Topical Report: Technology EH&S Risk Assessment

April 1, 2015 – March 31, 2016

Bench-Scale Process for Low-Cost Carbon Dioxide (CO_2) Capture Using a Phase-Changing Absorbent

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Acknowledgement and Disclaimer

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Executive Summary

GE Global Research was contracted by the Department of Energy to design and build a bench-scale process for a novel phase-changing aminosilicone-based CO_2 capture solvent (award number DE-FE0013687).

As part of this program, a technology EH&S assessment (Subtask 5.1) has been completed for a CO_2 capture system for a 550 MW coal-fired power plant. The assessment focuses on two chemicals used in the process, the aminosilicone solvent, GAP-0, and dodecylbenzenesulfonic acid (DDBSA), the GAP-0 carbamate formed upon reaction of the GAP-0 with CO_2, and two potential by-products formed in the process, GAP-0/SO_x salts and amine terminated, urea-containing silicone (also referred to as "ureas" in this report).

The EH&S assessment identifies and estimates the magnitude of the potential air and water emissions and solid waste generated by the process and reviews the toxicological profiles of the chemicals associated with the process. Details regarding regulatory requirements, engineering controls, and storage and handling procedures are also provided in the following sections.

A. Air, Water, and Solid Waste Identification for the Aminosilicone-based CO_2 Capture System for a 550 MW Coal-Fired Power Plant

This section describes the potential air and water emissions and solid waste streams from the proposed technology and estimates the magnitude of those streams for a 550 MW coal-fired power plant. Potential by-products were considered in the evaluation in addition to GAP-0.

This phase-changing process utilizes the solvent, 1,3-bis(3-aminopropyl)-1,1,3,3-tetramethyldisiloxane (GAP-0) (Figure 1), which has been demonstrated to readily react with CO_2 to form a carbamate salt. At elevated temperatures, the aminosilicone-carbamate salt releases CO_2, which permits the reuse of the solvent and capture of the CO_2.

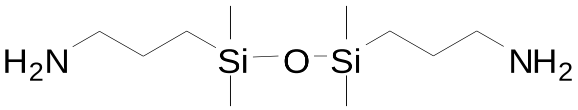


Figure 1. Chemical structure of GAP-0

The process flow diagram is provided in Figure 2 for the continuous CO_2 absorption/ desorption system. The flue gas composition (stream 1) is provided in Table 1. This represents the composition after the flue gas has gone through Flue-Gas Desulfurization (FGD) and the direct contact cooler (DCC). This composition also assumes the use of an additional scrubbing unit for SO_x prior to entering the absorber in the CO_2 capture system.

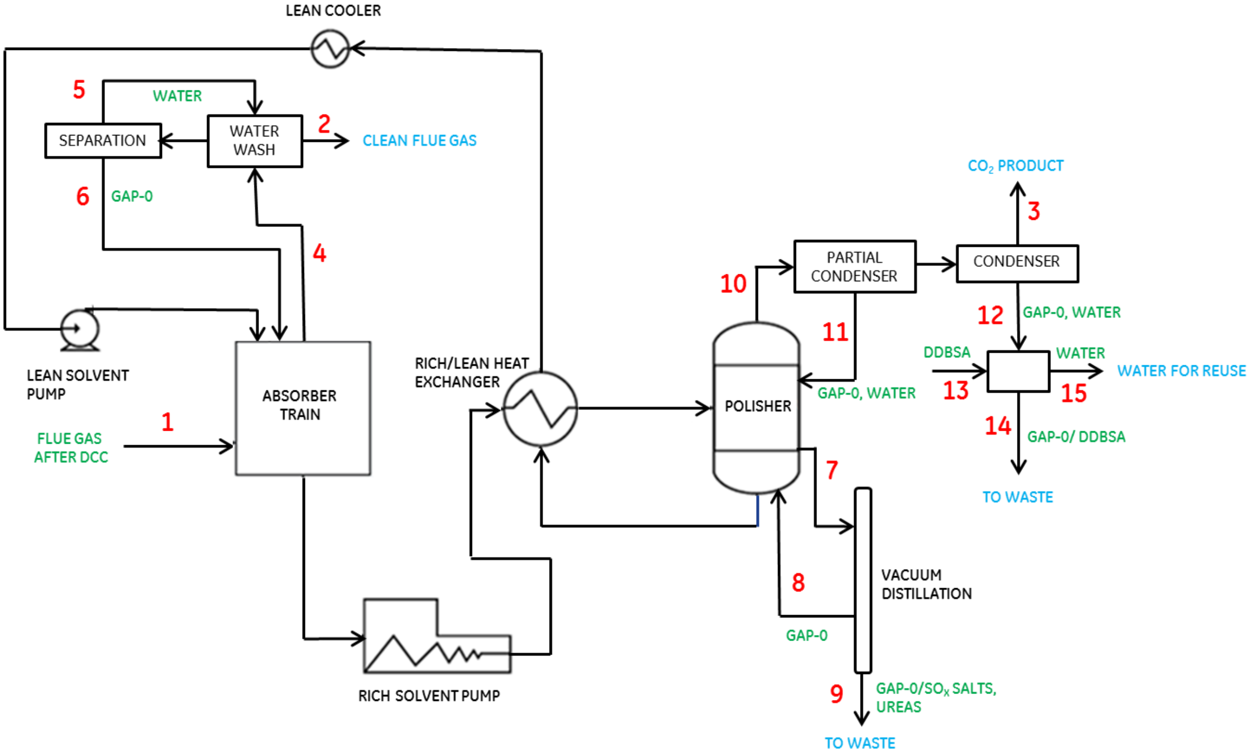


Figure 2. Continuous CO_2 absorption/ desorption system for a 550 MW coal-fired power plant.

The lean solvent enters the absorber, which for this system is a spray dryer, where it chemically reacts with CO_2 in the flue gas to form a carbamate. In the presence of humid flue gas, this is expected to result in the formation of a pumpable slurry. The slurry that is formed in the absorber is then pumped through the rich/ lean heat exchanger and into the polishing desorber where the solvent is regenerated.

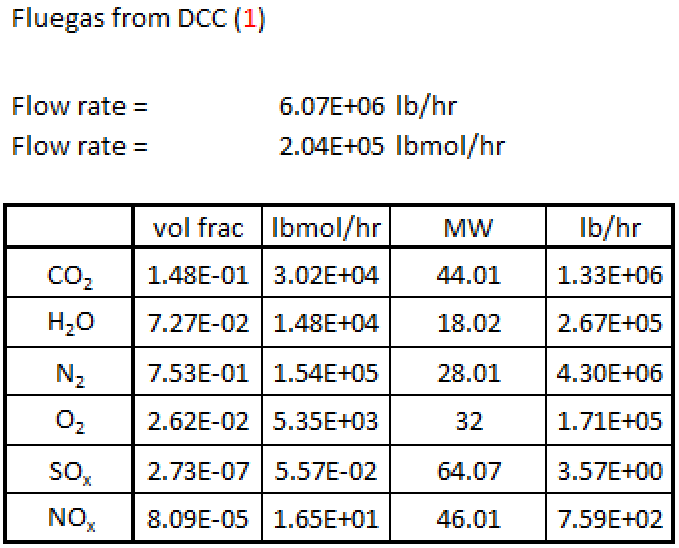
The regenerated solvent is then sent to the rich/lean heat exchanger before being pumped back to the absorber.

The flue gas stream leaving the absorber (stream 4) is then sent to a water wash to remove any GAP-0 that carried over with the gas. The clean flue gas (stream 2, Table 2) then exits the system. A purge stream containing GAP-0 and water is periodically removed from the water wash. This stream undergoes a separation step, such as decanting or heating, to result in a GAP-0 stream (stream 6) and a water stream (stream 5). Stream 6 is returned to the absorber and stream 5 is returned to the water wash.

The CO_2 stream leaving the polishing desorber (stream 10) goes through a partial condenser, where primarily GAP-0 is removed with some water. The GAP-0 and water is then returned to the polishing desorber (stream 11). The gas stream then goes through a second condenser, which results in the formation of a CO_2 product stream (stream 3, Table 3) and a water and GAP-0 stream (stream 12, Table 4). Stream 12 is then treated with a stream of DDBSA (stream 13, Table 5). A small stream of GAP-0/ DDBSA salt (stream 14, Table 6) is then removed from the water for disposal. Stream 15 (Table 7) is expected to only contain water and some dissolved gases and could be reused in the system in the water wash.

A purge stream from the polisher (stream 7) prevents buildup of the GAP-0/SO_x salts and ureas in the system. The production of ureas is estimated based on the results of thermal degradation testing completed at GE Global Research and assumes a 140°C temperature in the polisher. This also assumes that approximately one quarter of the system volume is being heated at a given time. This stream has the same composition as the material in the polisher. This stream undergoes a vacuum distillation to remove the contaminants. The GAP-0 stream (stream 8) would be returned to the polisher, and the GAP-0/SO_x salts and urea stream (stream 9, Table 8) would be removed for disposal. A detailed discussion of the handling of the waste streams is provided in the RCRA section of this report.

Table 1. Composition and flow rate of stream 1, inlet flue gas.

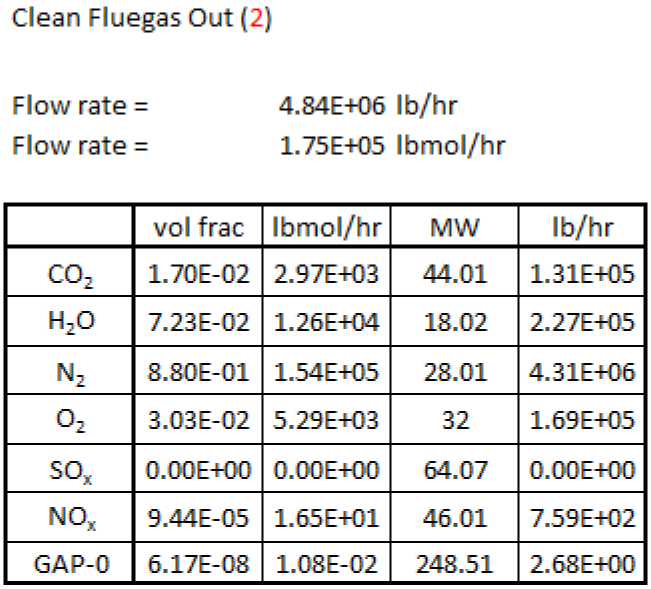


Fluegas from DCC (1)

Flow rate = 6.07E+06 lb/hr
Flow rate = 2.04E+05 lbmol/hr

	vol frac	lbmol/hr	MW	lb/hr
CO_2	1.48E-01	3.02E+04	44.01	1.33E+06
H_2O	7.27E-02	1.48E+04	18.02	2.67E+05
N_2	7.53E-01	1.54E+05	28.01	4.30E+06
O_2	2.62E-02	5.35E+03	32	1.71E+05
SO_x	2.73E-07	5.57E-02	64.07	3.57E+00
NO_x	8.09E-05	1.65E+01	46.01	7.59E+02

Table 2. Composition and flow rate of stream 2, clean flue gas.

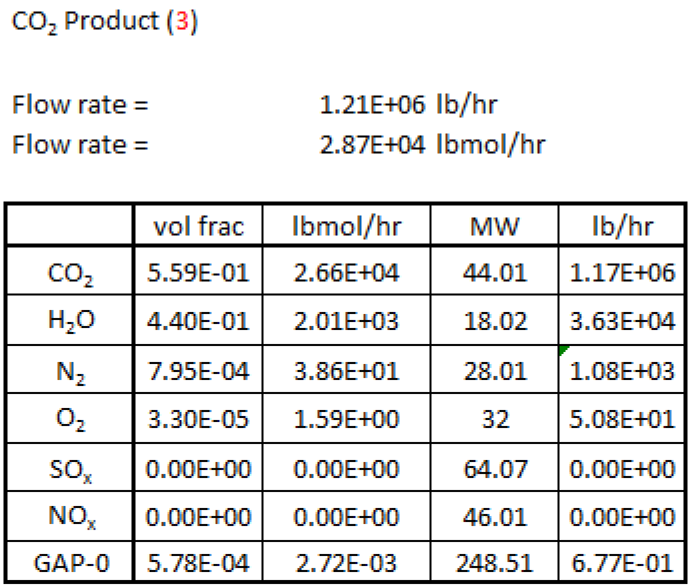


Clean Fluegas Out (2)

Flow rate = 4.84E+06 lb/hr
Flow rate = 1.75E+05 lbmol/hr

	vol frac	lbmol/hr	MW	lb/hr
CO_2	1.70E-02	2.97E+03	44.01	1.31E+05
H_2O	7.23E-02	1.26E+04	18.02	2.27E+05
N_2	8.80E-01	1.54E+05	28.01	4.31E+06
O_2	3.03E-02	5.29E+03	32	1.69E+05
SO_x	0.00E+00	0.00E+00	64.07	0.00E+00
NO_x	9.44E-05	1.65E+01	46.01	7.59E+02
GAP-0	6.17E-08	1.08E-02	248.51	2.68E+00

Table 3. Composition and flow rate of stream 3, CO_2 product stream.

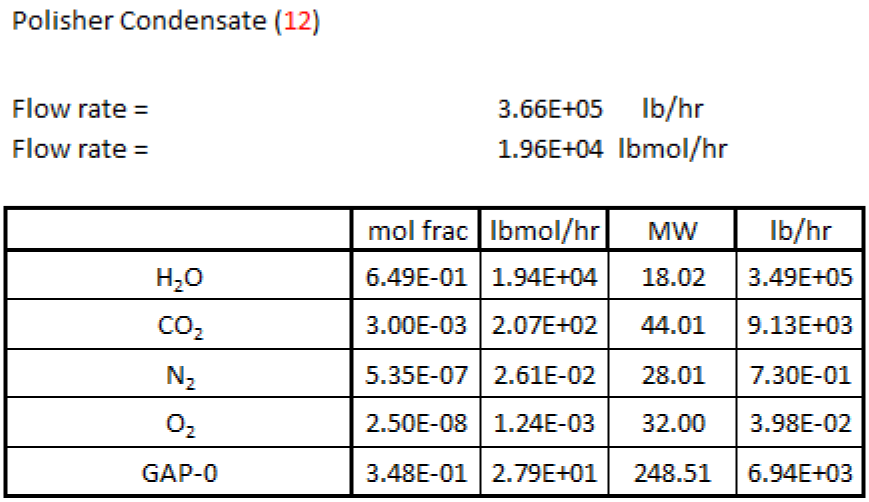


CO_2 Product (3)

Flow rate = 1.21E+06 lb/hr
Flow rate = 2.87E+04 lbmol/hr

	vol frac	lbmol/hr	MW	lb/hr
CO_2	5.59E-01	2.66E+04	44.01	1.17E+06
H_2O	4.40E-01	2.01E+03	18.02	3.63E+04
N_2	7.95E-04	3.86E+01	28.01	1.08E+03
O_2	3.30E-05	1.59E+00	32	5.08E+01
SO_x	0.00E+00	0.00E+00	64.07	0.00E+00
NO_x	0.00E+00	0.00E+00	46.01	0.00E+00
GAP-0	5.78E-04	2.72E-03	248.51	6.77E-01

Table 4. Composition and flow rate of stream 12, polisher condensate.

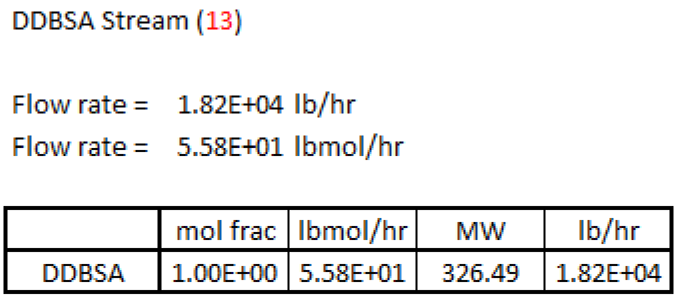


Polisher Condensate (12)

Flow rate = 3.66E+05 lb/hr
Flow rate = 1.96E+04 lbmol/hr

	mol frac	lbmol/hr	MW	lb/hr
H_2O	6.49E-01	1.94E+04	18.02	3.49E+05
CO_2	3.00E-03	2.07E+02	44.01	9.13E+03
N_2	5.35E-07	2.61E-02	28.01	7.30E-01
O_2	2.50E-08	1.24E-03	32.00	3.98E-02
GAP-0	3.48E-01	2.79E+01	248.51	6.94E+03

Table 5. Composition and flow rate of stream 13, DDBSA input stream.

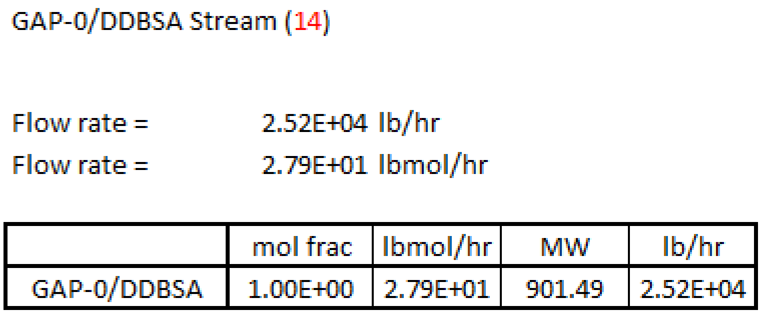


DDBSA Stream (13)

Flow rate = 1.82E+04 lb/hr
Flow rate = 5.58E+01 lbmol/hr

	mol frac	lbmol/hr	MW	lb/hr
DDBSA	1.00E+00	5.58E+01	326.49	1.82E+04

Table 6. Composition and flow rate of stream 14, GAP-0/DDBSA stream.

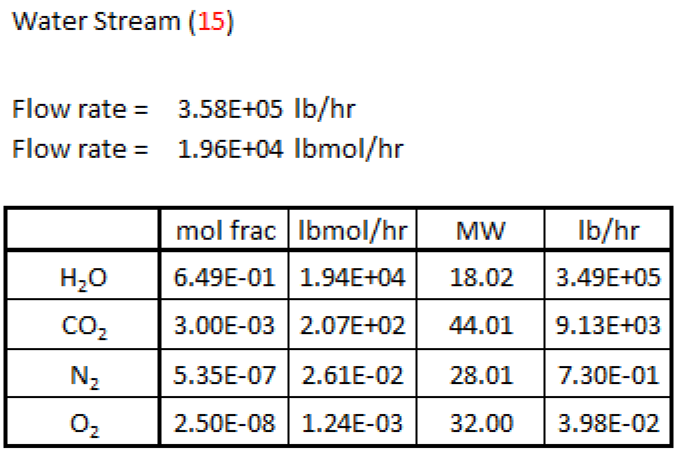


GAP-0/DDBSA Stream (14)

Flow rate = 2.52E+04 lb/hr
Flow rate = 2.79E+01 lbmol/hr

	mol frac	lbmol/hr	MW	lb/hr
GAP-0/DDBSA	1.00E+00	2.79E+01	901.49	2.52E+04

Table 7. Composition and flow rate of stream 15, water stream from condenser.

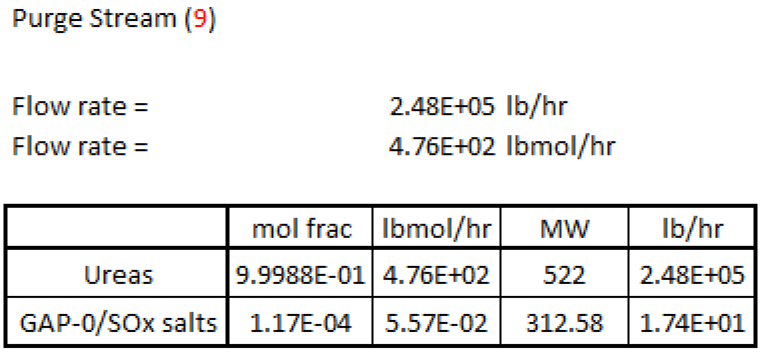


Water Stream (15)

Flow rate = 3.58E+05 lb/hr
Flow rate = 1.96E+04 lbmol/hr

	mol frac	lbmol/hr	MW	lb/hr
H_2O	6.49E-01	1.94E+04	18.02	3.49E+05
CO_2	3.00E-03	2.07E+02	44.01	9.13E+03
N_2	5.35E-07	2.61E-02	28.01	7.30E-01
O_2	2.50E-08	1.24E-03	32.00	3.98E-02

Table 8. Composition and flow rate of stream 9, purge stream from polisher.



Purge Stream (9)

Flow rate = 2.48E+05 lb/hr
Flow rate = 4.76E+02 lbmol/hr

	mol frac	lbmol/hr	MW	lb/hr
Ureas	9.9988E-01	4.76E+02	522	2.48E+05
GAP-0/SOx salts	1.17E-04	5.57E-02	312.58	1.74E+01

B. Toxicological Effects of Components in the Continuous CO_2 Absorption/Desorption Process

This section discusses the various toxicological information related to the chemicals associated with the CO_2 capture process, as identified in Section A. A thorough literature search was conducted to examine potential human health effects and eco-toxicity. Where information was lacking for a particular material, the material was either compared to similar substances or Quantitative Structure Activity Relationship (QSAR) models were used to predict toxicity levels of the particular chemical.

The specific chemicals of interest in this review are GAP-0, GAP-0 carbamate, DDBSA, and the amine-terminated, urea-containing silicone material. The GAP-0/SO_X salt shown in stream 9 in Figure 2 is not a registered compound and information regarding the structure of these salts is not available. Therefore, toxicity data are not available. Typically, acid/primary amine salts are less toxic than the free amine itself. For example, 1, 4 diaminobutane is a linear alkyl amine similar in structure to the GAP materials, except it is a carbon chain. Its National Fire Protection Association (NFPA) rating is Health hazard: 4, Fire: 2, Reactivity Hazard: 0, on a scale of 0-4 where 4 is severe[1]. In contrast, its acid salt, 1, 3-Diaminopropane dihydrochloride, has a NFPA rating of Health hazard: 2, Fire: 0, Reactivity Hazard: 0[2].

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[1] Sigma Aldrich MSDS for 1,4 diaminobutane. http://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=D13208&brand=ALDRICH&PageToGoToURL=http%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Faldrich%2Fd13208%3Flang%3Den

[2] Sigma Aldrich MSDS for 1,3-diaminopropane dihydrochloride. http://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=US&language=en&productNumber=D23807&brand=ALDRICH&PageToGoToURL=http%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Faldrich%2Fd23807%3Flang%3Den

The acid salt displays hazardousness to a far lesser degree. Thus, for analysis here the toxicity of GAP-0/SO_x is assumed to be less than or equal to its components, GAP-0 and SO_x. The difference in toxicity between amines and their corresponding salt forms is also discussed in further detail later in this section as it pertains to the GAP-0 carbamate salt.

If data were not available in literature for a specific endpoint, the QSAR models ECOSAR, EPIWIN, Toxtree, and T.E.S.T were used to predict potential human health effects and eco-toxicity for these materials. These models use the physical characteristics of the various parts of the chemical structure to predict the characteristics of the whole molecule. For example, molecules that contain the primary amine group, -NH_2, are known to have toxicity to fish. The siloxane group is known to be hydrophobic and decompose slowly in the environment. These and other "molecular descriptors" are combined through a series of mathematical equations to predict the hazard and toxicity properties of the entire molecule.

Through the years, the US EPA has learned that the accuracy of the aquatic toxicity models (ECOSAR) is limited for very hydrophobic molecules. As the molecule becomes more hydrophobic, it is less dispersive into water, preventing the chemical from being readily absorbed in aquatic life. A common method of measuring hydrophobicity is the octanol/water partition coefficient (K_{ow}). It is defined as the ratio of a chemical's concentration in n-octanol to its concentration in water at equilibrium. The log K_{ow} is more commonly reported. When the log K_{ow} is above the general limits provided in ECOSAR for certain classes of compounds and toxicity endpoints, the decreased water solubility of these chemicals limits potential effects from any degree of toxicity. Different cut-off values are provided for acute and chronic toxicity.

The following sections summarize the results of various tests used to estimate the toxicity to humans and the environment of the chemicals used in the aminosilicone-based CO_2-capture process. When available, experimental data were included. If not available, modeling data were included and are indicated as predicted in the tables. Resource information was also provided for clarification of how the data were obtained.

GAP-0 CAS# 2469-55-8 Toxicological Data

Table 9 summarizes the toxicological data available for GAP-0. Some testing on animals has been completed, which indicate that it is a severe eye and skin irritant. GAP-0 is also known to cause damage to mucous membranes. Very little other toxicological data have been reported for this chemical so the majority of the values in Table 9 were predicted using QSAR models.

The predicted aquatic toxicity values indicate that relatively low levels of GAP-0 can cause concerns for aquatic life. EPA has indicated a Bioconcentration Factor (BCF) or Bioaccumulation Factor (BAF) of greater than 5000 to be a high concern for bioaccumulation, greater than 1000 to be a moderate concern, and less than 1000 to be a low concern for bioaccumulation[3]. The range of predicted BCF values in Table 9 would indicate the potential for a moderate concern for bioaccumulation, and the predicted log K_{ow} of 4.27 indicates that bioaccumulation may be of potential concern[4]. The predicted soil adsorption coefficient, which is significantly above 500 L/kg, would suggest that it would blend and adhere well to most soils. This would limit its mobility in the environment. It is not predicted to be readily biodegradable according to the EPIWIN model.

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[3] EPA OPPT. 2012. "TSCA Work Plan Chemicals: Methods Document."

[4] EPA. 2000. "Bioacccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment. Section 4.2" http://www.itrcweb.org/contseds-bioavailability/References/2000_04_03_cs_biotesting_bioaccum.pdf

Table 9. GAP-0 Toxicological data.

CAS# 2469-55-8, GAP-0	Toxicity Test Result	Species	Time (hrs)	Resource/Model Software
Ingestion LD_{50} (mg/kg)	<500	Rat	N/A	Internal GE study[5]
Eye Irritation/Damage	Severe Irritant	Rabbit	24 hours (100 µL)	SiVance MSDS[6]
Dermal LD_{50} (mg/kg)	>2 g/kg	N/A	N/A	SiVance MSDS[6]
Skin Corrosion/Irritation	Severe Irritant	Rabbit	24 hours (100 µL)	SiVance MSDS[6]
Predicted Octanol Water Partition Coefficient, log K_{ow}	4.27	N/A	N/A	ECOSAR
Predicted Genotoxicity	Negative	N/A	N/A	Toxtree
Predicted Non-Cancer Toxicity	Negative	N/A	N/A	Toxtree
Predicted Mutagenicity	Negative	N/A	N/A	T.E.S.T.
Predicted Fish Toxicity LC_{50} (ppm)	1.54	N/A	96	ECOSAR
Predicted Fish Toxicity LC_{50} (ppm), Chronic	0.04	N/A	N/A	ECOSAR
Predicted Daphnia LC_{50} (ppm)	0.24	*D. magna*	48	ECOSAR
Predicted Daphnia Toxicity LC_{50} (ppm), Chronic	0.025	*D. magna*	N/A	ECOSAR
Predicted Algae EC_{50} (ppm)	0.12	N/A	N/A	ECOSAR
Predicted Algae Toxicity EC_{50} (ppm), Chronic	0.047	N/A	N/A	ECOSAR
Predicted Biodegradability	Not readily biodegradable	N/A	N/A	EPIWIN
Predicted Soil Adsorption Coefficient, K_{oc} (L/kg)	1751	N/A	N/A	EPIWIN
Predicted Bioconcentration Factor (BCF)	305[7] 956.7 - 1368[8]	N/A	N/A	EPIWIN EPIWIN

GAP-0 carbamate Toxicological Data

Table 10 summarizes the available toxicological data for the GAP-0 carbamate salt that is formed upon reaction of the GAP-0 with CO_2. As can be seen from the table, the predicted toxicity of the GAP-0 carbamate is anticipated to be less than that of GAP-0 based on the aquatic toxicity values modeled in ECOSAR. This is further supporting evidence that the salt forms of amines are anticipated to be less toxic than the amine itself.

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[5] GE CRD. 1992. Report of TSCA Section 8€ Information. https://yosemite.epa.gov/oppts/epatscat8.nsf/by+Service/F9F7B7C1C67EB31B852572580070BE35/$File/88920000901.pdf

[6] SiVance MSDS for DAP-0.

[7] Regression-based estimate.

[8] Arnot-Gobas BCF ranging across lower trophic, mid trophic and upper trophic levels.

It should be noted that the predicted water solubility of the GAP-0 carbamate is only 114.4 mg/L, which is lower than both the predicted fish acute LC_{50} and the predicted acute LC_{50} for *D. magna.*

The GAP-0 carbamate is not predicted to be readily biodegradable, and the relatively low predicted K_{oc} value provided in the table would indicate that it could have higher mobility if present in a subsurface environment. However, the EPIWIN software calculates the K_{oc} value using two different methods. The other method of calculating this value yielded a significantly higher K_{oc} value of 3332 L/kg, which would indicate that it would have low mobility in the subsurface. Based on the very low predicted BCF value, significant bioconcentration is not anticipated with this material.

Table 10. GAP-0 carbamate toxicological data.

GAP-0 carbamate	**Toxicity Test Result**	**Species**	**Time (hrs)**	**Resource/Model Software**
Predicted Octanol Water Partition Coefficient, log K_{ow}	2.14			ECOSAR
Predicted Genotoxicity	Negative	N/A	N/A	Toxtree
Predicted Non-Cancer Toxicity	Negative	N/A	N/A	Toxtree
Predicted Mutagenicity	Negative	N/A	N/A	T.E.S.T.
Predicted Fish Toxicity LC_{50} (ppm)	205.9	N/A	96 hr	ECOSAR
Predicted Fish Toxicity LC_{50} (ppm), Chronic	20.44	N/A	N/A	ECOSAR
Predicted Daphnia LC_{50} (ppm)	118.46	*D. magna*	48 hr	ECOSAR
Predicted Daphnia Toxicity LC_{50} (ppm), Chronic	11.98	*D. magna*	N/A	ECOSAR
Predicted Algae EC_{50} (ppm)	93.17	N/A	96 hr	ECOSAR
Predicted Algae Toxicity EC_{50} (ppm), Chronic	25.13	N/A	N/A	ECOSAR
Predicted Biodegradability	Not readily biodegradable	N/A	N/A	EPIWIN
Predicted Soil Adsorption Coefficient, K_{oc} (L/kg)	19.76	N/A	N/A	EPIWIN
Predicted Bioconcentration Factor (BCF)	3.162[9]	N/A	N/A	EPIWIN

DDBSA (CAS # 27176-87-0) Toxicological Data

The toxicological data for DDBSA are provided in Table 11. Relevant hazard data were identified in the REACH registration for DDBSA on the European Chemicals Agency (ECHA) website and are provided in Table 11 solely for the purposes of hazard communication/ assessment. Much of the

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[9] Regression-based estimate. Arnot-Gobas BCFs ranging from 8.548 – 12.8 (across lower, mid and upper trophic levels) were also reported.

available data are read across data for similar structures or analogues, including sodium dodecylbenzene sulfonate and linear alkylbenzene sulfonate (LAS). Instances where read across data are provided are noted in Table 11.

DDBSA is classified in REACH as a category 1C corrosive material based on skin corrosion testing. Some animal testing for DDBSA has been completed, including a reproductive/developmental study and a repeated dose toxicity test. The reproductive/ developmental study resulted in a NOAEL of 400 mg/kg b.w./day, which was the highest dose tested. The repeated dose toxicity tested determined a LOAEL of 200 mg/kg b.w./day based on effects to the stomach.

Some mutagenicity testing has been completed for DDBSA, which was negative for both the AMES test and the *in vitro* chromosome aberration test.[10] An *in vivo* chromosome aberration test completed on rats for a structural analogue was also negative.[11]

Aquatic toxicity values for both DDBSA and similar structures are summarized in the table. They indicate lower toxicity values for fish and *D. magna* than for green algae. Testing indicates that DDBSA is expected to be readily biodegradable. The low experimentally-determined BCF value indicates that bioaccumulation is not likely to be a concern with DDBSA. The very high measured Koc value indicates that low mobility would be expected in a subsurface environment.

Table 11. DDBSA toxicological data.

	Toxicity Test Result	**Species**	**Time**	**Resource/Model Software**
Ingestion LD$_{50}$ (mg/kg)	650	Rat	N/A	OECD report[10]
Eye Irritation/Damage	Irritant	N/A	N/A	ECHA 2015[11,13]
Skin Corrosion/Irritation	Corrosive (Cat 1C)	N/A	N/A	ECHA 2015[11,12]
Octanol Water Partition Coefficient, log K$_{ow}$	1.9			OECD report[10,13]
Repeated dose toxicity	NOAEL 100 mg/kg b.w./day, LOAEL 200 mg/kg b.w./day	Rat		OECD report[10]
Predicted Genotoxicity	Negative	N/A	N/A	Toxtree
Predicted Non-Cancer Toxicity	Negative	N/A	N/A	Toxtree
Mutagenicity	Negative for Ames and *in vitro* and *in vivo* chromosome aberration	*In vivo* test - rat	N/A	OECD report[10] and ECHA 2015[11,14]
Reproductive/ developmental toxicity	NOAEL of 400 mg/kg b.w./day (highest dose tested)	Rat		OECD report[10]
Fish toxicity, LC$_{50}$ (ppm)	3.2-5.6	*S. gairdnei*	96 hours	OECD report[10,13]
Fish toxicity, LC$_{50}$ (ppm)	4.1	*P. promelas*	96 hours	Holman and Macek 1980[15,16]
Fish toxicity, NOEC, chronic (ppm)	1	*L. macrochirus*	28 days	Maki 1981[16,17]
Fish toxicity, NOEC, chronic (ppm)	0.9	*P. promelas*	1 year	OECD report[10,16]
Daphnia LC$_{50}$ (ppm)	3.5 ± 1	*D. magna*	48 hours	OECD report[10,16]
Daphnia chronic NOEC (ppm)	1.18	*D. magna*	21 days	OECD report[10,16]
Daphnia chronic NOEC (ppm)	1.65	*D. magna*	21 days	OECD report[10,13]
Algae EC$_{50}$ growth rate (ppm)	65.4	*P. subcapitata*	72 hours	OECD report[10]
Algae EC$_{50}$ yield (ppm)	21	*P. subcapitata*	72 hours	OECD report[10]
Algae NOEC growth rate and yield (ppm)	7.9	*P. subcapitata*	72 hours	OECD report[10]
Biodegradability	Readily biodegradable	N/A	N/A	OECD report[10,16]
Soil Adsorption Coefficient, K$_{oc}$ (L/kg)	9076			OECD report[10,16]
Bioconcentration Factor (BCF)	36 to 119	Multiple	32 days	OECD report[10,16]

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[10] OECD. 2009. "SIDS Initial Assessment Profile." http://webnet.oecd.org/Hpv/UI/SIDS_Details.aspx?id=67DEF1CD-AA76-4461-B1F5-83EBAF49543D

[11] European Chemicals Agency (ECHA), 2015. REACH Registration of Dodecylbenzensulphonic acid (CAS 27176-87-0). Last modified 24 Dec 2015. http://echa.europa.eu/registration-dossier/-/registered-dossier/11796/1

[12] Read across data for CAS # 85536-14-7 (benzenesulfonic acid, C10-C13-alkyl derivatives)

[13] Read across data for sodium dodecylbenzene sulfonate

[14] Read across data for CAS# 69669-44-9 (C10-14 LAS, sodium salt)

[15] Holma, W.F. and Macek, K.J. 1980. "An aquatic safety assessment of linear alkylbenzenesulphonate (LAS); chronic effects on fathead minnows." *Trans. Am. Fish. Soc.* 109(1): 122-131.

[16] Read across data for CAS # 68411-33-3 (C10-C13 linear alkylbenzene sulfonate [LAS])

[17] Maki, AW. 1981. "A laboratory model ecosystem approach to environmental fate and effects studies." Unpublished Internal Report, Environmental Safety Department, Proctor and Gamble Company, Cincinnati, OH.

Amine terminated, urea-containing silicone Toxicological data

The ureas that could be formed as a result of the degradation of GAP-0 carbamate are not registered chemicals and no toxicological data exists. The structure provided in Figure 3 was used to estimate the toxicological properties using QSAR models though other similar structures could also be formed in the process. The chemical name of this structure is 1,3-bis(3-(5-(3-aminopropyl)-1,1,3,3,5,5-hexamethyltrisiloxanyl)propyl)urea.

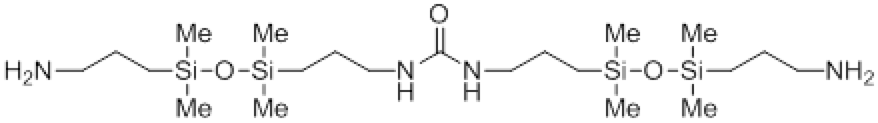

Figure 3. Structure of amine terminated, urea-containing silicone.

ECOSAR modeling was completed for the chemical. However, given that the log K_{ow} is higher than the cut-off points for all aquatic toxicity values, no aquatic toxicity data are provided in Table 12. Table 13 summarizes the log K_{ow} cut-off values for both substituted ureas and amines, which were the compounds used in ECOSAR for estimating the toxicity of this structure. According to ToxTree, this structure is not predicted to be carcinogenic. The T.E.S.T. model also predicts that the mutagenicity of this chemical is negative.

According to the EPIWIN model, the predicted soil adsorption coefficient is very high and is well above 500 L/kg. This indicates that this structure would be expected to sorb strongly to most soils and would have very limited mobility in a subsurface environment. The predicted BCF value is considerably below 1000 so it is not expected to bioaccumulate in fish.

Table 12. Amine terminated, urea-containing silicone Toxicological data.

	Value	**Resource**
Predicted Octanol Water Partition Coefficient (log K_{ow})	8.5	ECOSAR model
Predicted mutagenicity	Negative	T.E.S.T. model
Predicted carcinogenicity	Negative for genotoxic and nongenotoxic	ToxTree model
Predicted biodegradability	Not readily biodegradable	EPIWIN model
Predicted soil adsorption coefficient, K_{oc} (L/kg)	3.383×10^5	EPIWIN model
Predicted bioconcentration factor (L/kg wet weight)	620.2	EPIWIN model

Table 13. Summary of log K_{ow} cut-off values from ECOSAR model.

Endpoint	Log K_{ow} cut-off value from ECOSAR
Predicted fish toxicity, acute, LC_{50} (mg/L)	Substituted ureas: 5 Amines: 6
Predicted fish toxicity, chronic LC_{50} (mg/L)	Both classes: 8
Predicted daphnid toxicity, acute LC_{50} (mg/L)	Both classes: 5
Predicted daphnid toxicity, chronic LC_{50} (mg/L)	Both classes: 8
Predicted algae toxicity, acute EC_{50} (mg/L)	Substituted ureas: 6.4 Amines: 7
Predicted algae toxicity, chronic (mg/L)	Substituted ureas: 8 Amines: 7

C. Physical Properties of the Chemical Materials in the CO_2 Capture Process

This section summarizes the physical properties of the chemicals associated with the CO_2 capture system (Table 14). Given that little is known about the ureas that could be formed in this process, the physical properties in the table for this chemical are predicted by QSAR models. According to these models, it is not expected to be volatile or flammable. Most of property data for the GAP-0 carbamate provided in the table are also based on QSAR models, with the exception of those properties measured or observed (e.g. color, odor, solubility in alcohols) at GE Global Research.

GAP-0 is classified as a flammable chemical. Both GAP-0 and DDBSA are classified as corrosive materials. Contact with oxidizing agents should be avoided for both GAP-0 and DDBSA. DDBSA should also not come into contact with strong bases. The storage and handling of these materials is discussed more fully in Section F.

Table 14. Physical properties of chemicals associated with CO_2 capture system.

	GAP-0[18]	**GAP-0 carbamate**	**DDBSA**[10,19,20,21]	**Amine terminated, urea-containing silicone**
Flash Point	91 °C	228.18°C (modeled in T.E.S.T.)	149°C	240.5°C (modeled in T.E.S.T.)
Chemical Reactivity	May react with strong oxidizing agents	Not available	May react with metals, strong oxidizing agents, strong bases	Not available
Corrosivity	Corrosive	Corrosive	Corrosive	Not available
State, STP	Liquid	Solid powder	Liquid	Not available
Color	Clear or light yellow	White	Brown	Not available
Odor	Amine-like	Amine-like	Sulfur dioxide odor	Not available
Melting Point	~-90°C	181.85°C (modeled in EPIWIN)	10°C	213.92°C (modeled in EPIWIN)
Boiling Point	132°C at 11 mmHg	434.17°C (modeled in EPIWIN)	460°C (calculated)	502.83°C (modeled in EPIWIN)
Vapor Pressure	0.225 mmHg at 60°C[22]	3.75x10^{-6} Pa at 25°C (modeled in EPIWIN)	3x10^{-13} Pa (modeled)[13]	2.27x10^{-10} mmHg at 25°C (modeled in EPIWIN)
Density	0.901 g/cm^3@ 20 °C	0.3 g/cm^3 (bulk density)[22]	1.06 g/cm^3	0.92 g/cm^3 (modeled in T.E.S.T.)
Water Solubility	23.06 mg/L (modeled in EPIWIN)	114.4 mg/L (modeled in EPIWIN)	800 mg/L at 25°C[13]	1.169x10^{-5} mg/L (modeled in EPIWIN)
Solubility Properties	Soluble in chloroform, toluene, hexanes, alcohols	Soluble in alcohols	Not available	Not available
Viscosity, Dynamic	4.4 cP @ 25 °C[23]	Not applicable as solid powder	960 mPa-s at 20°C	Not available

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[18] MSDS from Sigma Aldrich

[19] MSDS from Acros Organics. http://www.fishersci.com/ecomm/servlet/msdsproxy?productName=AC240885000&productDescription=DODECYLBENZENE+SULFONIC+500GR&catNo=AC240885000&vendorId=VN00032119&storeId=10652

[20] U.S. Coast Guard, Department of Transportation. 1999. "CHRIS – Hazardous Chemical Data. Volume II." Washington, D.C. US Government Printing Office.

[21] Ash, M. and A. 2004. "Handbook of Green Chemicals, Second edition" Synapse Information Resources, Inc. Library of Congress Card Number 2004092740.

[22] As measured at GE Global Research

[23] Perry, R.J., S.E. Genovese, R.L. Farnum, I. Spiry, T.M. Perry, M.J. O'Brien, H. Xie, D. Chen, R.M. Enick, J. K. Johnson, S.S. Alshahrani. 2014. "A Combined Experimental and Computational Study on Selected Physical Properties of Aminosilicones." *Ind. Eng. Chem. Res.* 53: 1334-1341.

D. U.S. EH&S Law Compliance and Regulation Implications for the CO_2 Capture Process

The compliance of the chemicals used in and potential emissions from the proposed CO_2 capture system with US EH&S regulations is summarized in this section. The applicable laws addressed include: Toxic Substances Control Act (TSCA), Comprehensive Environmental Response and Liability Act of 1980 (CERCLA), Clean Water Act (CWA), Clean Air Act (CAA), Superfund Amendments and Reauthorization Act (SARA) Title III, the Occupational Safety and Health Act (OSHA), and the Resource Conservation and Recovery Act (RCRA). Table 15 summarizes the initial list of streams that were considered in preparing the regulatory review. The flue gas contaminants present in streams 1, 2, and 4 (SO_x, NO_x) come directly from the plant and are not addressed in this regulatory review.

Table 15. Streams considered for regulatory review.

Stream	Description	Components
1	Flue gas after DCC	CO_2, H_2O, N_2, O_2, NO_x, SO_x
2	Clean flue gas	CO_2, H_2O, N_2, O_2, NO_x
3	CO_2 product	CO_2, H_2O, N_2, O_2, GAP-0
4	Stream to water wash	CO_2, GAP-0, H_2O, N_2, O_2, NO_x
5	Water from water wash	H_2O
6	GAP-0 from water wash	GAP-0
7	Purge stream from polisher	GAP-0, GAP-0 carbamate, GAP-0/SO_x salts, ureas
8	GAP-0 stream returned to desorber	GAP-0
9	Waste stream from purge	GAP-0/SO_x salts, ureas
10	Gas stream to partial condenser	CO_2, GAP-0, H_2O, N_2, O_2
11	Return stream from partial condenser	GAP-0, H_2O
12	Polisher condenser stream	GAP-0, H_2O
13	DDBSA input stream	DDBSA
14	GAP-0/ DDBSA waste stream	GAP-0, DDBSA
15	Water for reuse	H_2O, CO_2, N_2, O_2

Based on the summary in Table 15, the following individual components are the focus of the regulatory review:

- GAP-0
- GAP-0 carbamate
- DDBSA
- GAP-0/ SO_x salts
- Amine terminated, urea-containing silicone

A summary of the applicable regulations for each component in this review is provided in Table 16. Each regulation in Table 16 is discussed separately in the following sections.

In Table 16, all substances are marked as being regulated by RCRA. This indicates that all of these materials are potential waste products of this process and would, therefore, be regulated under RCRA Subpart C or D. This table does not indicate hazardous or non-hazardous waste classifications. For a detailed discussion of those classifications for each waste stream, see the RCRA section of this report.

Table 16. Regulatory overview for components of CO_2 capture system.

	TSCA	CERCLA RQ (lbs/day)	CWA	CAA HAP	CAA VOC	SARA 302 EHS	SARA 311/312	SARA 313	OSHA Regulated	RCRA
CAS#2469-55-8, GAP-0	Y	N	N	N	Y	N	Acute Fire	N	Y	Y
CAS#27176-87-0, DDBSA	Y	1000	Y	N	Y	N	Acute	N	Y	Y
GAP-0 carbamate	N	N	N	N	Y	N	N	N	Y	Y
GAP-0/SOx salts	N	N	N	N	Y	N	N	N	Y	Y
Amine terminated, urea-containing silicone	N	N	N	N	Y	N	N	N	Y	Y

TSCA

GAP-0 and DDBSA are on EPA's TSCA Inventory allowing companies to manufacture and use the chemical commercially. The CAS numbers for both are included in Table 16. The GAP-0 carbamate is intentionally created and serves an intended purpose; therefore, at the commercial application level (not R&D) it would require further assessment and potential submissions under TSCA Section 5.

CERCLA

CERCLA hazardous substances are considered severely harmful to human health and the environment.[24] The reportable quantity (RQ) is the minimum release quantity that must be reported.[25] GAP-0, GAP-0 carbamate, GAP-0/SO_x salts and the ureas are not listed as CERCLA hazardous substances, but DDBSA is. The minimal reportable quantity for DDBSA is 1000 lbs/day.

DDBSA leaves the process through stream 14, which is discussed further in the RCRA section, but there is also the potential for spills of the pure material stored on-site for use in the process. This would need to be stored on-site in quantities greater than the reportable quantity. This emphasizes the importance of safe handling and storage of this material. In future, materials that could be substituted for DDBSA for treatment of stream 12 will also be investigated.

Clean Water Act

DDBSA is designated as a hazardous substance to the water supply in accordance with Section 311(b)(2)(A) of 40 CFR 116, the Clean Water Act (CWA).[26] The minimum reportable quantity for DDBSA is 1000 lbs/day (40 CFR § 117.3).

Clean Air Act

The definition of a VOC according to the Clean Air Act is any compound of carbon that participates in atmospheric photochemical reactions. Certain exclusions are listed in the regulatory definition (40 CFR §51.100(s)). All chemicals in this review are considered to be VOCs by this definition. However, if any of the chemicals were to be tested for photochemical reactivity and it was determined to be negligible, they could be excluded from the definition (40 CFR §51.100(s)(2)). It is assumed for this assessment that both the flue gas exit stream from the absorber (stream 2) and the CO_2 product stream (stream 3) would undergo gas treatment to keep the potential to emit for the CO_2 capture system (as

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[24] http://www.epa.gov/oem/docs/er/302table01.pdf
[25] http://www.epa.gov/superfund/policy/release/rq/index.htm#levels
[26] EPA 2005b 40 CFR 116.4

defined in 40 CFR 70) below the level required for reporting. This type of treatment could include a thermal oxidizer.

SARA

None of these chemicals pose an immediate hazard to a community upon release as described by EPA's SARA 302 list. For Safety Data Sheet reporting (SARA 311/312), GAP-0 and DDBSA are considered as acute, immediate health hazards. GAP-0 is considered as a fire hazard. None of the chemicals in this review are on the SARA 313 list, which requires reporting of certain chemical releases to public and government officials.

OSHA

All of the chemicals are regulated by OSHA, requiring proper safety data sheet, handling, shipping, and storage equipment. Safe handling and storage are discussed in further detail in Section F of this report.

RCRA

The relevant sections of RCRA are Subparts C and D of 40 CFR Part 260. Subpart D deals with municipal solid waste and non-hazardous waste, including that generated by industry, such as power plants. Waste not categorized under Subpart C as a hazardous waste is disposed of under Subpart D. Specific requirements for disposal under Subpart D would depend on the power plant location, and a detailed discussion of local requirements is outside the scope of this document. Specific disposal methods would need to be reviewed on a site-specific basis.

For the purpose of this review, only federal RCRA requirements are considered. These are the minimum requirements for RCRA. Some states administer their own programs, which are at least as stringent as EPA's. This EH&S assessment does not include a detailed review of state programs. These requirements would vary based on power plant location and an extensive review of all state RCRA programs is considered to be outside the scope of this document.

To determine if Subpart C applies to a given stream, the following questions must be answered (in order):

1. Is the material in question a solid waste?
2. Is the material excluded from the definition of solid waste or hazardous waste?

3. Is the waste a listed or characteristic hazardous waste?
4. Is the waste delisted?

If a stream is excluded from RCRA's definition of a solid or hazardous waste by answering one of these questions, it is not necessary to proceed through the remaining questions. Each of these questions is discussed in detail for the following streams (Figure 2):

- Absorber: 4, 5, 6
- Desorber: 7, 8, 9, 11, 14, 15

The overall conclusions for the streams are summarized at the end of this section in Table 18.

Absorber

Streams 4, 5, and 6

The flue gas in stream 4 goes through the water wash tower to remove GAP-0. A separation step, such as decanting or heating, is then completed. This separation step results in a water stream (stream 5), which is recycled back to the water wash, and a GAP-0 stream (stream 6), which is recycled back to the absorber train.

Question 1: Is the material in question a solid waste?

These streams require treatment before returning to the process. This would fall under RCRA's definition of reclamation so streams 4, 5, and 6 would be considered solid waste.

Question 2: Is the material excluded from the definition of solid waste or hazardous waste?

An exclusion is provided by RCRA for Closed loop recycling (40 CFR § 261.4(a)(8)). This excludes materials from the definition of solid waste if they are being reclaimed and recycled to the process through an enclosed system of pipes and tanks. This exclusion would apply to streams 4, 5, and 6 because the material is recycled back to the process. Therefore, all three streams are excluded from the RCRA definition of solid waste.

Desorber

<u>Streams 7, 8, and 9</u>

To purge the GAP-0/SO_x salts and ureas from the system, stream 7 is removed from the polisher. This stream undergoes a vacuum distillation, which produces the GAP-0/SO_x salts and urea stream (stream 9) and the GAP-0 stream (stream 8). Stream 8 is recycled back to the polisher.

Question 1: Is the material in question a solid waste?

Streams 7, 8, and 9 are considered to be solid wastes since a reclamation step is required before the GAP-0 stream can be recycled back to the polisher.

Question 2: Is the material excluded from the definition of solid waste or hazardous waste?

The GAP-0 in streams 7 and 8 is excluded from the definition of solid waste by the Closed loop recycling exclusion because the reclamation step will be fully enclosed and the GAP-0 stream (stream 8) will be returned directly to the polisher after reclamation.

Stream 9 will not return to the polisher and will require disposal and, is, therefore considered to be a solid waste.

Question 3: Is the material a listed or characteristic hazardous waste?

Stream 9 (GAP-0/SO_x salts and ureas) is not a listed waste. This stream also does not exhibit the characteristics listed in Table 17 so is not considered a characteristic waste. This waste will be disposed of under RCRA Subpart D as industrial, non-hazardous waste in accordance with local regulations at the plant in question.

Table 17. Criteria to be considered characteristic waste under RCRA Subpart C.

Characteristic	Criteria
Ignitability	Liquid wastes with flashpoints below 60 °C
Corrosivity	Aqueous with $pH \leq 2$ or ≥ 12.5
Reactivity	Explode or cause violent reactions or react to release toxic gas or fumes when exposed to water or under normal handling conditions
Toxicity	Presence of chemical above TCLP regulatory levels

Stream 11

Stream 11 contains GAP-0 and some water that is condensed out of the gas exiting the polisher in the partial condenser.

Question 1: Is the material in question a solid waste?

Stream 11 is recycled directly back to the desorber and does not require reclamation. Therefore, it is not considered solid waste.

Stream 14

Stream 14 is the GAP-0 and DDBSA stream produced from the treatment of stream 12, which is condensed out of the exit gas from the polisher.

Question 1: Is the material in question a solid waste?

Stream 14 is not returned to the process and would require disposal. It is, therefore, considered to be a solid waste.

Question 2: Is the material excluded from the definition of solid or hazardous waste?

Stream 14 is not excluded and is, therefore, considered to be solid waste.

Question 3: Is the material a listed or characteristic waste?

GAP-0 and DDBSA are not on the F, K, P, or U lists. They are not considered listed wastes. The GAP-0 and DDBSA stream would not exhibit any of the criteria in Table 17. It is not a characteristic hazardous waste. This waste would be disposed of under RCRA Subpart D as industrial, non-hazardous waste in accordance with local regulations at the plant in question.

Stream 15

Stream 15 is expected to only contain water with some dissolved gases (see Table 7).

Question 1: Is the material in question a solid waste?

There is the option to return stream 15 to the process (to the water wash) without further treatment. In this case, it would not be considered a solid waste. It is assumed for the purpose of this review that this water would be recycled back to the process.

Table 18. Summary of RCRA classifications.

Stream Number	Materials	Classification and other relevant RCRA Information
Absorber		
4	GAP-0 and water	Not solid waste under Closed loop recycling exclusion
5	Water	Not solid waste under Closed loop recycling exclusion
6	GAP-0	Not solid waste under Closed loop recycling exclusion
Desorber		
7	GAP-0, GAP-0/SO_x salts, ureas	Not solid waste under Closed loop recycling exclusion
8	GAP-0	Not solid waste under Closed loop recycling exclusion
9	GAP-0/SO_x salts, ureas	Industrial, non-hazardous solid waste to be disposed of under Subpart D
11	GAP-0	Not solid waste – recycled back to process without reclamation
14	GAP-0/DDBSA	Industrial, non-hazardous solid waste to be disposed of under Subpart D
15	H_2O, CO_2, N_2, O_2	Not solid waste – recycled back to process without reclamation

E. Engineering Analysis and Controls for the CO_2 Capture Process

The entire system requires some plant-wide engineering controls. Many of these are common in the chemical industry but might be new for a power plant facility. For example:

1) To protect groundwater, a double containment drain system is necessary. These keep rainwater separated from any chemical drainage system, not allowing them to mix. The containment system should be built with chemical resistant, high strength concrete.

2) A volatile vapor detection sampling and monitoring system is necessary to identify when leaks occur.

3) A pressure/relief, vapor condensation/recovery system should be considered for all vessels. This prevents undesired backflow from one vessel to another, and it is required to minimize leaks and meet VOC release standards.

4) The equipment and piping arrangement chosen for the system should be designed to minimize leaks. For example, a shell and tube heat exchanger is much better than a plate and frame heat exchanger for minimizing leaks given the large number of gaskets in a plate and frame heat exchanger, which are potential VOC emission points.

5) The gas streams, #2 and #3 in Figure 2, require a final gas polishing process such as an activated carbon absorption bed or thermal oxidizer. This removes any remaining VOCs, lowering potential emissions.

6) The thermal oxidizer equipment requires its own safety failure analysis. Equipment like detonation arrestors, back-flow valves, etc. is needed. Vendors of such equipment are well versed in the requirements and design of a specific unit, which is outside the scope of this task.

F. Handling and Storage for the CO_2 Capture Process

The following sections provide handling and storage recommendations for GAP-0, GAP-0 carbamate, DDBSA, and the ureas. As discussed in Section B, the toxicity of GAP-0/SO_x salts is assumed to be less than or equal to its components, GAP-0 and SO_x. Details of handling and storage of GAP-0/SO_x are not available but are assumed to be less rigorous than those needed for its components. The safety and handling requirements are also not available for the ureas. For the ureas, the handling requirements were assumed to be similar to those for dibutylurea, which are summarized in this section.

a) GAP-0 (CAS # 2469-55-8)[18]

GAP-0 is classified as a hazardous chemical by the OSHA standard and is considered a combustible and corrosive liquid. It is regulated under both DOT and IATA as a corrosive liquid. Its NFPA Classification is a 3 for health hazard, a 2 for flammability, and a 0 for reactivity.

1) Storage and Handling Recommendations

Inhalation of vapor or mist should be avoided during handling. This material should also be kept away from sources of ignition and the build-up of electrostatic charge should be avoided. It should be kept away from oxidizing materials.

2) Accidental Release Measures

In the event of an accidental release, personnel should be evacuated to safe areas. Personal protective equipment should be used, and personnel should avoid breathing vapors, mist or gas. The product should not be allowed to enter drains and should be soaked up with inert absorbent material for disposal.

3) Health Effects and Exposure limits

   This material is extremely destructive to the tissue of the mucous membranes and the upper respiratory tract and may be harmful if inhaled. It also causes skin and eye burns. It may be harmful and cause burns if ingested. No workplace exposure limits were available for this chemical.

4) Respiratory Protection Recommendation

   If the risk assessment shows that air-purifying respirators are necessary and engineering controls are also in place, use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges. If the respirator is the only means of protection, use a full-face supplied air respirator tested and approved of under NIOSH (US) or CEN (EU).

5) Hand and Eye Protection Recommendation

   This material should be handled with gloves that are compatible with aminosilicone materials and safety glasses should be worn.

6) Skin and Body Protection Recommendation

   At a minimum, gloves should be worn. The need for additional protective clothing should be evaluated based on the concentration and amount of chemical used.

b) <u>GAP-0 carbamate</u>

As discussed in Section B of this report, the toxicity of GAP-0 carbamate is anticipated to be less than that of GAP-0. The storage and handling procedures for GAP-0 carbamate are assumed to be similar to those required for GAP-0. However, it should be noted that, if dry GAP-0 carbamate powder needs to be handled without adequate ventilation, respiratory protection (e.g. dust mask or options discussed in Section F (a)(4) for GAP-0) is recommended due to the risk of inhaling a corrosive, fine powder.[27]

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[27] Based on experience working with GAP-0 carbamate powder at GE Global Research

c) DDBSA (CAS# 27176-87-0)[19,28]

DDBSA is classified as hazardous by the OSHA Standard based on corrosivity. It is regulated under both DOT and IATA as a corrosive material. Its NFPA Classification is a 3 for health hazard, 0 for flammability, and 0 for reactivity.

1) Storage and Handling Recommendations

   This material should be stored in a cool, dry place and the container kept closed when not in use. It should be kept away from oxidizing materials, metals, and alkaline substances. It should be used in a well-ventilated area.

2) Accidental Release Measures

   In the case of a spill, personnel should be evacuated to a safe area and trained spill control officials should be notified. The area should be ventilated, and the material absorbed with inert materials (e.g. vermiculite, sand or earth). For environmental protection, precautions should be taken to avoid any runoff into drains, storm sewers, or ditches.

3) Health Effects and Exposure Limits

   DDBSA causes severe burns to skin and eyes and may cause irreversible eye injury. It is harmful to the digestive tract and respiratory system. The material should be used in a well-ventilated area. No OSHA PEL has been established for this chemical.

4) Respiratory Protection Recommendation

   No specific recommendations for exposure limits for respirator usage were available. When risk assessment indicates it is necessary, respirators should meet OSHA 29 CFR 1910.134 and ANSI Z88.2 requirements.

5) Hand and Eye Protection Recommendations

   Appropriate gloves and safety glasses/ splash goggles should be worn during use.

6) Skin and Body Protection Recommendations

   At a minimum, gloves should be worn. The need for additional protective clothing should be evaluated based on the concentration and amount of chemical used.

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[28] http://datasheets.scbt.com/sc-226619.pdf

d) Amine terminated, urea-containing silicone, dibutylurea as surrogate (CAS# 1792-17-2)[29]

Dibutylurea is not classified as a hazardous substance by the OSHA standard. It is not classified as dangerous goods according to DOT or IATA. Its NFPA rating is 0 for health hazard, 0 for flammability, and 0 for reactivity.

1) Storage and Handling Recommendations

   The material should be stored in a dry and well-ventilated location. The formation of dust and aerosols should be avoided and appropriate exhaust ventilation provided in areas where dust is formed.

2) Accidental Release Measures

   In the case of an accidental release, do not let the product enter drains and make sure to arrange disposal without creating dust. The material should be kept in closed containers prior to disposal.

3) Health Effects and Exposure Limits

   No health effects are provided for this material. No OSHA PEL or other exposure limit is available.

4) Respiratory Protection Recommendations

   Respiratory protection is not required for this material. If protection against nuisance levels of dust are needed, use type N95 (US) or type P1 (EN 143) dust masks.

5) Hand and Eye Protection Recommendations

   The material should be handled with gloves. Eye protection equipment should be used and approved under appropriate government standards such as NIOSH (US) or EN 166 (EU).

6) Skin and Body Protection Recommendations

   At a minimum, gloves should be worn. The necessity for and type of protective equipment should be based on the concentration and amount of the substance in the specific workplace.

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[29] Sigma Aldrich MSDS. http://www.sigmaaldrich.com/MSDS/MSDS/PleaseWaitMSDSPage.do?language=&country=US&brand=ALDRICH&productNumber=S546577&PageToGoToURL=http%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fsearch%3Fterm%3D1792-17-2%26N%3D0%26focus%3Dproduct%26lang%3Den%26region%3DUS