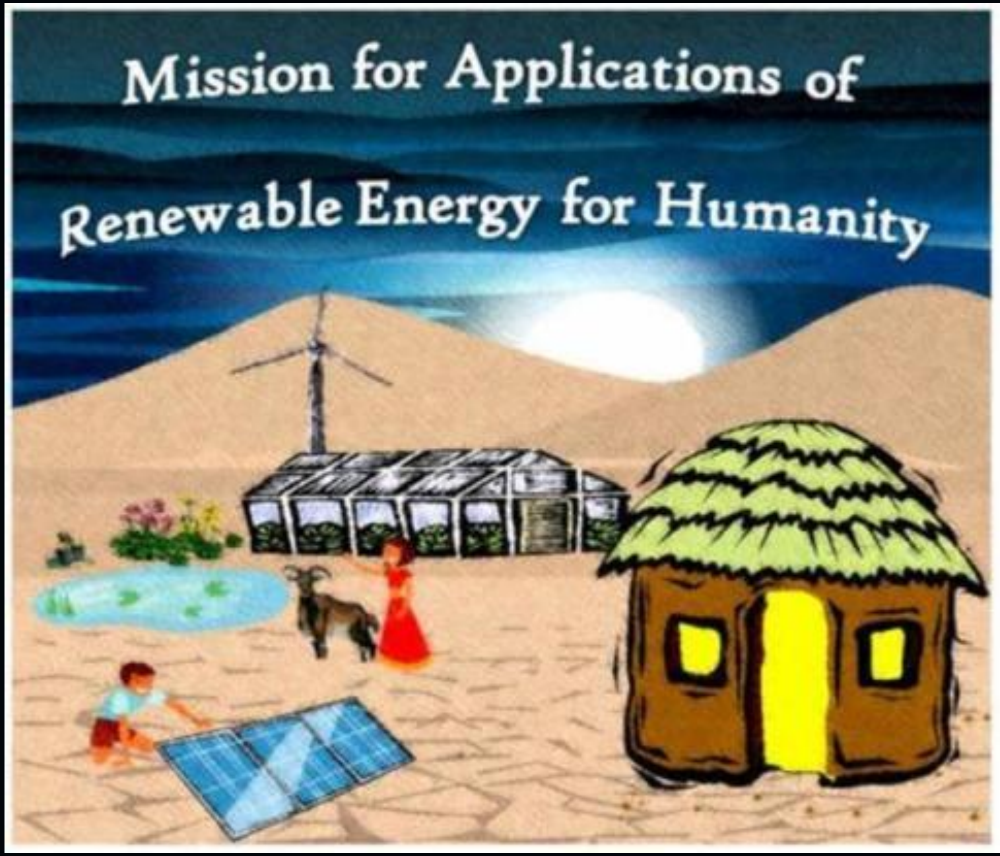
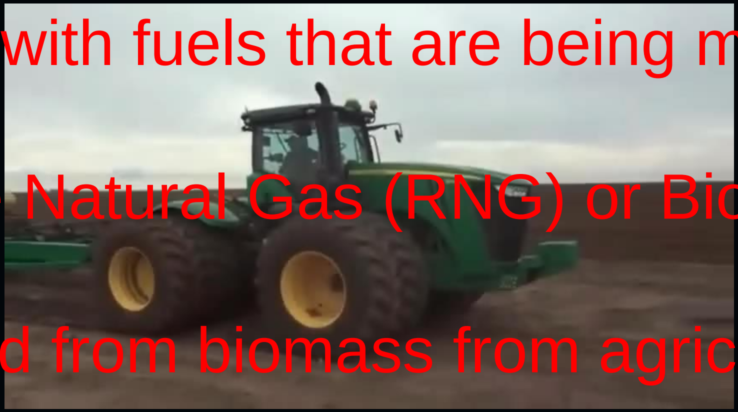


Arkansas State University – Jonesboro, AR
Renewable Energy Conference
October 14, 2016

MAREH / 361 Southwest Drive, #153, Jonesboro, AR 72401 / (870) 206-0160 / www.mareh.org

Methane the Other Renewable Fuel

All of the vehicles you saw and many more are powered with fuels that are being made from Renewable Natural Gas (RNG) or Biogas, which is produced from biomass from agriculture, leaf clippings, garbage and food waste, solid municipal waste, plastics, and even aluminum.



Bio-Mass to Biogas

Renewable Energy Technologies

Waste to Energy

The Other Renewable Fuel, Methane. Preserving the environment with a safe and clean fuel base that can meet the needs of an ecologically minded society.

Dr. Robert L. Straitt, CEM, CDSM

Chief Scientist, MAREH

Co-Authors/Researchers

Nadine Straitt, CEA

Ex. Director, MAREH

Jacob Holloway

New Mexico State University,

Cooperative Extension Services, Zuni Office

Energy Efficiency Management For a Cleaner and Brighter World

What is Bio-Gas or Renewable Natural Gas (RNG)?

Bio-Gas or RNG, is Methane that is capture from the anaerobic decay or gasification of biomass materials and/or certain other materials like plastics, Black Liqueur, and even aluminum scrap.

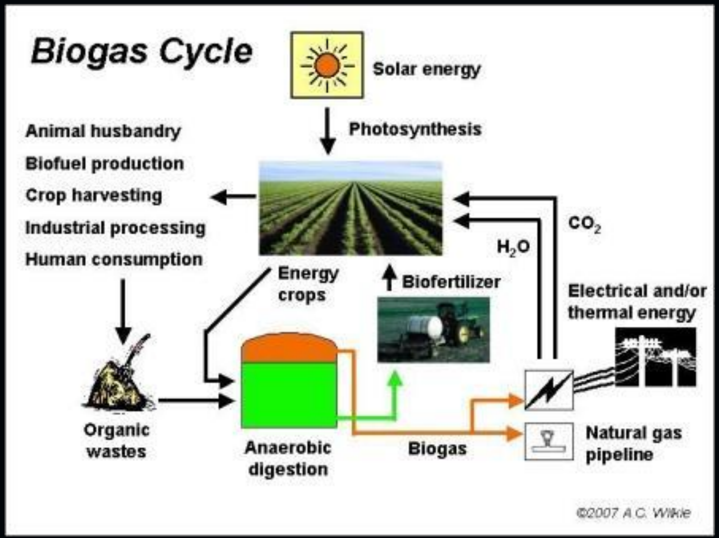
Methane is Commercially Available From Two Sources

Natural Methane

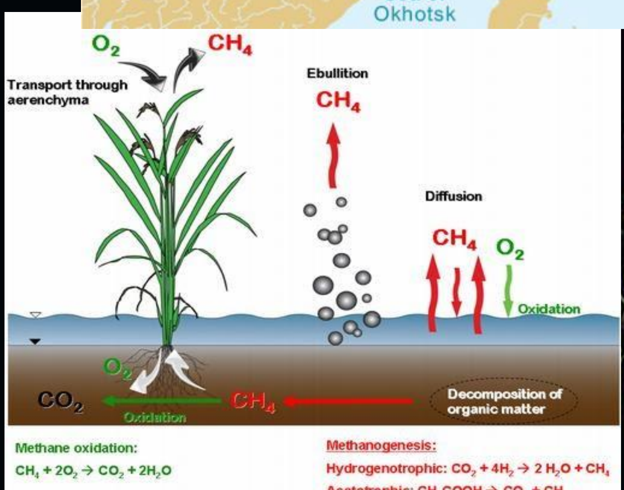
Capturing of naturally occurring sources of Methane below the ground and on the surface.

Synthetic Methane

Conversion of Bio-Mass and other materials into Renewable Natural Gas (methane) through anaerobic digestion or gasification



Natural Methane is Renewable Energy



Methane can be naturally produced through anaerobic decomposition of plant matter by bacteria.

- Rice production is one of the top sources of naturally occurring methane.
- Methane is produced in marshes and wetlands where it is often called swamp gas.
- Methane is produced wherever any type of biomass is subjected to anaerobic conditions
- Animal waste naturally produces methane beginning in the animals digestive track
- Methane is produced in the oceans through
  - Thermogenic process in the deep oceanic crust
  - Biogenic methane is a waste product of methanogenic archaea, a microorganism

http://sanjeetbiotech.blogspot.in/2011/06/wetland-rice-cultivation-major-cause-of.html. http://www.independent.co.uk/news/science/vast-methane-plumes-seen-in-arctic-ocean-as-sea-ice-retreats-6276278.html http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

Mission for Applications of Renewable Energy for Humanity

Methane the Other Renewable Fuel

Natural Methane is Renewable Energy

Methane can also be naturally produced through a process known of carbonate reduction.

- Abiogenic process well below the biomass layers of the crust convert Methane was formed from FeO, CaCO3 -calcite, and water at pressures between 5 and 11 GPa and temperatures ranging from 500°C to 1,500°C.
- Carbonate reduction methane rises though cracks and fissures in the mantle until it reaches an Impermeable rock formation referred to as cap rock

Generation of methane in the Earth's mantle: *In situ* high pressure–temperature measurements of carbonate reduction

Henry P. Scott*†‡, Russell J. Hemley‡, Ho-kwang Mao‡, Dudley R. Herschbach§, Laurence E. Fried¶, W. Michael H
and Sorin Bastea‖

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Branch Road NW, Washington, DC 20015; §Department of Chemistry and Chemical Biology, Harvard University, Cambridge, MA 02138; and ¶Che
Materials Science Directorate and ‖Physics and Advanced Technologies Directorate, Lawrence Livermore National Laboratory, Livermore, CA 945

Contributed by Russell J. Hemley, August 12, 2004

We present *in situ* observations of hydrocarbon formation via carbonate reduction at upper mantle pressures and temperatures. Methane was formed from FeO, $CaCO_3$-calcite, and water at pressures between 5 and 11 GPa and temperatures ranging from 500°C to 1,500°C. The results are shown to be consistent with multiphase thermodynamic calculations based on the statistical mechanics of soft particle mixtures. The study demonstrates the existence of abiogenic pathways for the formation of hydrocarbons in the Earth's interior and suggests that the hydrocarbon budget of the bulk Earth may be larger than conventionally assumed.

Understanding the speciation of carbon at the high pressures and temperatures that prevail within the Earth has a long and controversi
exists in several

understood, and available thermodynamic databases
rately predict phase stability. For example, studies of t
system in relation to crustal fluids and fluid inclusions
carried out by using well established techniques (7, 8)
theoretical modeling is both thermodynamically and
tionally consistent at pressures <≈1 GPa (e.g., ref. 9
satisfactorily treat organic species (10). Previous exp
and theoretical work has shown that methane m
important fluid phase at pressures of up to 1 GPa and l
fugacities, and that methane may be the dominant
fluid phase at substantially reducing conditions (e.g
Furthermore, it has been shown that meteorite hydroca
be formed by the thermal decomposition of $FeCO_3$-

Chapter 1

Abiogenic Deep Origin of Hydrocarbons and Oil and Gas Deposits Formation

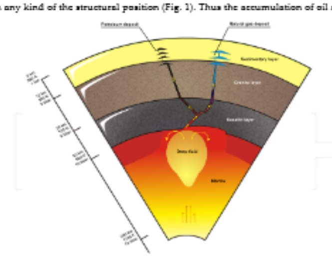
Vladimir G. Kutcherov

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/51549

1. Introduction

The theory of the abiogenic deep origin of hydrocarbons recognizes that the petroleum is a primordial material of deep origin [*Kutcherov, Krayushkin 2010*]. This theory explains that hydrocarbon compounds generate in the asthenosphere of the Earth and migrate through the deep faults into the crust of the Earth. There they form oil and gas deposits in any kind of rock in any kind of the structural position (Fig. 1). Thus the accumulation of oil and gas is



ure 1. A scheme of genesys of hydrocarbons and petroleum deposits formation.

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PUBLIC RELEASE: 13-SEP-2004

Methane in deep earth: A possible new source of energy

DOE/LAWRENCE LIVERMORE NATIONAL LABORATORY

SHARE PRINT E-MAIL

LIVERMORE, Calif. -- Untapped reserves of methane, the main component in natural gas, may be found deep in Earth's crust, according to a recently released report* in the *Proceedings of the National Academy of Sciences* of the United States of America (PNAS). These reserves could be a virtually inexhaustible source of energy for future generations.

The team of researchers from Lawrence Livermore National Laboratory, Carnegie Institution's Geophysical Laboratory, Harvard University, Argonne National Laboratory and Indiana University, South Bend, through a series of experiments and theoretical calculations, showed that methane forms under conditions that occur in Earth's upper mantle.

Methane is the most plentiful hydrocarbon in Earth's crust and is a main component of natural gas. However, oil and gas wells are typically only drilled 5 to 10 kilometers beneath the surface. These depths correspond to pressures of a few thousand atmospheres.

GPa – Giga Pascal / 11 GPa = ~1,595,415 PSI

Synthetic Methane (Biogass) is Renewable Energy

biogas digester at New Hope Dairy in Galt, Calif http://cdrf.org/wp-content/uploads/2014/12/DairyCares-MOR-11-14.bmp

Synthetic Methane or Biogas is a form of Renewable Natural Gas (RNG) is man-made by converting waste materials into methane and other useful bi-products

- Agricultural plant waste products
- Animal and human digestive waste
- Municipal Solid waste such as paper, wood, lawn residue and food waste
- Plastics, Black Liqueur, and other industrial products

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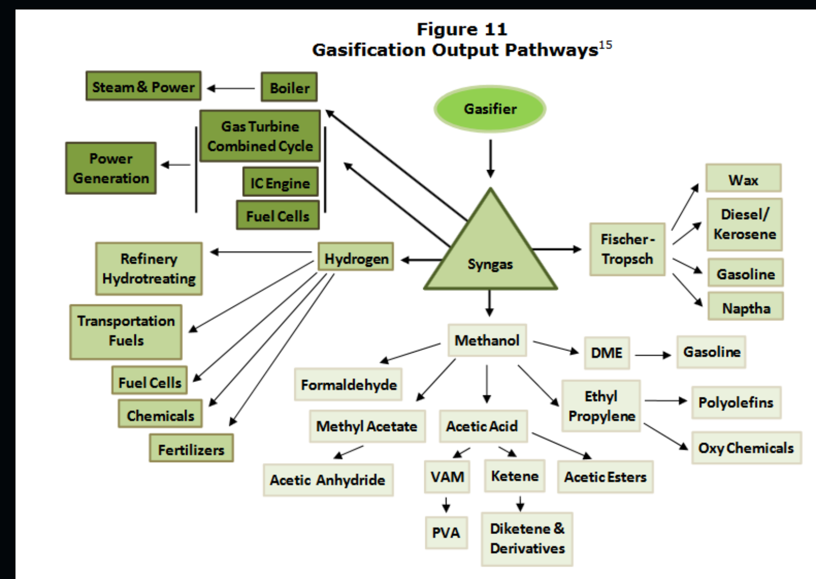
Methane the Other Renewable Fuel

Two Main Methods of Generating Renewable Natural Gas

Digestion

http://www.theecoambassador.com/images/Anaerobicsolutioncompressed.jpg

Gasification



https://plastics.americanchemistry.com/Sustainability-Recycling/Energy-Recovery/Gasification-of-Non-Recycled-Plastics-from-Municipal-Solid-Waste-in-the-United-States.pdf

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Methane the Other Renewable Fuel

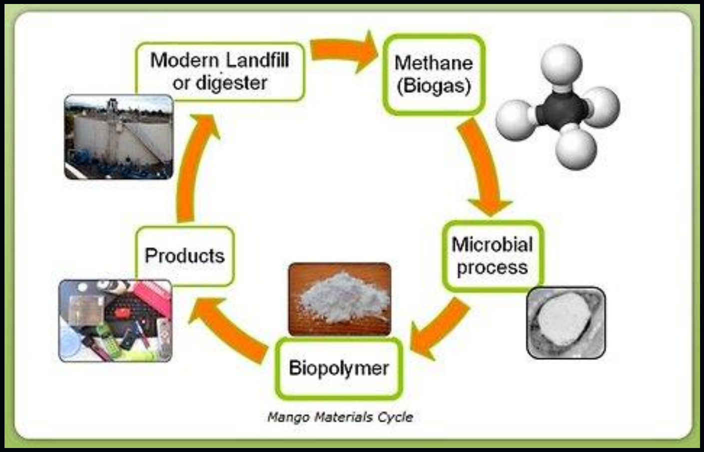
Methane Produced from Plastics is Renewable Energy

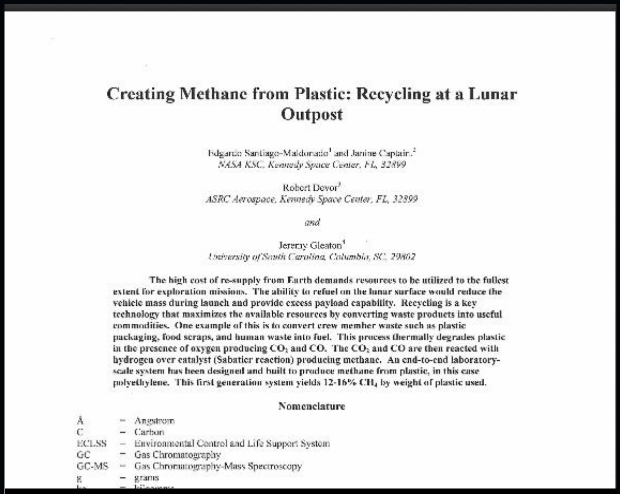
Landfilled Plastics Could Power 5.2 Million U.S. Households

Scientists at Columbia University say that the energy potential in non-recycled plastic is at least enough to fuel 6 million cars or power 5.2 million homes each year.

http://www.seas.columbia.edu/earth/wtert/sofos/ACC_Final_Report_August23_2011.pdf

In addition to organic waste plastic, food and product wrappers, shipping materials, Styrofoam, plasticulture, and many other plastic products are disposed into landfills daily. These plastic items, many of not recyclable by traditional means, can easily be converted into RNG and then into other fuel types





Creating Methane from Plastic: Recycling at a Lunar Outpost

Edgardo Santiago-Maldonado[1] and Janine Captain.[2]
NASA KSC, Kennedy Space Center, FL, 32899

Robert Devor[3]
ASRC Aerospace, Kennedy Space Center, FL, 32899

and

Jeremy Gleaton[4]
University of South Carolina, Columbia, SC, 29802

The high cost of re-supply from Earth demands resources to be utilized to the fullest extent for exploration missions. The ability to refuel on the lunar surface would reduce the vehicle mass during launch and provide excess payload capability. Recycling is a key technology that maximizes the available resources by converting waste products into useful commodities. One example of this is to convert crew member waste such as plastic packaging, food scraps, and human waste into fuel. This process thermally degrades plastic in the presence of oxygen producing CO_2 and CO. The CO_2 and CO are then reacted with hydrogen over catalyst (Sabatier reaction) producing methane. An end-to-end laboratory-scale system has been designed and built to produce methane from plastic, in this case polyethylene. This first generation system yields 12-16% CH_4 by weight of plastic used.

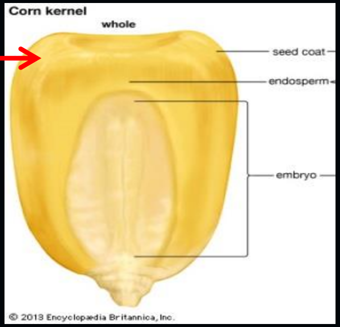
Nomenclature

Å – Angstrom
C – Carbon
ECLSS – Environmental Control and Life Support System
GC – Gas Chromatography
GC-MS – Gas Chromatography-Mass Spectroscopy
g – grams

http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110008529.pdf

Why Methane (RNG) Instead of Other Renewable Fuels?

Only 66% of corn kernel is used to make ethanol – Source USDA



- More BTUs per acre
- Independent of crop type
- Uses 100% of plant versus just the seeds, kernels, or grains
- Cheaper to produce per BTU delivered
- Weather independent
- RNG/Biogas production can be supplemented with any biomass based materials or waste (wood, manure, paper, leaf litter)

http://www.usda.gov/oce/reports/energy/2015EnergyBalanceCornEthanol.pdf

Methane is More Cost Effective to Produce

Ethanol

328 gal @ 1.51 = $495/acre

http://www.neo.ne.gov/statshtml/66.html

- Only 66% of corn kernel is used to make ethanol
- 7,110 pounds of corn grains/kernel per acre
- Processes into 328 gallons of ethanol or 239 GGE.
- 140 gallons of fossil fuels and costs $347 per acre
- the feedstock costs $1.05 per 76,100 BTUs (gallon) of ethanol (E-85)

http://www.extension.iastate.edu/agdm/crops/html/a1-70.html

RNG/Biogas

1,286 Ccf @ .5199 = $826/acre

https://www.theenergy.coop/RNG-price-check

- 100% of corn stove and grain is used to make RNG/Biogas
- 50,000+ pounds of corn silage/biomass per acre
- Processes into 1,589.16 Ccf of RNG/Biogas or 1,286 GGE .
- 140 gallons of fossil fuels and costs $347 per acre
- the feedstock costs $.17 per 76,100 BTUs (.667 gallon) of RNG /Biogas

http://utbfc.utk.edu/Content%20Folders/Forages/Hay%20and%20Silage/Publications/sp434d.pdf

Methane Feedstocks Require Less Weed Control

http://cropwatch.unl.edu/diflexx-herbicide

Herbicide Costs Per Application
1000 acres @ $40/acre = $40,000

- Because all biomass harvested from the fields can be converted into RNG/Biogas less herbicide applications are need
- Herbicide costs per acre can range from $20 to $65 dollars depending on weeds to be controlled, with Palmer amaranth or waterhemp being the most costly to rescue.

http://www.agweb.com/mobile/article/weed-control-that-makes-cents-naa-sonja-begemann/

Mission for Applications of Renewable Energy for Humanity

Methane the Other Renewable Fuel

Alternative Fuels Data Center – Fuel Properties Comparison

	Gasoline/E10	Low Sulfur Diesel	Biodiesel	Propane (LPG)	Compressed Natural Gas (CNG)	Liquefied Natural Gas (LNG)	Ethanol/E100	Methanol	Hydrogen	Electricity
Chemical Structure [1]	C_4 to C_{12} and Ethanol ≤ 10%	C_8 to C_{25}	Methyl esters of C_{12} to C_{22} fatty acids	C_3H_8 (majority) and C_4H_{10} (minority)	CH_4 (majority), C_2H_6 and inert gases	CH_4 same as CNG with inert gasses <0.5% (r)	CH_3CH_2OH	CH_3OH	H_2	N/A
Gasoline Gallon Equivalent [4]	97% - 100%	1 gallon of diesel has 113% of the energy of one gallon of gasoline.	B100 has 103% of the energy in one gallon of gasoline or 93% of the energy of one gallon of diesel. B20 has 109% of the energy of one gallon of gasoline or 99% of the energy of one gallon of diesel.	1 gallon of propane has 73% of the energy of one gallon of gasoline.	5.66 pounds or 123.57 cu ft. of CNG has 100% of the energy of one gallon of gasoline. [2][5](q)	5.38 pounds of LNG has 100% of one gallon of gasoline and 6.06 pounds of LNG has 100% of the energy of one gallon of diesel (r)	1 gallon of E85 has 73% to 83% of the energy of one gallon of gasoline (variation due to ethanol content in E85). 1 gallon of E10 has 96.7% if the energy of one gallon of gasoline. [3]	1 gallon of methanol has 49% of the energy of one gallon of gasoline.	1 kg or 2.198 lbs. of H_2 has 100% of the energy of one gallon of gasoline.	33.70 kWh has 100% of the energy of one gallon of gasoline.
Energy Content (Lower heating value)	112,114 - 116,090 Btu/gal (g)	128,488 Btu/gal (g)	119,550 Btu/gal for B100 (g)	84,250 Btu/gal (g)	20,160 Btu/lb [2](q)	21,240 Btu/lb (r)	76,330 Btu/gal for E100 (g)	57,250 Btu/gal (g)	51,585 Btu/lb (g)	3,414 Btu/kWh

http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf

Mission for Applications of Renewable Energy for Humanity

Methane the Other Renewable Fuel

How RNG/Biogas can be used in your Community

Biogas to Electricity

- The most common use of biogas is the local generation of electricity
- Biogas from the digester is piped a short distance to a turbine or reciprocating engine that then turns an electrical generator
- Smaller biogas generation facilities benefit from this less complex and less costly model
- Heat from the plant is captured and used for domestic water and facility heating

How RNG/Biogas can be used in your Community

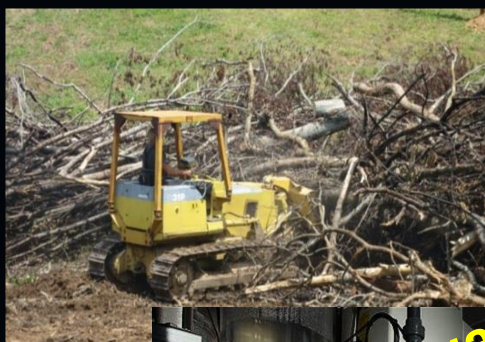
Compressed RNG/Biogas and Propane

- The second most common use of RNG/biogas is liquefied bio gas for cars, trucks, and farm vehicles
- Some RNG/biogas is converted to propane and bottle in high pressure tanks for use to heat homes and make domestic hot water
- Whether used directly as liquefied biogas or processed into more common compressed propane RNG/biogas powers our homes and our vehicles, cleaner , cheaper, and safer then any other form of natural fuel or biofuel

Mission for Applications of Renewable Energy for Humanity

Methane the Other Renewable Fuel

How RNG/Biogas can be used in your Community



Gasoline from Biogas

$$CO + 2H_2 \leftrightarrow CH_3OH \quad (1)$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \quad (2)$$

$$2CH_3OH \leftrightarrow CH_3OCH_3 + H_2O \quad (3)$$

$$n\, CH_3OH \leftrightarrow n\, (CH_2) + n\, H_2O \quad (4)$$

$$n\, CH_3OCH3 \leftrightarrow n\, 2(CH_2) + n\, H_2O \quad (5)$$

How Wood and Paper can cleanly power our cars and trucks!

- Gasoline that is virtually sulfur free can be economically synthesized from RNG/biogas (bio-methane)
- Because RNG/biogas is compatible with natural methane, synthesis of gasoline can be supplemented from commercial pipeline sources of methane
- Synthesized gasoline burns cleaner and more efficiently to power vehicles with less environmental impacts
- Cost to synthesize one gallon of gasoline - about **$0.53** per gallon

Mission for Applications of Renewable Energy for Humanity

Methane the Other Renewable Fuel

How RNG/Biogas can be used in your Community

Wood and Paper powers tractors to produce food and fuel…

- Diesel fuel is essential to power our modern agricultural production process
- Inefficient biomass to directly to fuel process are environmentally insensitive and economically questionable
- Biogas a form of methane can be cleanly and economically converted to clean affordable burning diesel fuels with virtually now Sulphur or other dangerous pollutants
- Left over solids are field ready compost and tail water is ready for irrigation purposes

Capital Costs of an RNG/Biogas Plant

526 kW Biodigester and Generator		
Civil Works	$0.00	$0.00
Preparation of Site on site	on site	
Fence and Gate	on site	
Street Works	on site	
Civil Works in general	on site	
Reception Tank for Liquid Input	$105,082.60	$110,826.00
Concrete Tank, diameter 17.00 m, height cyl. 6.00 m, volume 1,360 m³	$55,895.00	
2 mixers, submerged, 11 kWe each	$22,358.00	
Cage Ladder with Platform	$4,471.60	
Cover (simple roof)	$16,768.50	
Flanges	$5,589.50	
	$0.00	
Pasteurisation Unit	$0.00	
no Pasteurisation included	$0.00	
Digester	$632,731.40	$667,314.00
Foundation, concrete, diameter 18.00 m	$31,301.20	
Leakage Control for Foundation	$3,353.70	
Steel Tank, glass coated, diameter 17,50 m, height cyl. 17,50 m, volume 4,210 m³	$503,055.00	
Leak-/Over-/Underpressuretest	$0.00	
1 mixer, top mounted, 15 kW	$78,253.00	
Insulation	included	
Cage Ladder, Platform, Viewing Glass	included	
Over-/Under pressure Valve and Safety Equipment	included	
Freight, Assembly, Documentation	included	
Flanges	$16,768.50	

Secondary Digester	$201,222.00	$212,220.00
Concrete Tank, diameter 20.00 m, height cyl. 6.00 m, volume 1,885 m³	$72,663.50	
Leakage Control for Foundation	$4,471.60	
2 mixers, side-mounted, 11 kWe each	$39,126.50	
Double Membrane Gas Holder Roof, volume about 640 m³	$36,890.70	
Insulation	$31,301.20	
Cage Ladder, Platform, Viewing Glass	$6,707.40	
Over-/Underpressure Valve	$3,353.70	
Flanges	$6,707.40	
	$0.00	
Storage Tank	$0.00	
according to local regulations, may be lagoon	$0.00	
Gas System	$184,453.50	$194,535.00
Emergency Flare, 250 m³/h	$27,947.50	
Gas Blower	$11,179.00	
Gas Cooler	$55,895.00	
Gas desulphurisation	$89,432.00	
Gas Engine	$402,444.00	$424,440.00
Gas Engine, Jenbacher, 526 kW el. Power	$391,265.00	
completely equipped to be installed in a building	included	
incl. heat distribution, safety devices, control cabinet	included	
Heat for start-up operation	$11,179.00	
Building	$72,663.50	$76,635.00
Pumping Room between digesters and secondary digester	$33,537.00	
1 Building for electrical devices	$11,179.00	
Building for Gas Engines	$27,947.50	
Reception Hall	$0.00	
Biofilter	$0.00	
Toilet, shower, office	$0.00	
Office Building	$0.00	

Capital Costs of an RNG/Biogas Plant (Cont.)

Building	$72,663.50	$76,635.00
Pumping Room between digesters and secondary digester	$33,537.00	
1 Building for electrical devices	$11,179.00	
Building for Gas Engines	$27,947.50	
Reception Hall	$0.00	
Biofilter	$0.00	
Toilet, shower, office	$0.00	
Office Building	$0.00	
Equipment	$159,300.75	$168,007.50
Pumps	$25,152.75	
Grinder	$0.00	
Heat Exchanger	$67,074.00	
Pipes	$67,074.00	
Weigh Bridge	$0.00	
Gas-, Electric-, Heating System Installations	$122,969.00	$129,690.00
Electrical Equipment	$89,432.00	
Process Control Equipment	$22,358.00	
Measurement Devices	$11,179.00	
Lightning Protection	Included	
Transformer	on site	
Connection to Transformer	on site	
Engineering	$335,370.00	$353,700.00
Subtotal, net, without VAT		$2,337,367.50
Onsite Preparation activities	$200,000.00	$200,000.00
Estimated Total for a 525kW ssystem		**$2,537,367.50**

A complete 526kW biomass to electric plant installed for about $3,000,000

4,607,760 kWh /year @ $0.1246
$574,126 per year revenue
Simple pay back period ~8.5 years

https://energypedia.info/wiki/File:Cost_Assessment_of_Biogas_Plant_Components_Tupandi.pdf

Summary and Conclusion

Problem:

- Focus of Bio-Energy research and development is lagging significantly behind the state of the technology.
- Many classes of bio-fuels have reached a natural state of obsolescence and are no longer financially or environmentally viable.

Solution:

- State of the art digestion and gasification technologies and other energy reclamation technologies are available and affordable today.
- Reclaimed energy from a variety of waste products can pay for treatment facilities in a few years and provide significant positive cash flows over the life of the system.

Conclusion:

- Replacing even newly constructed obsolete-technology-systems now, with positive cash flows to the community, can be significantly cheaper then the continued operation of current systems.

How MAREH Can Help

Requirements/Conception:

- MAREH can identify and codify your requirements into a set of proposal-ready specifications and produce an effective Statement-of-Work (SOW)

Project Oversight:

- MAREH can serve as the "Clerk of the Works" we represent your community's interests in monitoring the various contractors involved in making your RNG/Biogas system a reality

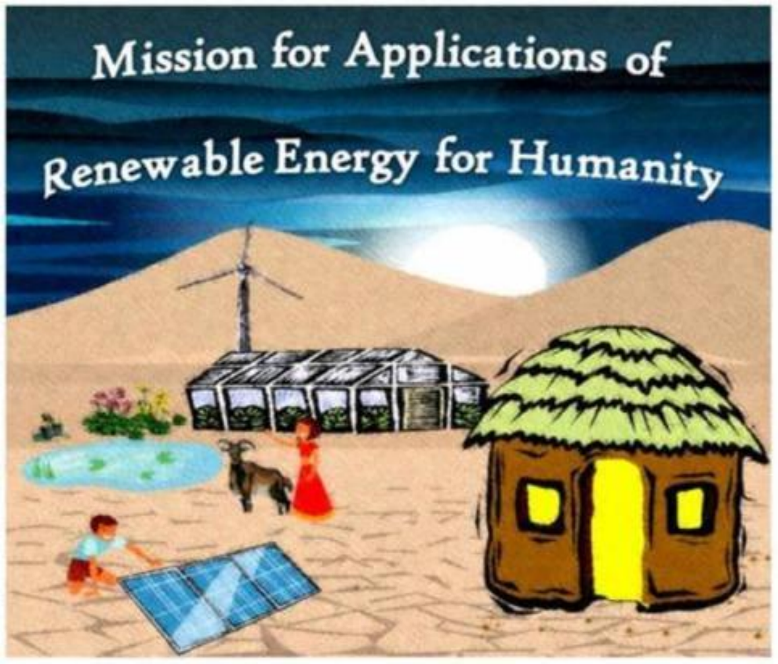
Verification and Commissioning:

- MAREH can serve as your verification and commissioning agent to ensure you get what you paid for in your Biogas Plant and that it works as designed.

Lower Costs:

- As a non-profit MAREH is a cost affordable alternative to high priced commercial engineering and management firms.

The End



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