

Final Report: Application of Aqueous-Phase Carbohydrate Reforming for Electricity Generation from Agricultural Products

Focus on Energy
Virent Energy Systems, Inc.
3571 Anderson Street
Madison, WI 53704
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Project Summary

The economics and efficiencies of a distributed APR system can address major transport, storage and safety issues that are current roadblocks to the adoption of renewable gaseous fuels. The project “Application of Aqueous-Phase Carbohydrate Reforming for Electricity Generation from Agricultural Products” main objective was to validate that the SuperNatural™ Gas (SG) produced by the Virent™ system would effectively run an unaltered Marathon engine system.

Power levels and other metrics for engine performance were monitored by Marathon during the test. The Marathon engine can run on natural gas or propane. Validation that an unaltered natural gas and/or propane engine can run on the Virent gas mixture is an exciting development. The less modification required of a conventional natural gas engine, the less resistance to the adoption of this fuel platform in the marketplace. The presence of hydrogen and other alkanes in the Virent gas should enable a cleaner burn. Under the previous MGE demonstration project, early emission data for NOx and other emissions was extremely promising. Emission data was also carried out under this effort to confirm the significant environmental benefits of use of this fuel with the Marathon engine.

Virent produced SuperNatural Gas (SG), detailed below in Table 1 below. Three gas cylinders of gas were produced in the demonstration unit constructed for the MGE demonstration, shown in Photo 1 below. The SG was produced from a feedstock that consisted of biomass derived glycerol and water. The gas was bottled in cylinders and transferred to Marathon in Troy, WI.

Gas Constituent	Volume %
Hydrogen	38%
Methane	9%
Ethane	9%
Propane	5%
Carbon Dioxide	39%
Heating Value (LHV)	434 btu/ft ³
% of Heat Value vs Natural Gas	41.3%
Lower Flammability Limit	3.9%
Upper Flammability Limit	51.6%

Table 1: SuperNatural Gas Properties



Photo 1: Virent SG Demonstration Unit (MGE Project)

The first visit of Virent personnel to Marathon occurred on 6/30/06. The visit consisted of individuals from Virent and Focus on Energy meeting with individuals at Marathon. The trip consisted of Marathon giving an oral history on the engine. It was originally designed to burn natural gas and integrates with a heat pump to provide space cooling. York bought the technology which was developed by Gas Technology Institute in the mid '80's and subcontracted it's production to Copeland (generators), Briggs and Stratton (engines), and Honeywell (controls). They sold approximately 6,000 units in the early to mid-nineties, but didn't have the support staff to keep up with maintenance calls dealing mostly with installation issues.

Marathon has continued to develop the engine and has a partner in Germany with whom they build the EcoPower, a household CHP unit. Utilizing propane as a fuel, the CHP unit has an exhaust gas at 680°C off of the engine, after heat exchange with water and a 3-way catalyst the temperature is dropped to 93°C. Typically the output is 13.5 kWt and 5 kWe though one variable can be varied at the expense of the other. Marathon currently ships 70 to 100 engines per month, mostly to Germany. Domestically they have a cathodic protection unit and a battery charger which is used for signal lighting in the railroad industry.

Exhaust gas temperature of 460-500°C were achieved when combusting SG provided by Virent. During testing, Marathon consumed one tank in the initial test setup and one while Virent and Focus on Energy individuals were present. The initial test confirmed that Virent provided SG can effectively ran in an unaltered Marathon engine setup. The initial engine performance indicated that the performance of the engine changed when the SG tank pressure fell to ~100psi. Emissions and efficiency data were not obtained during this first trip due to the variable performance in the low-pressure region.

A second trip to Marathon occurred on 4/18/2007. Two individuals from Virent, along with one individual from the MATC automotive department made the trip. The automotive instructor from MATC provided a MAC Tools (OTC Solarity) exhaust gas analyzer. The exhaust gases for the Marathon engine operating on LP and SG were quantified for CO₂, CO, hydrocarbon (HC), O₂, nitrogen oxides (NO_x), and air-to-fuel ratio (AFR). A summary of the test results follows below in Table 2.

Run	1	2	3	4	5	6	7	8	9	10
Engine RPM	1800	3600	1800	3600	1800	1800	1800	1800	3600	3600
Fuel	LP	LP	LP	LP	LP	LP	SG	SG	SG	SG
Power (HP)		7.2	4.3	7.1	4.2	4.2	<1		0.8	1.68
CO ₂ , %	10.58	10.35	11.01	11.05	11.51	11.13	11.02		10.22	10.33
CO, %	3.53	4.53	1.97	2.75	1.49	2.6	1.59		0.49	0.58
Hydrocarbon, ppm	292	225	253	136	226	277	217		655	662
O ₂ , %	0.77	0.25	1.82	1.06	1.73	1.28	2.22		9.98	10
NO _x , ppm	5 - 7	13	-	-	-	20	13			
Air-to-fuel ratio		12.79	14.99	14.11	15.29	14.55	16.76		22.93	22.93

Table 2: Summary of Emissions Testing

Several issues of note arose during the testing. The portable exhaust gas analyzer was only able to measure NO_x reliably in the first 10 minutes of operation. NO_x measurements were obtained at two RPM settings on LP and one RPM setting on SG. Run 7 which details the NO_x measurement for SG on the engine is not reliable due to the NO_x monitor uncertainty and low power level of the point. The final gas tank was consumed in this testing. Positive results from the emission testing were the confirmation of lower carbon monoxide readings on SG versus LP. The hydrocarbon readings from SG were also in line with the LP readings. The testing also confirmed that the Marathon engine can be run without modification in an efficient, similar manner when compared to LP.

Overall, the renewable SG with its wide flammability range, noted in Table 1 above, leads to a wide range of operational air to fuel ratios. This wide range of air to fuel ratios allows for optimization of emissions from the engine unit. Higher air-to-fuel ratios can lead to lower combustion temperatures for gas fired engines. The main cause of NO_x formation is the dissociation of N₂ which is greatly increased at flame temperatures above 1200°C. The lower combustion temperatures which are due to the increase in air to fuel ratio, along with the natural exhaust gas recycle (EGR) of CO₂ in the fuel will

theoretically reduce NO_x formation. This NO_x formation reduction has previously been accurately measured on the MGE unit shown in Photo 1 above.

Next Steps

Mike Cocking expects that the EcoPower unit will receive UL approval in the next three weeks. This would open the door to future collaborations with Virent. The parties will initially evaluate possible demonstration of a combined energy system. It is clear that more data is needed on the overall system performance before moving forward with a plan for a system product offering. Ultimately, the parties believe a biomass fueled ICE would be well received in marketplace.