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USING THE ROTAPOWER® ENGINE TO REDUCE ATMOSPHERIC METHANE CONTENT

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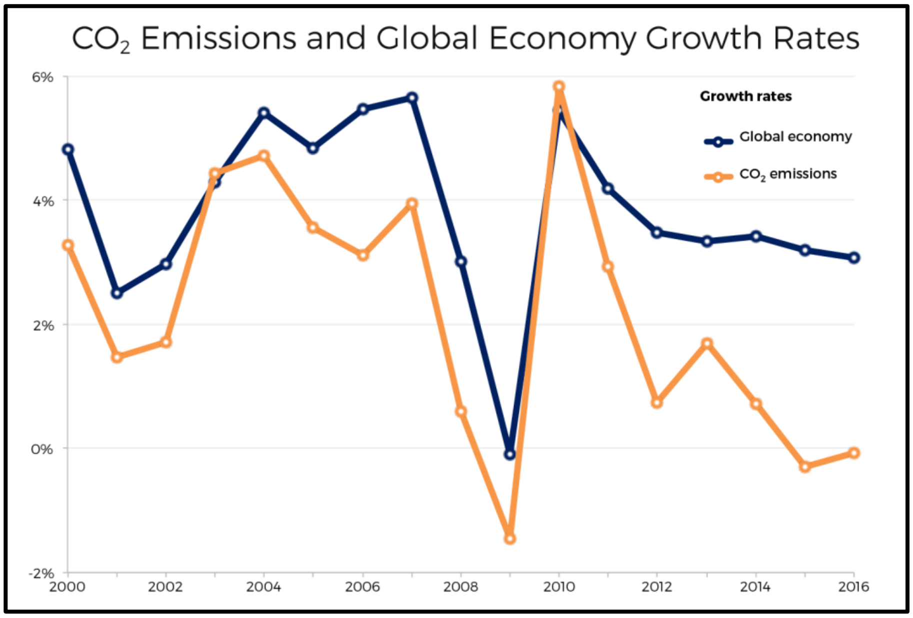
Methane (CH_4) is the main component in natural gas. Historically it has been considered the second-most important global warming gas (GWG), but that assumption is now being challenged by a number of scientists because of changes in the sources of greenhouse gases. Carbon dioxide (CO_2) has dominated most discussions of GWGs. However, the rate of increase in CO_2 production has recently slowed to near zero while the rate of methane production has increased by 20 times. Since a molecule of methane traps 85 times more heat during its lifetime than one of CO_2, many Earth scientists believe that methane is a far more immediate threat due to its ability to create a "runaway greenhouse gas scenario".

Most of the methane increase is coming from biogas generated from man-made sources like landfills and wastewater treatment plants. Ideally, this biogas with its high methane content would be used in an engine to produce electricity. However, if the methane content is too low or the hydrogen sulfide or silica content too high, the biogas may not be usable in an engine. In this case, the biogas may be flared or released directly to the atmosphere.

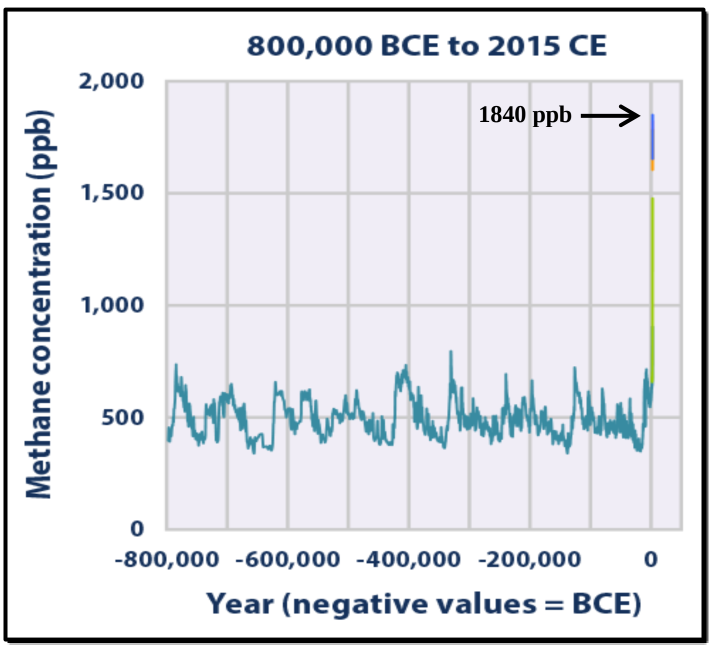
Freedom Motors has developed a unique rotary engine that is resistant to hydrogen sulfide and silica. It can also operate on biogas with lower methane content than is possible with piston engines. Our Rotapower® rotary engine is the ideal candidate to generate electricity from methane emissions whether natural or man-made.

METHANE'S CONTRIBUTION TO GLOBAL WARMING:



Earth scientists like Dr. Robert Jackson at Stanford University, who is part of the renown Global Carbon Project, recently wrote, "Looking at the scenario for future emissions, methane is starting to approach the most greenhouse gas-intensive scenario." He went on to say, "That's bad news. We are going in the wrong direction." As the CO_2 growth rate has approached zero, the methane growth has increased from 0.5 ppb to 10 ppb in the last few years [1].

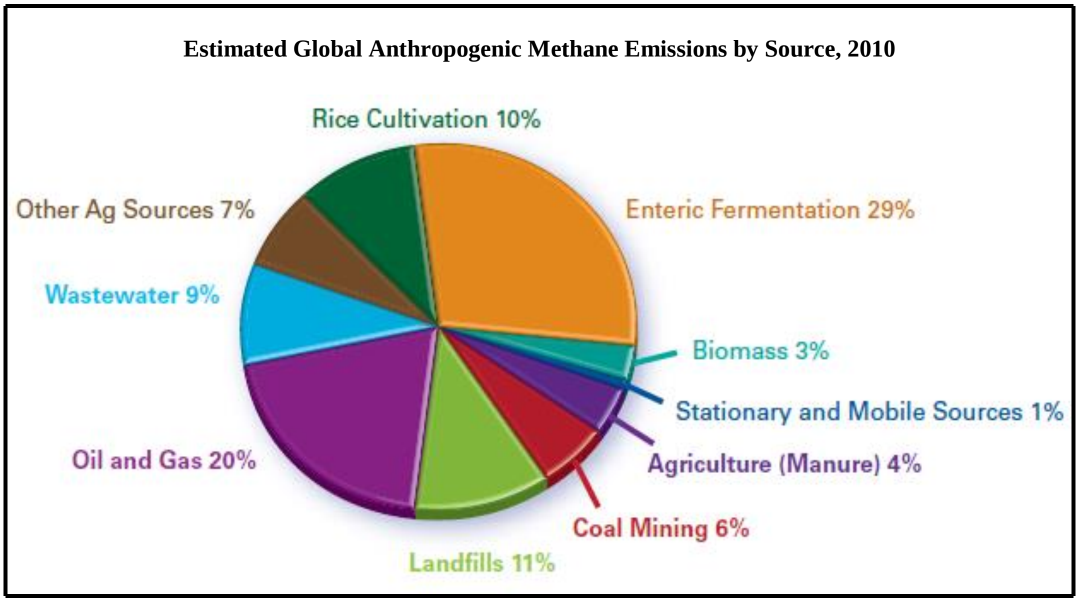
To distinguish the climate warming effect of various gases, the Environmental Protection Agency (EPA) introduced the term Global Warming Potential (GWP) and assigned CO_2 the value of one. Methane has a GWP of 85 during its lifetime of approximately 10 years. This means a molecule of methane traps eighty-five times more heat than a molecule of CO_2.



According to Steve Hamburg, who is the Chief Scientist at the Environmental Defense Fund (EDF), "By emitting just a little bit of methane, mankind is greatly accelerating the rate of climate change." [2] This concern was compounded by a study at Princeton University which showed that methane production is extremely sensitive to a temperature rise. This study concluded that methane production from agricultural sources increased fifty-seven times when atmospheric temperature rose 30 degrees Celsius [3]. Many peer-revised climatological articles use the phrase "runaway greenhouse effect" when describing the consequences of a positive feedback loop strong enough to cause a planetary body's water to boil off [4]. There is dispute as to whether CO_2 has a weak positive or a weak negative feedback loop. There is no debate whether methane has a strong positive feedback loop [5].

SOURCES LEADING TO THE INCREASE IN METHANE:

The US is the leading source of anthropogenic (man-made) methane emissions, which make up 64% of the total methane produced world-wide annually [6]. The following figure shows world-wide sources of anthropogenic methane:



Those methane sources that can be conveniently utilized to create energy are landfills, wastewater, animal manure, and associated petroleum gas (APG) which is a component in the oil and gas segment. In effect, approximately 30% of the total world-wide anthropogenic methane can be utilized to produce energy, and in the process, reduce the consequences of methane's very high global warming potential (GWP).

LANDFILL PRODUCED BIOGAS:

The Environmental and Energy Study Institute (EESI) notes that only 450 of the 2300 landfills in the US have operational biogas projects, while 61% of landfills have no biogas collection systems. Despite this very small utilization of the potential energy available from landfills, the produced biogas provides 14.8 billion kWh annually along with 102 billion cubic feet of consumer quality natural gas [7]. This amount of methane removal is equivalent to the CO_2 emissions from approximately 240 million barrels of consumed oil.

Landfill waste in the US totals 250 million tons annually [8]. One ton of municipal landfill can produce 120 cubic meters of methane [9]. Therefore, landfills in the US could provide 30 billion cubic meters of natural gas; enough to fuel a gas engine capacity of 60 MWh that roughly corresponds to the average power demand for 5,400,000 homes.

WASTEWATER FROM HUMANS AS A SOURCE OF BIOGAS:

One way to recover energy from wastewater is to use anaerobic digesters which create biogas through bacterial action in an oxygen-free environment. The biogas produced is a nearly equal mix of methane and CO_2. Two-thirds of the 3200 large wastewater treatment plants (WWTPs) (> 1 million gallons per day) do not use anaerobic digestion to produce biogas. In addition, there are 12000 smaller facilities (< 1 million gallons per day) where only a few anaerobic digesters are used. One-third of those facilities that do produce biogas release it directly in to the atmosphere [10]. The Water Environmental Research Foundation found WWTPs collectively could meet 10% of the national electricity demand, and has the potential to generate 851 trillion BTUs annually enough to heat 13 million homes [11].

Biogas created by anaerobic digesters using human waste can contain a high amount (up to 10,000 ppm) of hydrogen sulfide (H_2S). This complicates its use on-site to create energy and may account for why it is often flared or released directly to the atmosphere.

PETROLEUM EXTRACTION AND DISTILLATION AS A SOURCE OF METHANE:

Associated Petroleum Gas (APG) is a form of natural gas which is found with deposits of petroleum. It may be dissolved in the oil and removed during distillation or as a “gas cap” above the oil in the reservoir. Historically, this type of gas was released as a waste product from the petroleum extraction industry. It may be a stranded reserve due to the remote location of the oil field either at sea or on land, and is simply burned off in a gas flare. When this occurs, the gas is referred to as ‘flare gas’ [12]. The World Bank estimates that 150 billion cubic meters of natural gas is flared annually with a value of 30.8 billion dollars. This is equivalent to 25% of the US yearly natural gas consumption [2].

MANURE FROM ANIMALS AS A SOURCE OF BIOGAS:

Animal waste has the potential, through the use of anaerobic digesters to double the current biomass electric generation capacity in the US. Factory farms typically use manure filled lagoons to create anaerobic digestion. The resulting biogas is a nearly equal mix of methane and CO_2. Like biogas from human waste, it includes a relatively high amount of hydrogen sulfide (H_2S) gas which makes it difficult to use it in engines to generate electricity. Removing the H_2S adds a significant cost. Currently, there are 239 anaerobic digesters on dairy farms in the US. The potential exists to add digesters to an additional 2,350 farms.

World-wide animal manure production totals 13 billion tons, and each pound of manure can create one cubic foot of biogas [13]. Assuming this biogas is 50% methane, manure could create 368 billion cubic meters of natural gas. This equates to nearly half of the annual natural gas consumption of the US [14].

PROBLEMS ASSOCIATED WITH USING BIOGAS TO FUEL AN ENGINE:

Four-stroke piston and typical rotary engines have many of the following limitations as a powerplant using biogas as fuel:

- The oil bath lubrication system used by these engines becomes acidified by hydrogen sulfide (H_2S). Biogas from human or animal waste contains 700 - 10,000 ppm of H_2S. Its presence in an engine is a major source of corrosion. The maintenance cost for a 500 kW engine operating on farm-generated biogas with various levels of H_2S is shown in the table below [15]:

H_2S Concentration	**Annual Maintenance Cost**
2000 ppm	$246,612
500 ppm	$80,180
< 4ppm	$43,171

- Cannot tolerate small amounts of silica because of its abrasion affect and valve damage. Silica is becoming increasingly present in human waste due to its widespread use in many household items; particularly in cosmetics. Silica appears as a fine dust form of sand. During anaerobic digestion in landfills and WWTPs, it evolves into siloxane. This ceramic-like material is deposited on engine valves and wears surfaces with destructive consequences [16].

- Cannot maintain high enough combustion surface temperatures to efficiently combust biogas; particularly when the methane content is significantly below 50%.

- Expensive per kilowatt of energy production which may not make it economically viable.

- Has so many parts that any level of corrosive activity compounds the maintenance costs.

- H_2S above 250 ppm may void the engine manufacturer's guarantee.

HOW THE ROTAPOWER ROTARY ENGINE OVERCOMES THESE LIMITATIONS:

The following features allow the Rotapower rotary engine to efficiently utilize biogas to create energy:

- Uses a lubrication system where very small quantities of oil are metered to the roller bearings and seals. Any remaining oil then exits the engine before becoming acidic.

- Can tolerate siloxanes by using chrome carbide wear surfaces and silicon nitride seals (9 Mohs versus 6-7 Mohs for silica). The rotary engine does not need or use valves.

- Uses a stainless-steel rotor with a low thermal conductivity as opposed to aluminum used in piston engines. This results in a rotor surface temperature of up to 900°F versus a piston at 400°F. This contributes to combustion of biogas with lower methane content.

- The rotary engine, as distinct from a piston engine, has an intake chamber that is separate from the expansion chamber. This prevents the expansion chamber surfaces from being pre-cooled by the intake charge, which further aids in combustion.

- A single rotor rotary engine has only two moving parts. By comparison, a single cylinder piston engine can have fifteen moving parts with each subject to the corrosive effects of H_2S.

- Cost should be substantially less than that for a biogas burning piston engine at "$2,300 per kilowatt" or a microturbine at "$5,500 per kilowatt" [17]. This conclusion is based on experience of Outboard Marine Corporation (OMC) with its rotary engine on which the Rotapower® engine is based. Because of emission issues, OMC was considering the use of a rotary engine to replace the two-stroke engines in its Johnson and Evinrude outboard motors. To reduce the risk, it decided to first replace the two-stroke with a rotary in its smaller snowmobile market. OMC was able to determine after producing 65,000 snowmobile engines that it could come within 10% of the cost of the two-stroke engine it replaced [18]. Four stroke piston engines are typically 25 to 40% more expensive to produce than two-stroke engines.

ROTAPOWER ENGINE TESTS USING SOURGAS EQUIVALENT AS A FUEL:

Freedom Motors constructed a portable dynamometer as seen in the picture below.

Its portability allows operation at a local landfill site to introduce the corrosive effects of hydrogen sulfide if testing at our facility is not possible (odors, availability, etc.). This test facility allows the ratio between methane and CO_2 to be infinitely varied. Since the engine tested was normally aspirated, power output was much lower than would be expected when a turbocharger is added. Remarkably, the engine was able to run on a methane content of 40%, which would not have been possible with a normally aspirated piston engine. Toxic emissions were recorded at a typical 50/50 mixture of methane and CO_2. Some tests included a small amount of water as an effective way to reduce NO_x emissions. Further tests will determine the precise relationship between water quantity, NO_x emissions, and power following the addition of a turbocharger, supercharger or through compounding the engine [19].

The table below shows the toxic emission results:

Tests with 50% Natural Gas (Methane) and 50% CO_2				
Emissions (ppm)	Test Results (No Water)	Test Results (Water)	NSPS Standard* (Natural Gas)	NSPS Standard (Sour Gas)
NO_x	< 100	< 55	82	250
CO	< 120	< 120	270	610
HC	< 1	< 1	60	80
(*) New Source Performance Standards				

ADDITIONAL CONSIDERATIONS:

Reducing atmospheric methane emissions qualifies for carbon credits and is in the national interest. It should therefore qualify for grants to mitigate methane's much higher GWP.

Methane generated by anthropogenic sources are far more amenable to nearly immediate reduction. This could provide the additional time needed to address the more difficult goal of reducing CO_2 emissions.

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