Q & A

Biogas Uses and Upgrades

Luca Zullo, Ph.D.

Sr. Director of Science and Technology, AURI

Agricultural Utilization Research Institute

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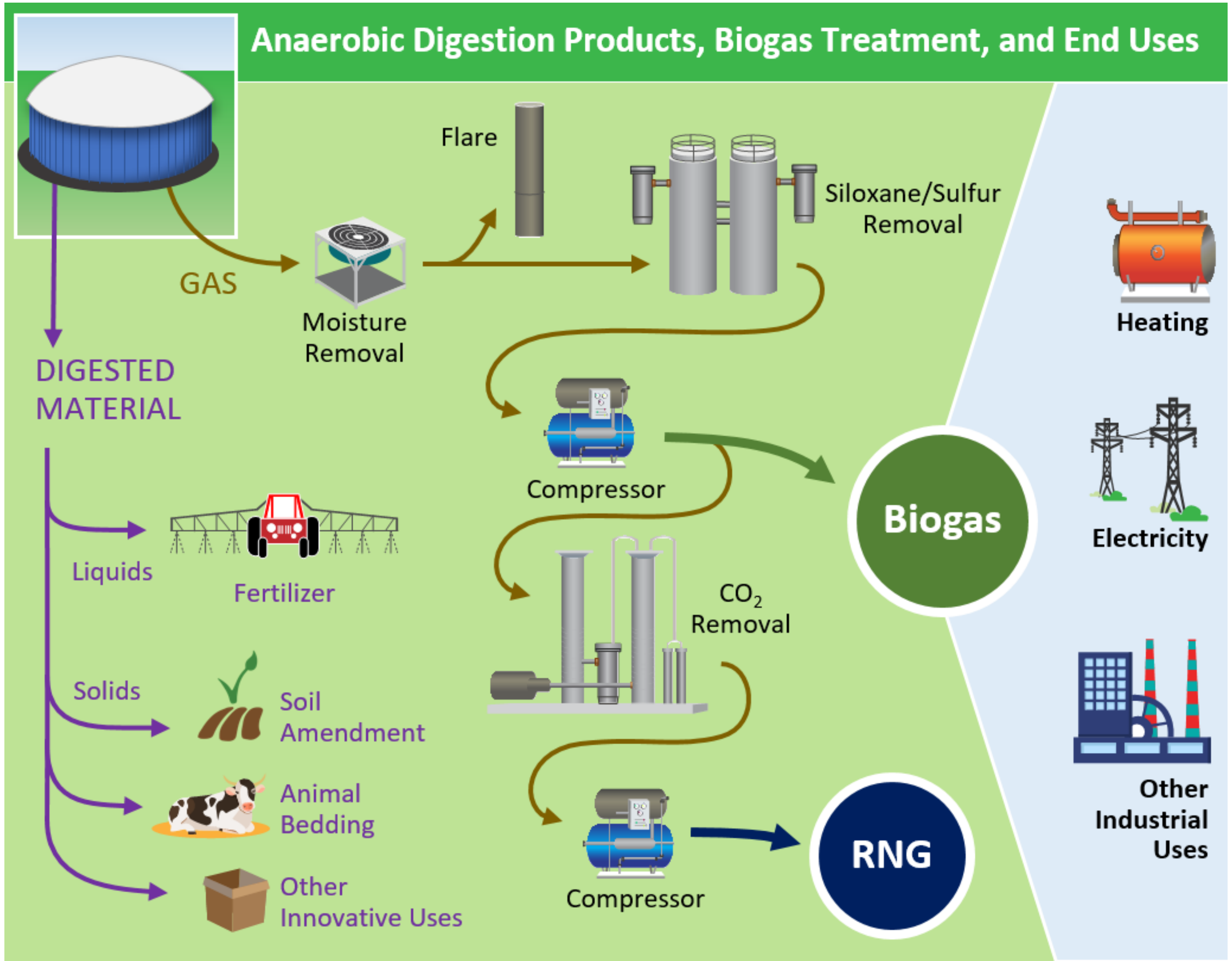
Research
Institute

Biogas conditioning and upgrade

Foster long-term economic
benefit for Minnesota
through value added
agricultural products.

An anaerobic digestion project briefly



Source:EPA

Biogas Composition

Component	% (v/v) dry basis
Methane	50-70
Carbon Dioxide	50-30
Nitrogen, Oxygen, Hydrogen	Traces
Ammonia	< 1%
Hydrogen Sulfite	From traces to few thousands' ppm
Water	Saturated

Removal needed depending on use

Always manage

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What is the gas used for?

- On-site use
  - No carbon dioxide separation
  - Sulfur removal extent depending on applications
    - Gas engines designed for biogas can tolerate up to 1000 ppm H_2S or higher with proper lubrication and metallurgy, typically around 200 to 300 ppm
    - Boilers require less than 500 ppm
    - Some microturbines tolerates up to 5000 ppm
- Pipeline injection
  - Typically, 97% or higher methane
  - 1% or less CO_2
  - No oxygen or nitrogen
  - 1-4 ppm sulfur or less

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Water and ammonia removal

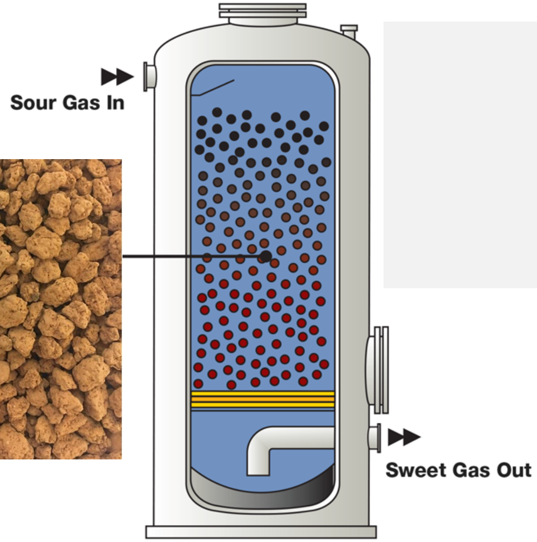
- A gas chiller suffices for most applications
  - Water with ammonia in the solution condenses
  - Some applications may require a secondary drying, typically flowing the gas through a desiccant bed

Sulfur removal technologies

	Efficiency	Capital Cost	Operating Cost	Complexity
Biological Fixation	Medium to High	Medium	Low	Medium to High
Air Injection	Medium	Low	Low	Low
Iron Chloride dosing	Medium	Low	Medium	Low
Water Scrubbing	High	High	Medium	High
Iron Sponges	High	Medium to Low	Medium to High	Low to Medium
Sodium Hydroxide Scrubbing	Very High	High	High	High

Sulfur removal – Iron or Carbon sponges

- Sulfur-laden gas flows through a bed of either
  - Iron oxide shavings
  - Activated carbon with alkaline or oxide solids
- Hydrogen sulfide reacts with the media, and elemental sulfur precipitates
- Beds need to be replaced regularly
- Low capital cost
- Relatively expensive chemical and maintenance costs due to frequent bed replacements
- Spent media are classified as toxic waste in some geographies



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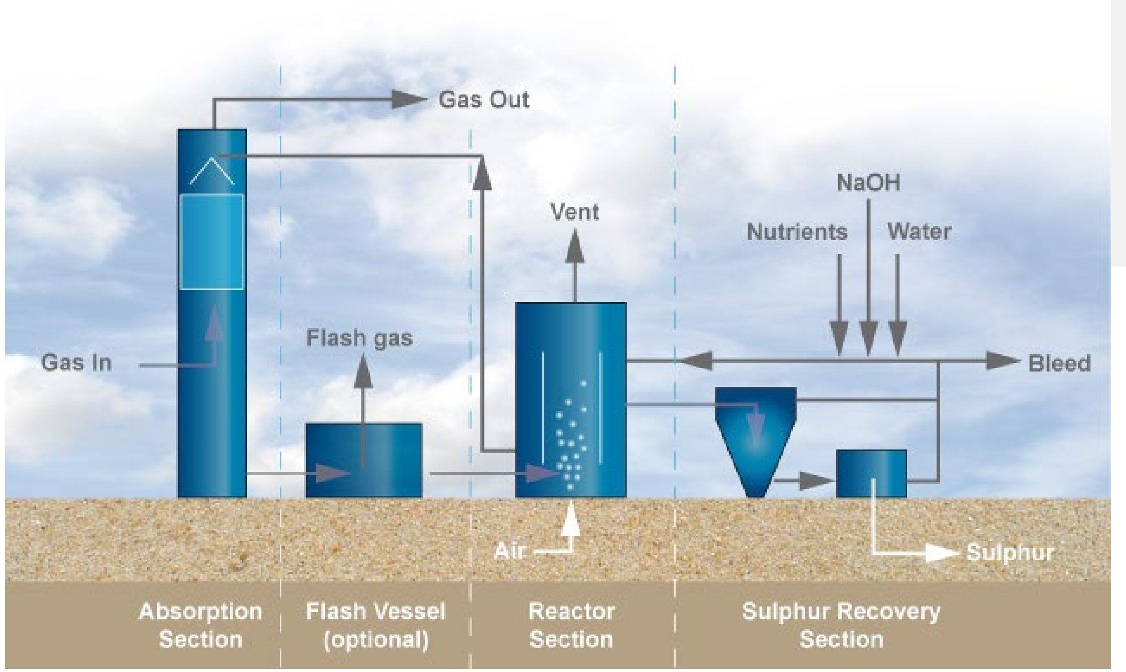
Sulfur removal – Biological Fixation

- Originally patented technology marketed as Thiopaq by Paques in the Netherlands
- Other vendors and implementation exist today
- H2S is scrubbed by water, and sulfides are oxidized to elemental sulfur by micro-organisms
- A cake of elemental sulfur is recovered and disposed



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CO2 removal

- Four major commercial technologies
  - Amine scrubbing
  - Water scrubbing
  - Pressure Swing Adsorption (PSA)
  - Membrane

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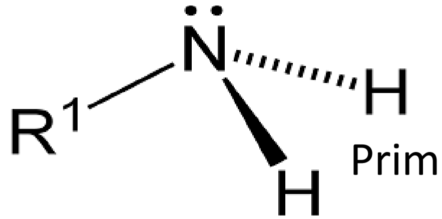
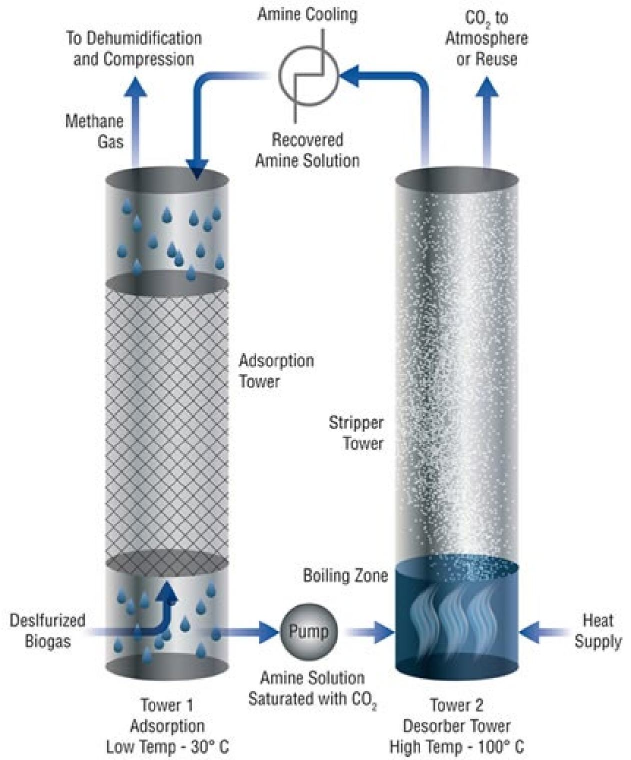
Amine Scrubbing





Source: Biocycle

Used by the oil and gas industry since 1930's

Exploits:

High differential solubilty of carbon dioxide and methane in amines

High temperature dependency of carbon dioxide solubility

Robust, highly selective, does not scale well for small applications

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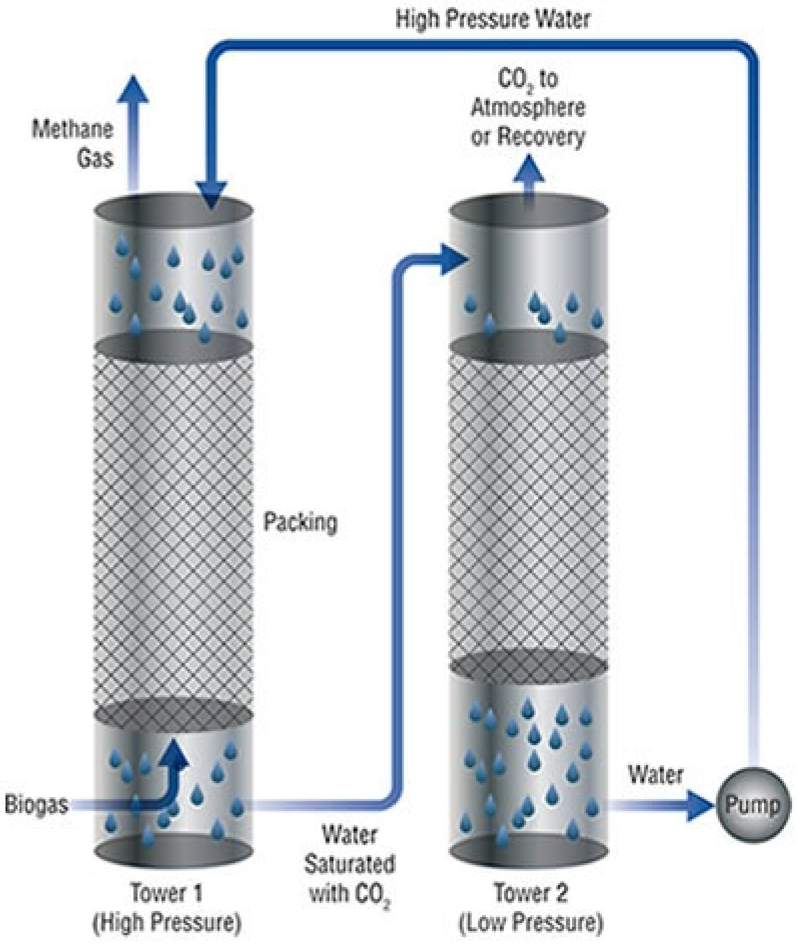
Water scrubbing



Cheaper than amine scrubber

Exploits:

- High differential solubility of carbon dioxide and methane in water
- High pressure dependency of carbon dioxide solubility

Robust, good selectivity, many commercial vendors, scales better for small applications

Can handle raw biogas as both hydrogen sulfide and ammonia are scrubbed by water

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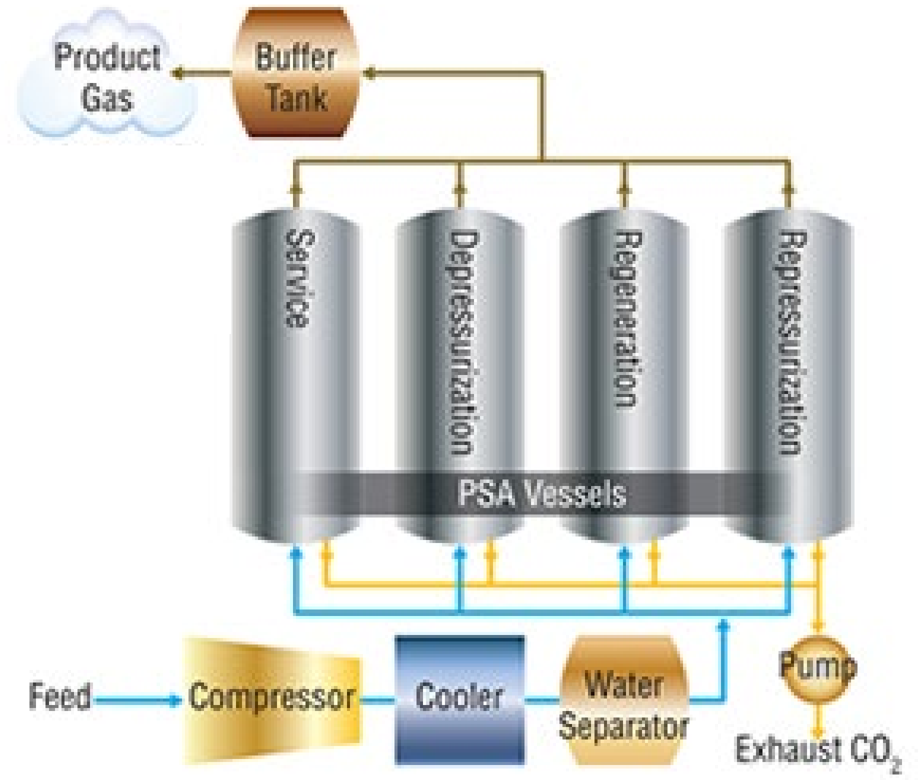
Pressure Swing Adsorption (PSA)



- Relatively expensive
- Can remove oxygen and nitrogen
- Relatively high losses in tail gas
- Very compact

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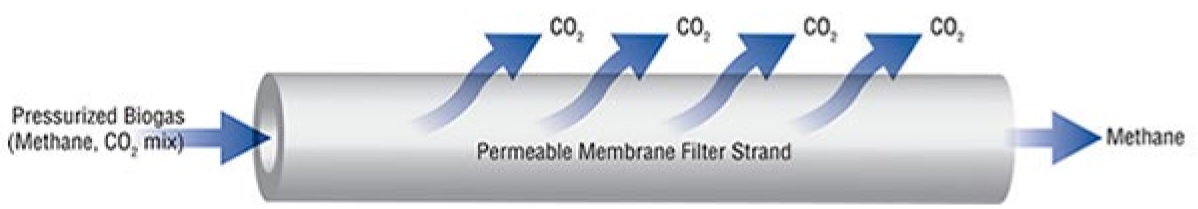
Membrane separation



- Inexpensive and compact
- Relatively higher compression costs
- Very scalable
- Sensitive to physical and chemical impurities

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Gas scrubbing at a glance

	Amine Scrubbing	Water Scrubbing	PSA	Membranes
Type of process	Wet	Wet	Dry	Dry
Operating pressure (psig)	0-3	150	150-200	180-250
Temperature (F)	75-220	Ambient	Ambient	Ambient
Off-gas treatment	No	Yes	Yes	Yes
Desulfurization required	Yes	No	Yes	Yes
Dry gas required	Yes	No	Yes	Yes
Removes Oxygen and Nitrogen	No	No	Yes	No
Heat demand	Yes	No	No	No
Methane loss in tail gas	Negligible	<1%	~1%	<0.5-2.0%
Electrical needs (kWh/m3 of CH4)	0.20	0.45	0.40-0.50	0.50-0.55
Capital cost	$$$	$$	$$$$	$
Operating costs	$$$	$$	$$$$	$$

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Conclusion

- Conditioning and upgrading biogas is relatively simple
- Plenty of robust commercial technologies exist with different economic and performance trade-offs
- Choosing the right process technology depends on project specifics such as project scale, gas quality, and intended gas use
- It is nonetheless an essential part of project economics which should not be overlooked at the early stages of planning and scope definition

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Biogas Uses and Upgrades

Kevin Harrison, Ph.D.

Program Manager, V-Research, National Renewable Energy Lab

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Turning Waste Streams into Energy for Long-Duration Energy Storage and Decarbonization with Hydrogen

Nancy Dowe, Kevin Harrison, and Claire Victor

December 1st, 2022

AURI’s Minnesota Renewable Energy Roundtable

Future Biogas Uses and Upgrades

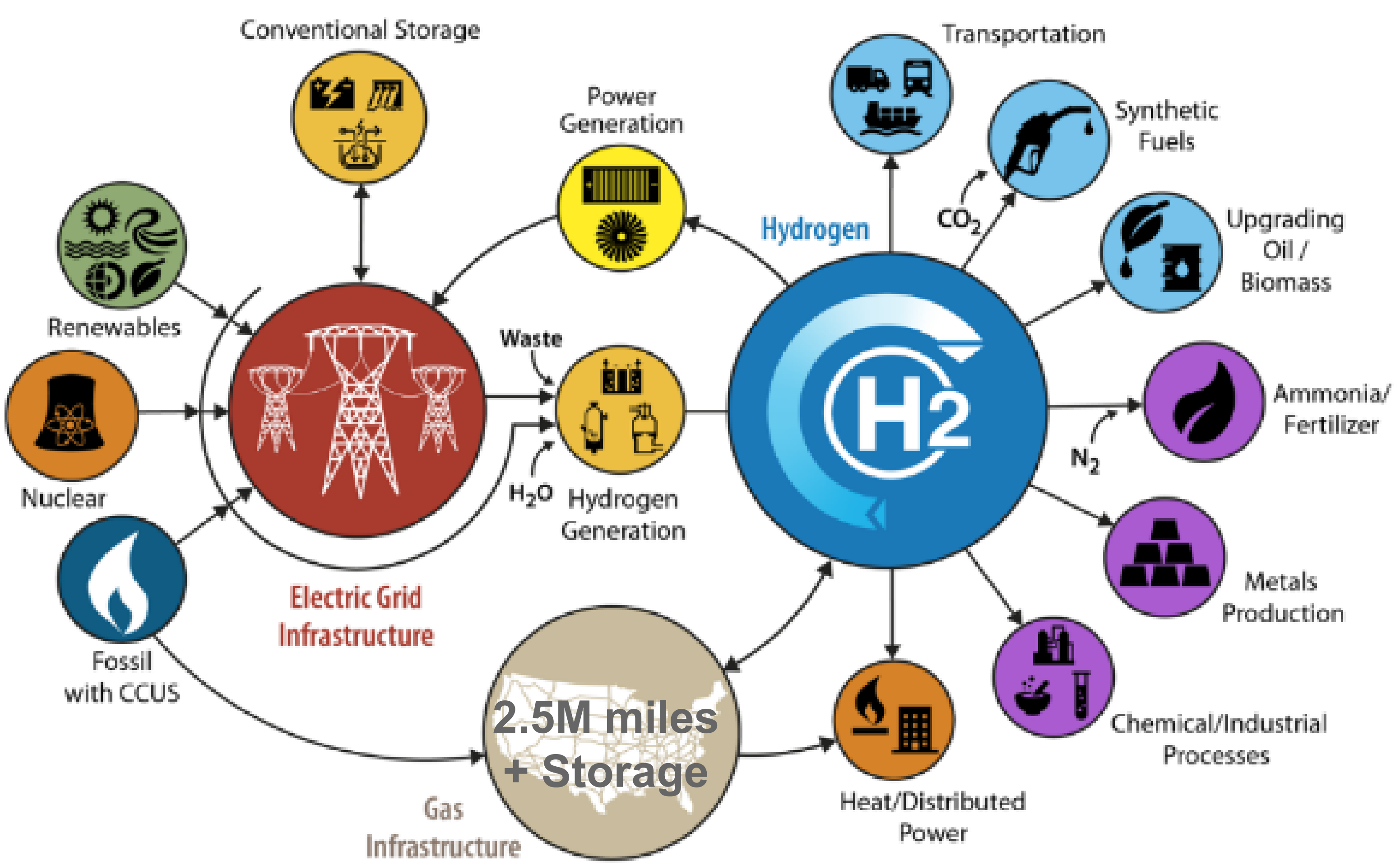
FarmAmerica Waseca, Minnesota

NREL Transforming ENERGY | 45Th anniversary

Presentation Outline

- Technology Descriptions
  - H_2 Production (Highlight H_2@Scale)
  - Biogas (Highlight Waste-to-Energy)
  - Biomethanation - Biocatalysts
- Enablers
  - Need for Long-Duration Energy Storage
  - Low-cost Low-Carbon Electricity
  - Carbon Markets
- Market Potential
- NREL Capabilities

H_2@Scale Initiative



Benefits of Renewable H_2

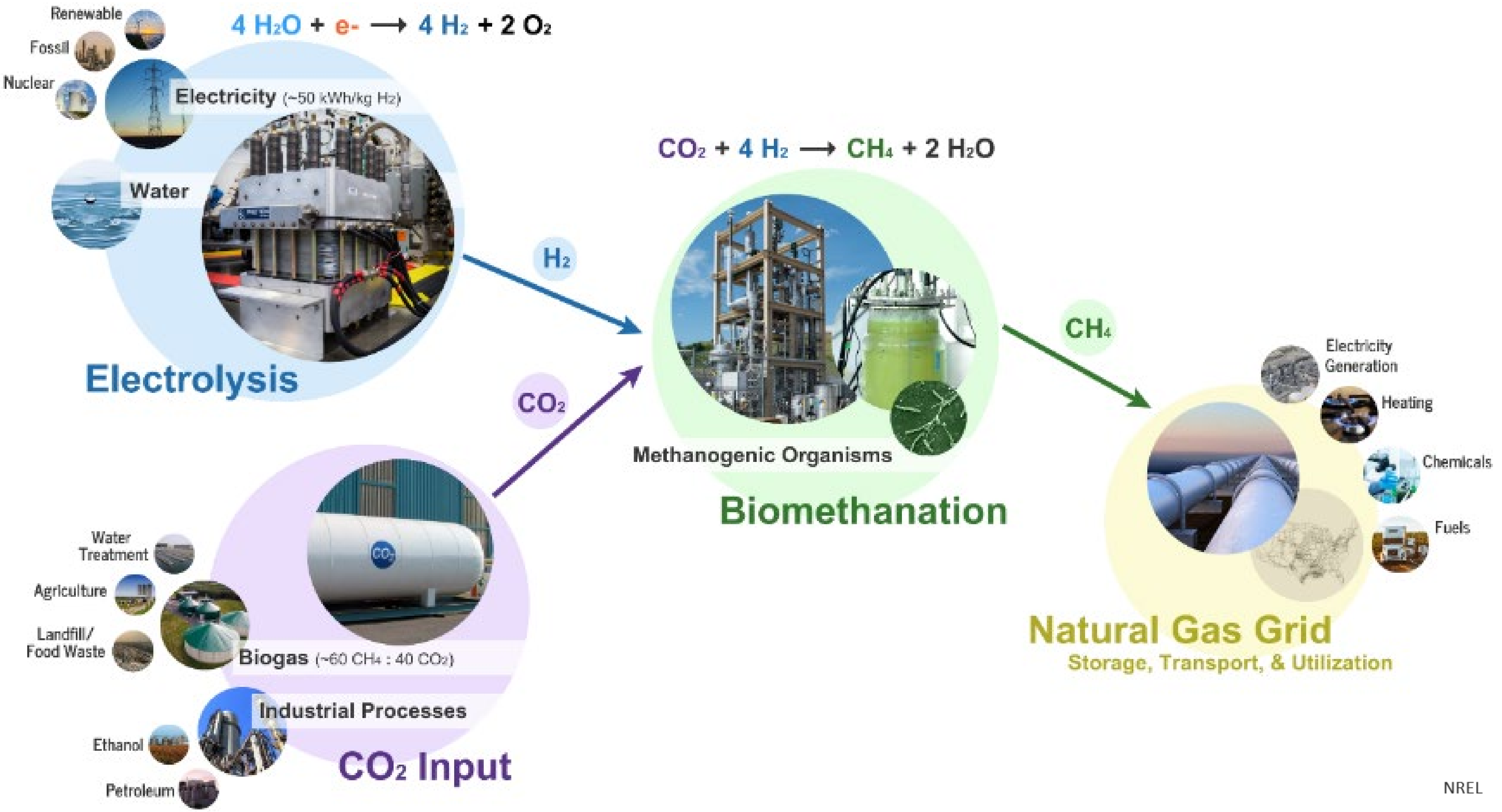
- Enables higher penetration of renewable electricity
- Electrolyzer can provide grid services
- H_2 is used in many aspects of our energy system
- O_2 is a byproduct
- Growing transportation sector
- Reduces fossil fuel consumption
- Scalable, non-toxic, low temperature process

H2@Scale U.S. Department of Energy

10 MM tons H_2 /year in U.S.

https://www.energy.gov/eere/fuelcells/h2scale

RNG PRODUCTION - TECHNOLOGY OVERVIEW



AD > H2 > Biomethanation

Anaerobic Digester
Mesophilic (30°C – 38°C) or
thermophilic (49°C – 57°C)

Heat

50 Nm³/h CO_2 (from Biogas)

75 Nm³/h CH_4 (from Biogas)

Biomethanation, 60°C

CO_2 (carbon dioxide) + 4 H_2 (hydrogen) → CH_4 (methane) + 2 H_2O (water) + Heat

Synthetic Biomethane 50 Nm³/h

Organic Biomethane 75 Nm³/h

Natural Gas grid

160 kW, 60°C Heat

H_2 Production, 60 – 80°C
1MW, ~20kg/hr
80% efficient (HHV)

50 – 55 kWh / kg H_2 @Scale

9L per kg H_2 Electrolysis only

200 Nm³/h H_2

400 Nm³/h O_2

200 kW, 60°C Heat

KEY ENABLERS

1

Low-cost, Low-carbon Electricity

Select renewable technologies (e.g., utility scale solar PV and wind) are cost-competitive with conventional generation technologies when considering unsubsidized levelized cost of electricity

2

Waste-to-Energy

Biomethanation via the 13,500+ potential biogas and other CO_2 sources can increase RNG production by ~70% over gas separation technologies (e.g., membranes, amine)

3

Carbon Markets

	Federal RFS	CA LCFS
Manure	D3 $19.93/mmbtu	-250 CI $61.98/mmbtu
Food Waste	- -	0 CI $15.54/mmbtu -25 CI $20.18/mmbtu
Wastewater	D3 $19.93/mmbtu	
Landfill	D3 $19.93/mmbtu	45 CI $7.18/mmbtu

Examples of Federal and state carbon markets support RNG and other fuel production

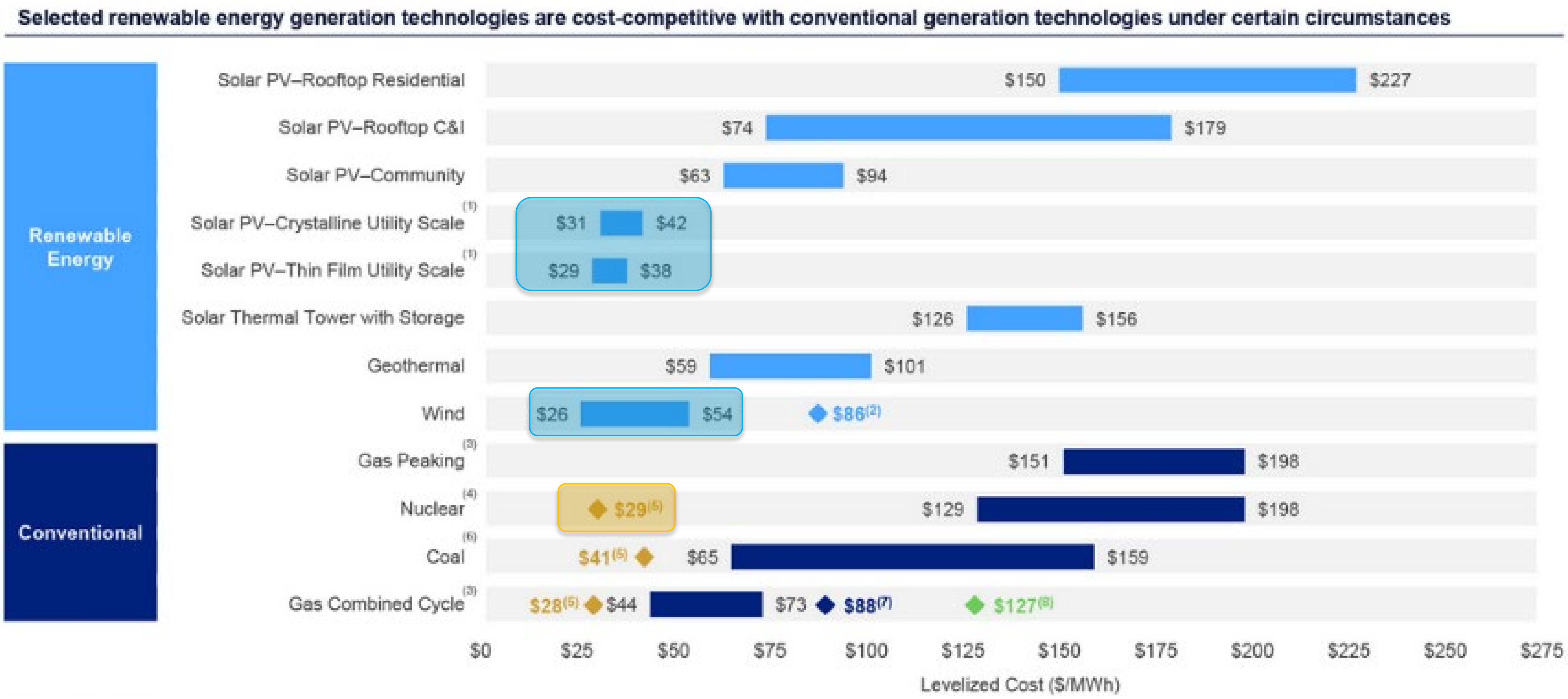
4

Long-duration Energy Storage

In addition to its high energy density, methane has high storage capacity for long-duration energy storage

The U.S. NG Network alone has Terawatt-hour-scale energy storage capacity via underground geological and pipelines

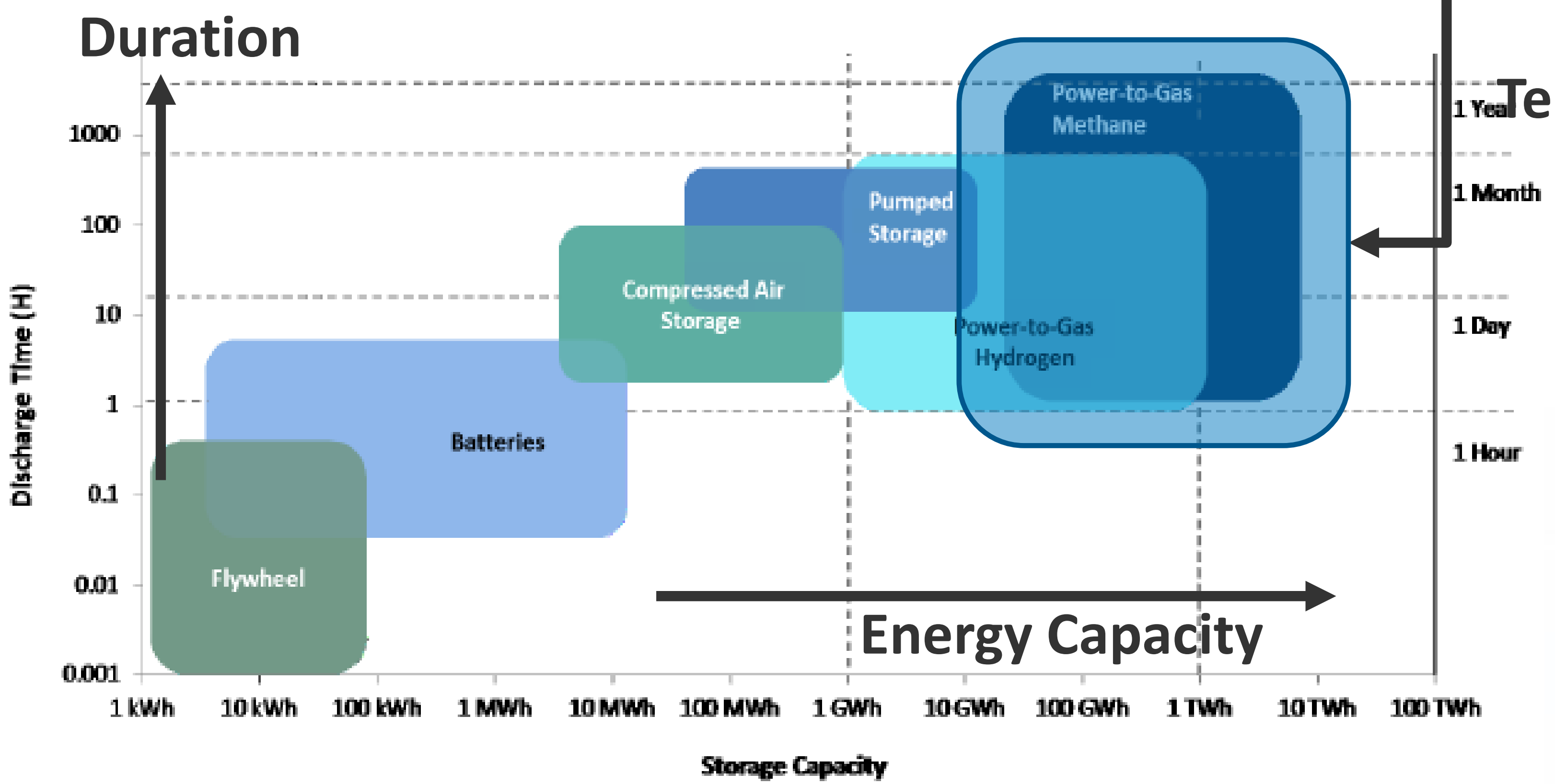
Key Enabler: LCOE (unsubsidized)



(5) Represents the midpoint of the marginal cost of operating fully depreciated conventional facilities…

https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/

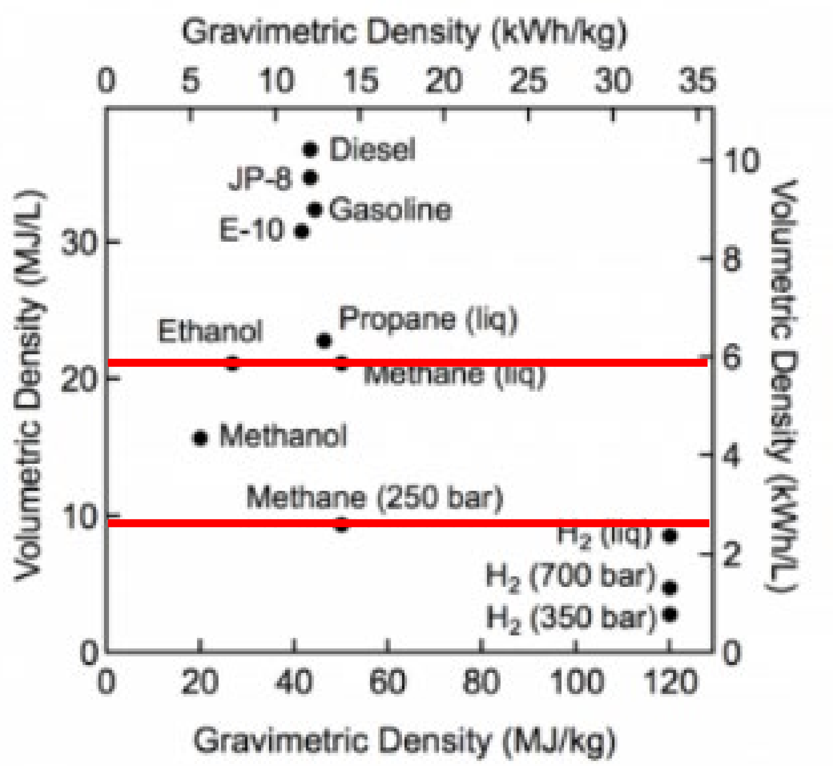
Energy Storage: Electrons to Molecules



Highest Energy Density

Terawatt-hour-scale energy storage in the existing NG Network

- **For example, 1 TW-h requires 25,000 10MW batteries (4 hr)**



Over 130 billion cubic feet of natural gas storage capacity exists in Southern California.

To put this in perspective, this is enough to supply all of the gas-fired generation in the region for more than two months.
- SoCalGas

https://www.energy.gov/eere/fuelcells/hydrogen-storage

Carbon Markets

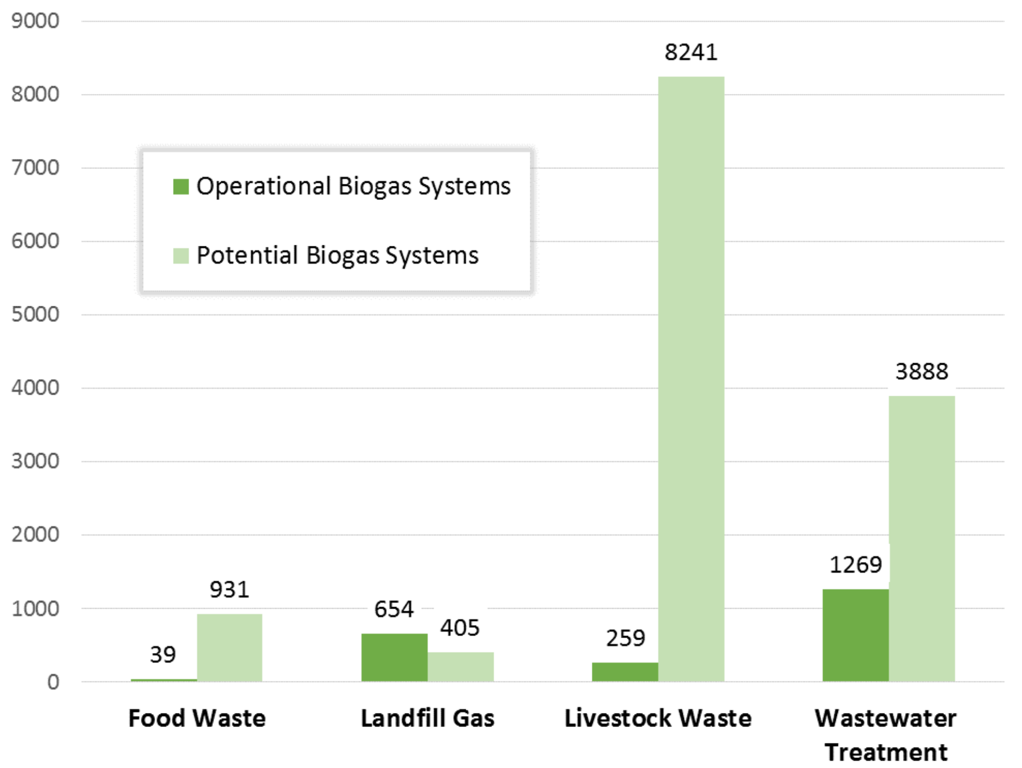
	Natural Gas Value (Physical)	Voluntary Corporate (EA)	Pre-Compliance (EA)	Compliance RFS $1.70/D3 RIN $0.75/D5 RIN	Compliance LCFS $195/LCFS
DAIRY/SWINE MANURE $84/mmbtu	$1.50-$2.00/ mmbtu	N/A	N/A	D3 $19.93/mmbtu	-250 CI $61.98/mmbtu
FOOD WASTE $9-20/mmbtu Tip Fees!	$1.50-$2.00/ mmbtu	$8-11/mmbtu	$8-11/mmbtu	D5- N/A $ 8.79/mmbtu	0 CI $15.54/mmbtu -25 CI $20.18/mmbtu
WASTEWATER TREATMENT $31/mmbtu	$1.50-$2.00/ mmbtu	$8-11/mmbtu	$8-11/mmbtu	D3 $19.93/mmbtu	30 CI $9.96/CI
		$8-11/mmbtu	$8-11/mmbtu	D5- N/A	N/A
LANDFILL GAS $28/mmbtu	$1.50-$2.00/ mmbtu	$8-11/mmbtu	N/A	D3 $19.93/mmbtu	45 CI $7.18/CI

bluesource

NOT ALL RNG IS CREATED EQUAL

https://www.bluesource.com/services/procure-renewable-energy/

Biogas: Market Potential & Anaerobic Digestors



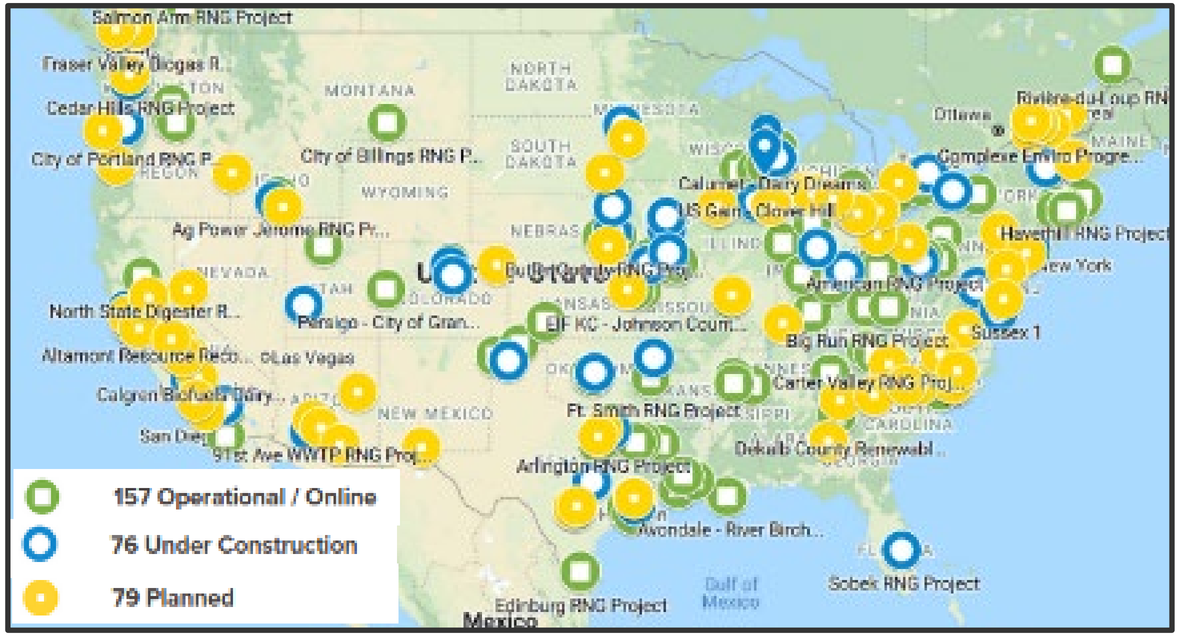
https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy

https://www.vanguardrenewables.com/one-gas-identifies-175-bcf-of-renewable-natural-gas-resources-lines-up-projects/

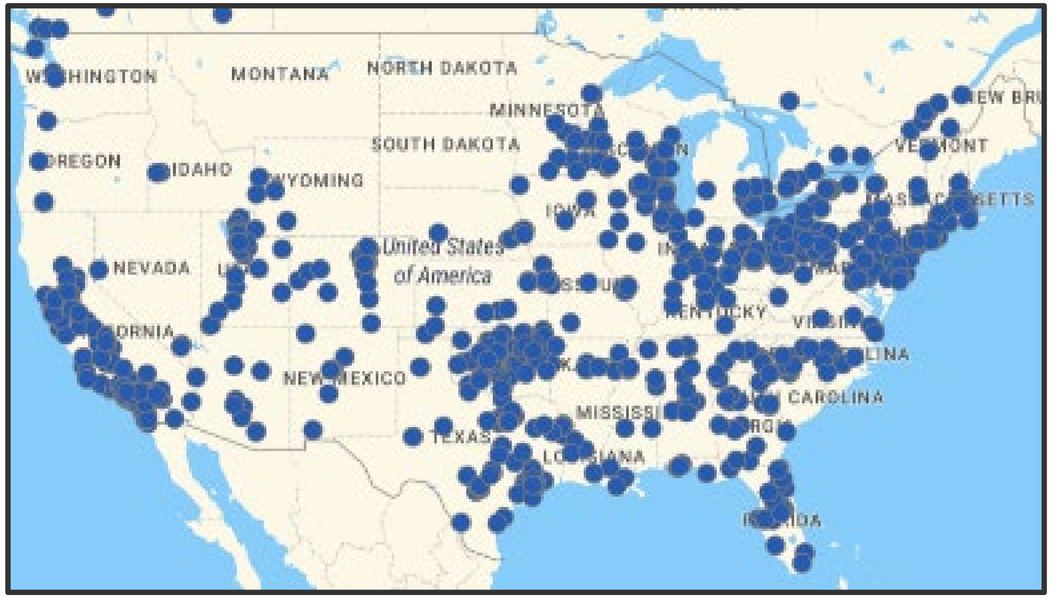
Biogas: Waste-to-Energy

2,200 Operational Biogas Systems

- 157 RNG production facilities (13,500 potential)
  - Using gas separation technologies
  - 59M MMBTU/y
  - 530M GGE/y
  - 109 have pipeline injection



https://www.rngcoalition.com/rng-production-facilities



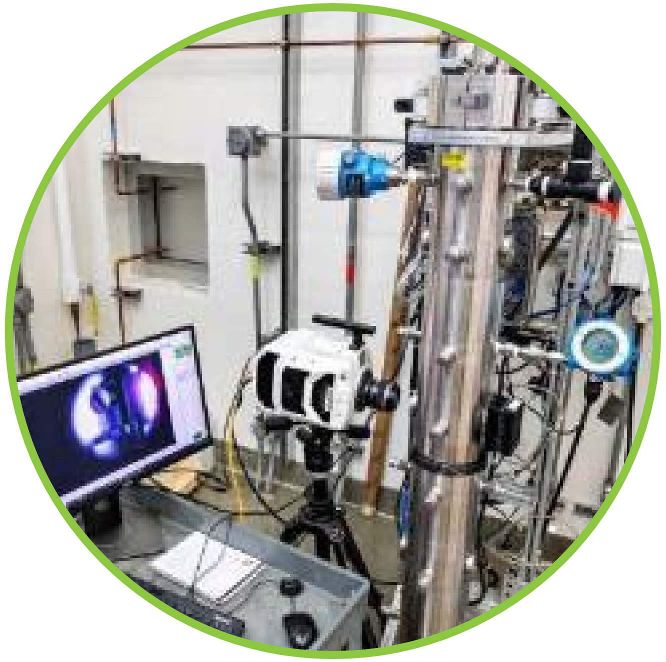
https://afdc.energy.gov/stations/#/find/nearest?fuel=CNG

- 863 CNG & 55 LNG Fueling Stations
- +80 additional in planning
- 175,000 vehicles in the U.S.

RNG produced by recycling CO_2 with renewable H_2 can impact medium- and heavy-duty transportation, today…

- **Biomethanation would increase RNG production by 60 – 70%**

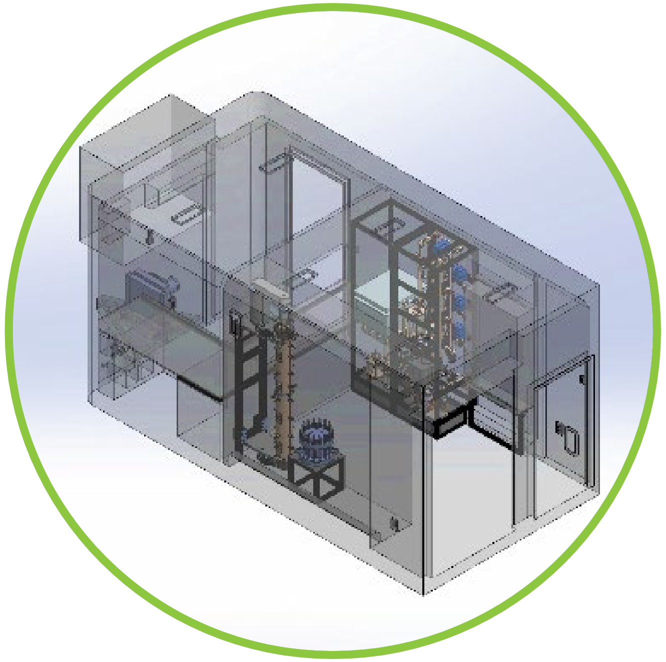
CURRENT PROJECTS



EL/Bioreactor Integration

SoCalGas, BETO, HFTO, & University of Chicago

Close-coupling of electrolyzer and bioreactor to advance IP, advancing water management techniques, and improving hydrogen mass transfer with advanced gas mixing



Biopower

BETO, Electrochaea, & SoCalGas

Producing pipeline quality RNG from Biomethanation via 20L bioreactor on a mobile RD&D platform and collaborating with ANL to investigate CI from dairies with TEA/LCA

Peaks Renewables

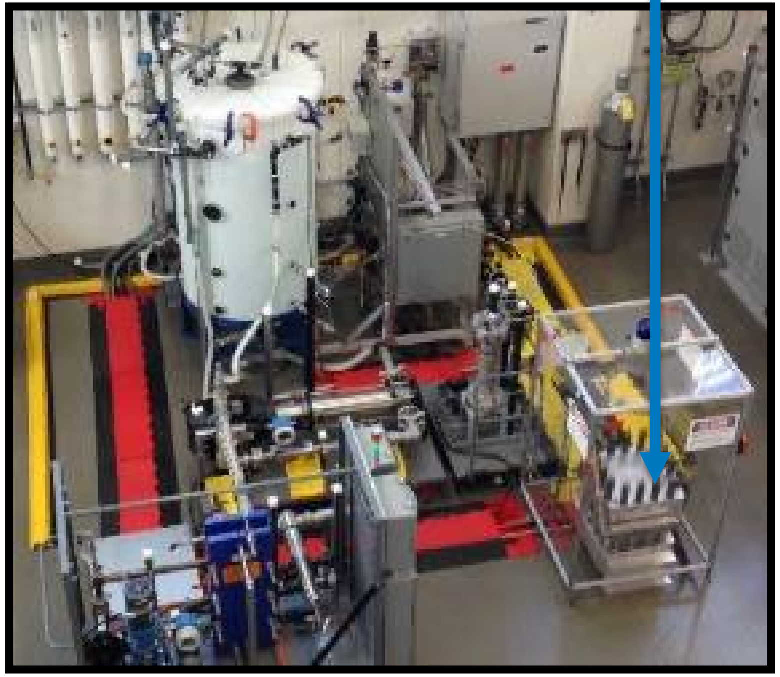
BETO, SoCalGas, Electrochaea, Plug, & CDM Smith

Summit Utilities/Peaks Renewables to successfully deploy biomethanation at a diary digester, integration with renewable electricity & hydrogen production

NREL R&D Capabilities – Make, Store & Use

Electrolyzer Capability

- 1 MW AC/DC power
  - 4000 A at 250 V
- 750 kW PEM stack
  - ~13 kg H_2 / hr
- 30 bar H_2 Pressure
  - Up to 70 bar max



H_2 and RNG R&D Site

#1) 350 and 700 bar pre-cooled H_2 dispensing (LD, HD)
#2) Diaphragm and piston compressors
#3) 700L bioreactor – 18 bar (260 psig) 60°C
#4) 200, 400 & 900 bar storage – 625 kg Total

RESULTS

[Operations]

Installed, commissioned, & operated 700L , 18 bar reactor for 300+ hours

[Mobile RD&D]

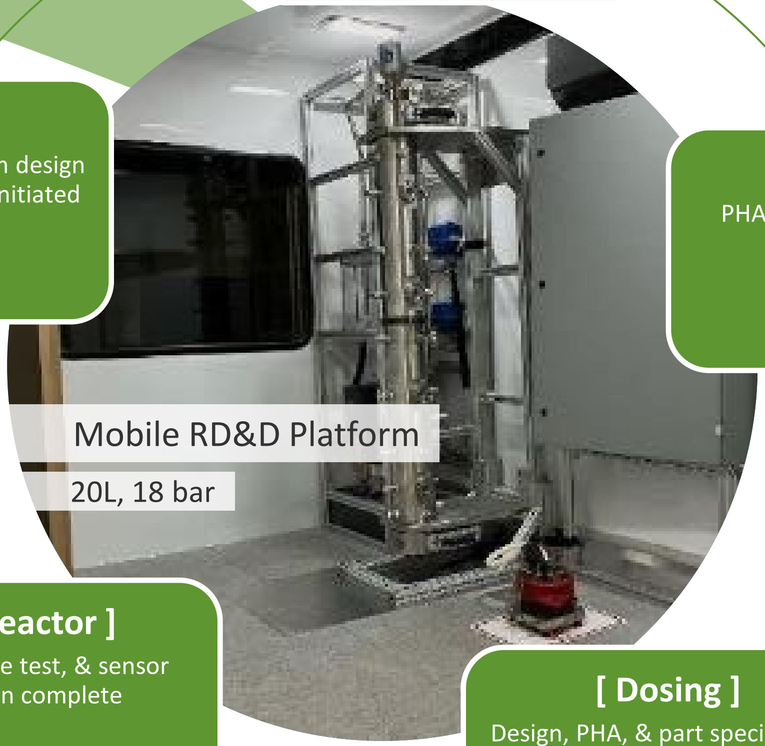
3D model & control room fabrication complete

[Controls]

Power and control system design complete & installation initiated

[Thermal]

PHA, fabrication, & leak test complete



[Bioreactor]

PHA, pressure test, & sensor validation complete

[Dosing]

Design, PHA, & part specification complete

2021 Patent Applications

Application No. 17/261,473

Improving capital and operating costs of the electrolyzer

- 5-10% EL capital cost reduction
- 3-5% EL system efficiency improvement
- Advancement of operational safety via elimination of dissolved H_2 at EL anode

Application No. 17/397,665

Using stack current for H_2 mass flow and gas ratio control

- Enhancement of mixed gas ratio control
- Improvement of H_2 mass transfer
- Elimination of H_2 mass flowmeter and flow control valve

P2G/E2M - OPPORTUNITIES

Start with Electrons

Renewable electrolysis requires low-cost low-carbon electricity; start with small PV & wind

Integration & Flexibility

Focus on systems integration to demonstrate the versatility of electrons-to-molecules; starting with dispatchable electrolysis which will enable more renewable electricity

Pilot Demonstrations

Partnerships to demonstrate near-commercial viability for low-carbon hydrogen production with low-carbon (off-grid) electrons

Analysis & Data

Identify and focus on end-use case studies that can start to make an impact in the near-term (< 5 yrs)

Education & Outreach

Partnerships between industry, academia, and government to enhance learning-by-doing. Small systems run safely

Contact Information

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Thank You

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