APPENDIX D

Greenhouse Gas Potential of Urea for Use with Selective Catalytic Reduction Systems

Greenhouse Gas Potential of Urea for Use with Selective Catalytic Reduction Systems

Background

Urea is a common reducing agent used with Selective Catalytic Reduction (SCR) emission control systems. Urea's chemical composition is $CO(NH_2)_2$. For use in an SCR, urea is diluted with water to a ratio of 32.5-50% urea and 77.5%-50% water for more precise injection into the exhaust gas stream. As the liquid is injected into the exhaust stream, it atomizes and reacts with nitrous oxides (NO_x) and oxygen (O_2) to produce water (H_2O), nitrogen (N_2), and carbon dioxide (CO_2), thus reducing the NOx emissions levels. Urea is typically used instead of ammonia to prevent ammonia slip (excess ammonia injection leads to unreacted ammonia in the exhaust stream).

Expected Emissions

Based on vendor supplied information[1] for the 2G800BG (an 800 KW unit) and 2G1200BG (a 1200 KW unit) 2G-Cenergy integrated internal combustion engines with SCR controls, the expected urea consumption is 0.24 gal/hr and 0.34 gal/hr respectively. Urea is traditionally mixed with water to a concentration of 40% urea, 60% water (resulting in the consumption of 0.60 gal/hr and 0.85 gal/hr respectively of urea/water mix). Based on the vendor supplied information, Table 1 shows the annual expected urea consumption at full operation (100% capacity factor – greatest possible annual consumption rate of 8,760 hours).

Table 1. Annual Expected Urea Consumption

	2G800BG Engine	2G1200BG Engine
Average Consumption of Urea/Water Mix	0.60 gal/hr	0.85 gal/hr
Concentration of Urea	40%	40%
Average Consumption of Pure Urea	0.24 gal/hr	0.34 gal/hr
Hours of Operation	8,760 hr/yr	8,760 hr/yr
Annual Expected Consumption	2,102.4 gal/yr	2,978.4 gal/hr
Density of Pure Urea[2]	11.14 lb/gal	11.14 lb/gal
Annual Expected Consumption	**11.71 tons/yr**	**16.59 tons/yr**

Greenhouse Gas Life Cycle Analysis

The National Renewable Energy Laboratory (NREL) conducted a life cycle analysis for urea in their report titled "Selective Catalytic Reduction Urea Infrastructure Study"[3]. The study focused

[1] Phillip C. Turwitt, Cenergy Power Systems Technology, Inc., St. Augustine, FL.
[2] From Material Safety Data Sheet (MSDS) for pure urea: http://avogadro.chem.iastate.edu/MSDS/urea.htm.
[3] Fable, S., Kamakaté, F., & Venkatesh, S. "Selective Catalytic Reduction Urea Infrastructure Study". A.D Little. Subcontractor Report to the National Renewable Energy Laboratory NREL/SR-540-32689. Golden, Colorado. July 2002. http://www.nrel.gov/vehiclesandfuels/apbf/pdfs/adl_urea.pdf

on urea in SCR units in diesel trucks and evaluated nine urea life cycle pathways concluding that the pathway focused on the production and distribution of foreign-made granular urea is estimated to produce the most greenhouse gases (GHG). For this analysis of the Cenergy SCR units, the GHG findings from the NREL-calculated highest emissions pathway was utilized to estimate the GHG impact of urea usage (with the exception of the pathway step "Truck Stop Operation" as the urea will not be utilized in a truck stop for the application of urea in this type of engine). The stoichiometric chemical reaction of the urea as it goes through the SCR unit has been added to the NREL study numbers. Table 2 displays the findings from the NREL study.

Table 2. Life Cycle Analysis of Urea for SCR, NREL Findings[4]

Pathway Step	Emissions (g/ton-Urea)		
	CH_4	N_2O	CO_2
Production	6,428	9	735,003
Offshore Shipping	57	0	55,445
Transfer	1	0	785
Domestic Transport to Terminal	13	1	28,045
Terminal Operations	65	1	45,129
Transport to Truck Stop	36	1	25,107
Use in Engine[5]	0	0	664,620
Total [g/ton-Urea]	**6,600**	**12**	**1,554,134**
Total [tons/ton-Urea]	**0.0073**	**0.000013**	**1.71**
Project Emissions for the Engines			
2G800BG Total [tons]	**0.085**	**0.00016**	**20.07**
2G1200BG Total [tons]	**0.121**	**0.065**	**28.43**

[**Note**: The CO_2 emissions from the use of urea in the engine may already be counted in the engine emissions numbers in a system GHG analysis of an engine. Check to ensure that the system greenhouse gas calculations do not double count these emissions.]

To convert the emissions findings to carbon dioxide equivalent (CO_2e), the global warming potential 100-year conversion factors for each of the emissions categories will be utilized as indicated in Table 3.

[4] The NREL study did not review the use of urea in an engine, see the following footnote.
[5] Calculated based on stoichiometric conversion of urea: $4NO + 2CO(NH_2)_2 + O_2 \rightarrow 4N_2 + 4H_2O + 2CO_2$

Table 3. Global Warming Potential 100-Year Conversion Factors[6]

Common Name	Chemical Formula	GWP CO_2e – 100 year
Methane	CH_4	25
Nitrous Oxide	N_2O	298
Carbon Dioxide	CO_2	1

Using the data in Tables 1, 2, and 3, the expected annual GHG emissions (expressed in CO_2e equivalents) for the urea usage over its lifetime are shown in Table 4.

Table 4. Greenhouse Gas Potential from the Urea

Emissions Source	2G800BG Engine		2G1200BG Engine	
	Annual Emissions Rate [tons/yr]	CO_2e [tons/yr]	Annual Emissions Rate [tons/yr]	CO_2e [tons/yr]
Methane (CH_4)	0.085	2.13	0.121	3.02
Nitrous Oxide (N_2O)	0.00016	0.046	0.000219	0.065
Carbon Dioxide (CO_2)	20.07	20.07	28.43	28.43
	Total:	**22.24**	**Total:**	**31.51**
	Total Net of Engine Use[7]:	**13.66**	**Total Net of Engine Use[8]:**	**19.35**

Conclusions

Based on the above analysis, the net additional GHG emissions from the use of SCR on the 2G-Cenergy 800 KW IC engine is 13.66 tons per year of CO_2e. For the 1,200 KW unit, the net additional GHG burden is 19.35 tons per year of CO_2e. As the proposed UC Davis 50 ton per day anaerobic digester is calculated to displace 4,836 tons of CO_2e per year[9], the addition of CO_2e from the use of an SCR emissions control unit is relatively insignificant.

[6] Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp., (http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-errata.pdf).
[7] This represents the life-cycle from production to liquid stage before injection into the engine.
[8] See previous footnote.
[9] Calculated using Table B.3 and Equation 5.4 of the Organic Waste Digestion Project Protocol, Climate Action Reserve, Board Draft Version 1.0, September 2009.