SLIPSTREAM PILOT-SCALE DEMONSTRATION OF A NOVEL AMINE-BASED POST-COMBUSTION TECHNOLOGY FOR CARBON DIOXIDE CAPTURE FROM COAL-FIRED POWER PLANT FLUE GAS

Topical Report:

Preliminary Environmental, Health and Safety Risk Assessment

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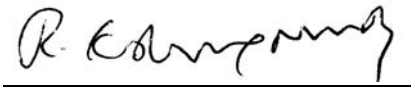
Signature of Submitting Official: 

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Executive Summary

This topical report presents the preliminary environmental, health and safety (EH&S) risk assessment for the project DE-FE0007453 involving the design, engineering, construction, operation and testing of a 1 MWe Linde-BASF post-combustion capture pilot plant incorporating BASF's OASE® blue aqueous amine-based solvent. Currently, the project is at the end of the pilot plant design and detailed engineering phase and getting ready for the procurement and construction phase. An updated risk assessment will be performed upon completion of the 1 MWe slipstream pilot-scale test campaign to be conducted at the National Carbon Capture Center (NCCC) operated by Southern Company Services (SCS).

The preliminary risk assessment incorporates a number of systematic processes and requirements, as noted below:

1. All pilot and commercial scale processes built and operated by Linde require completion of a five stage process safety review (PSR) methodology guided by comprehensive check-lists covering all aspects of EH&S. This process also addresses the code and regulatory compliance requirements as well as the requirements and input from the technology owner/partner (BASF) and the site owner (SCS/NCCC). As per the requirement, the first three stages (project initiation/definition, award/start, design) have been completed, and the fourth (construction) and fifth (plant operation) stage reviews will be incorporated at the appropriate timeframe as the project progresses.
2. As per DOE-NETL requirements, an environmental questionnaire (National Environmental Policy Act implementing procedures) has been completed for this project in conjunction with the host site organization (SCS/NCCC).
3. As standard procedures for all engineering and construction projects, a formal Hazop study has been completed and the actions from this are either incorporated into updating the pilot plant design and procedures, or slated for implementation during the construction, commissioning and operations/testing periods.

This topical report summarizes the key plant EH&S concepts and approach. Key EH&S risk factors assessed and addressed as part of the overall approach are provided in tabular form including the risk mitigation factors.

Project and Pilot Plant Set-up

The Linde-BASF post-combustion capture (PCC) pilot plant will be located in the post combustion test facilities of the National Carbon Capture Center (NCCC), which is in the confines of Alabama Power's E.C. Gaston Steam Plant. The plant is located in a rural area near Wilsonville, AL, adjacent to the Coosa River. The E.C. Gaston Power Plant generates approximately 1,880 MW net electrical power from five pulverized bituminous coal-fired units.

As Figure 1 illustrates, the NCCC has been configured to test multiple technologies utilizing a single slipstream (equivalent of 3 MW) from Gaston Power Unit 5, a 880 MW supercritical unit. The flue gas streams from all test units within NCCC are being returned back to the Gaston Plant, upstream of the flue gas desulfurization (FGD) unit without any external air/gas emissions except through the existing power plant stack. The Linde-BASF pilot plant is designed to utilize a slipstream in the equivalent of 1.0 to 1.5 MW.

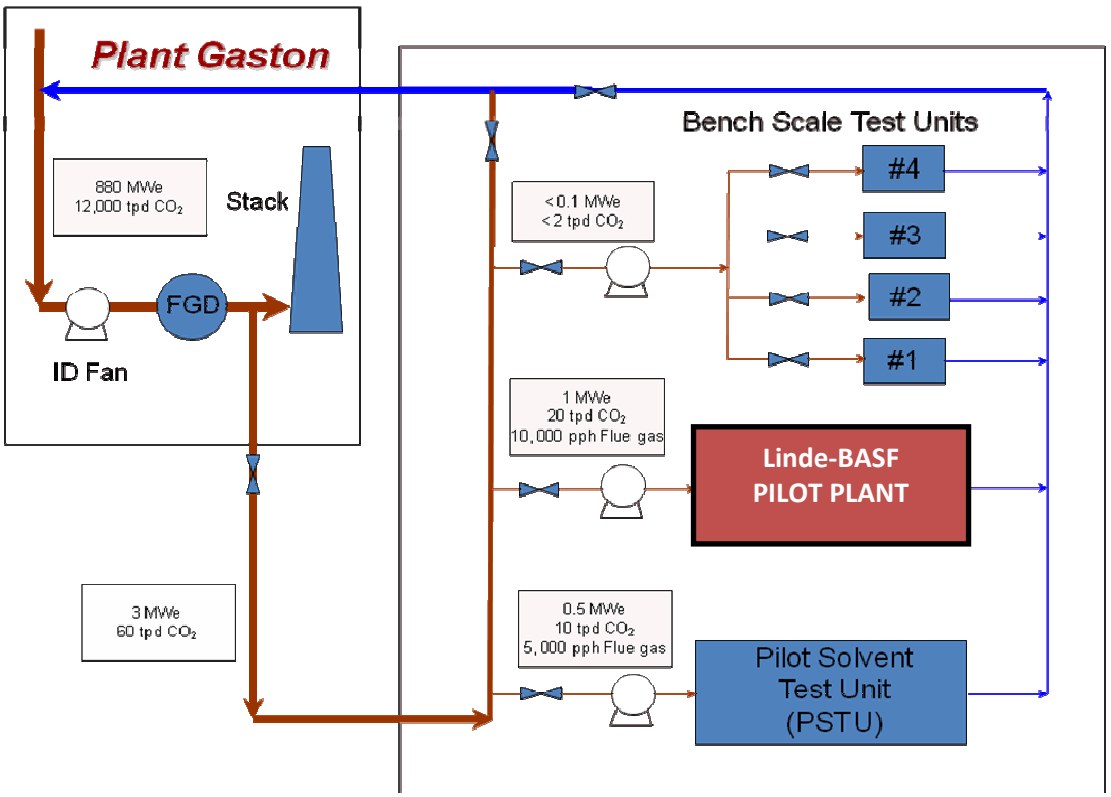

Figure 1. Integration of NCCC Post-Combustion Carbon Capture Center (PC4) with Gaston Power Plant Unit 5

As Figure 2 shows, the Linde-BASF pilot plant is fully-integrated with the NCCC facility. Its allocated plot area is approximately 50 ft by 60 ft. The majority of the pilot plant units have been designed for installation within six modular structures, as shown in Figure 3. The absorption and stripping columns are free-standing units with appropriate access ladders and platforms with interconnecting piping, instrumentation, and controls to the equipment in the modules and the host site tie-in points.

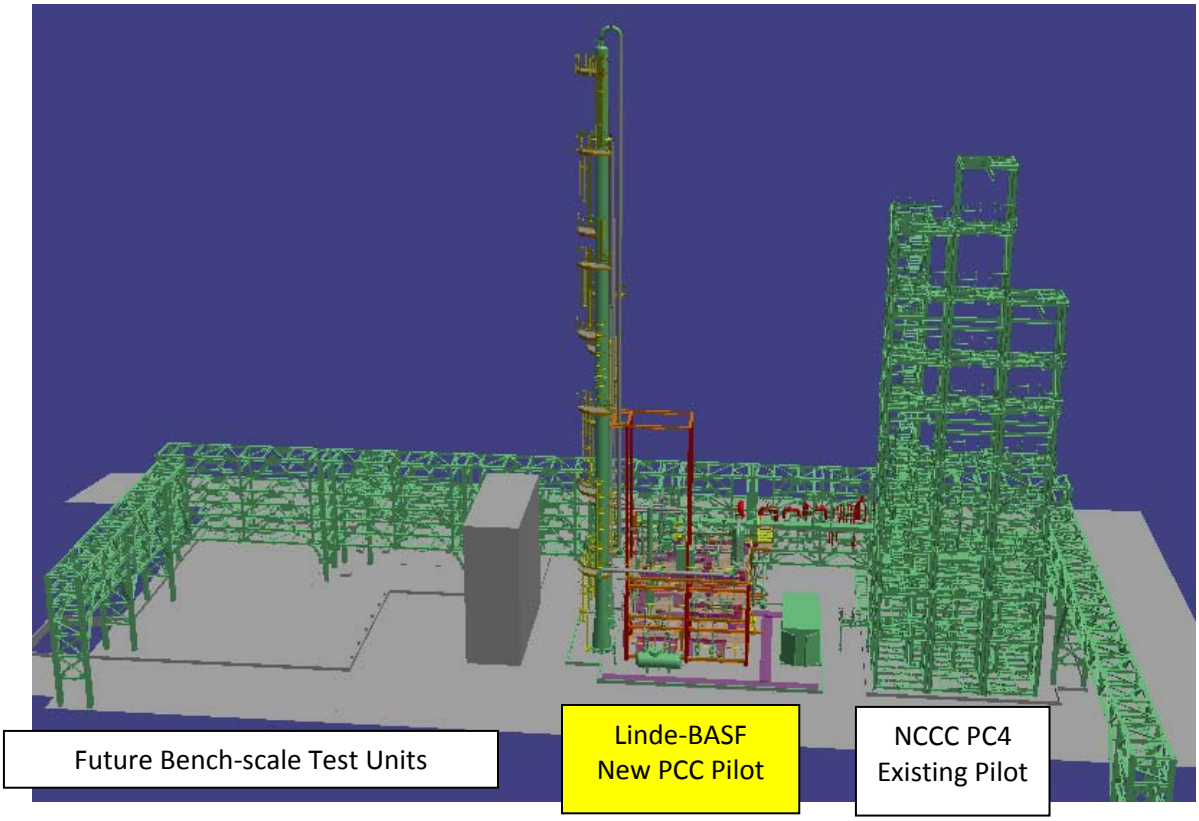

Figure 2. 3D Model of Linde-BASF Pilot Plant Installed at NCCC in Wilsonville, Al

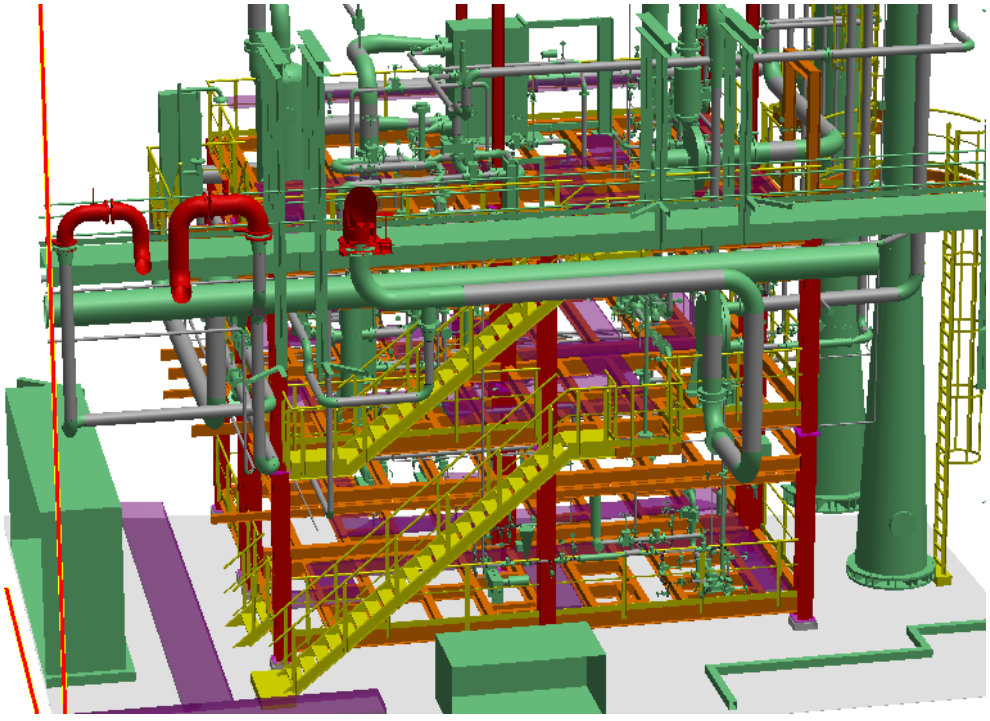

Figure 3 3D Model of Linde-BASF Modular Pilot Plant Design

Some of the safety design features can be noticed in the above figures, including an eye-wash and emergency shower shown in the left top corner, as well as stairs between platforms with handrails (in yellow) designed for safe access and according to governing codes and standards. The red pipes visible on the left top side of Figure 3 are the tie-in connections between the Linde-BASF pilot plant and NCCC facilities.

A simplified schematic shown in Figure 4 illustrates that the Linde-BASF pilot plant is fully-integrated with NCCC infrastructure, without any separate gas, liquid, or solid waste streams emitted to the environment.

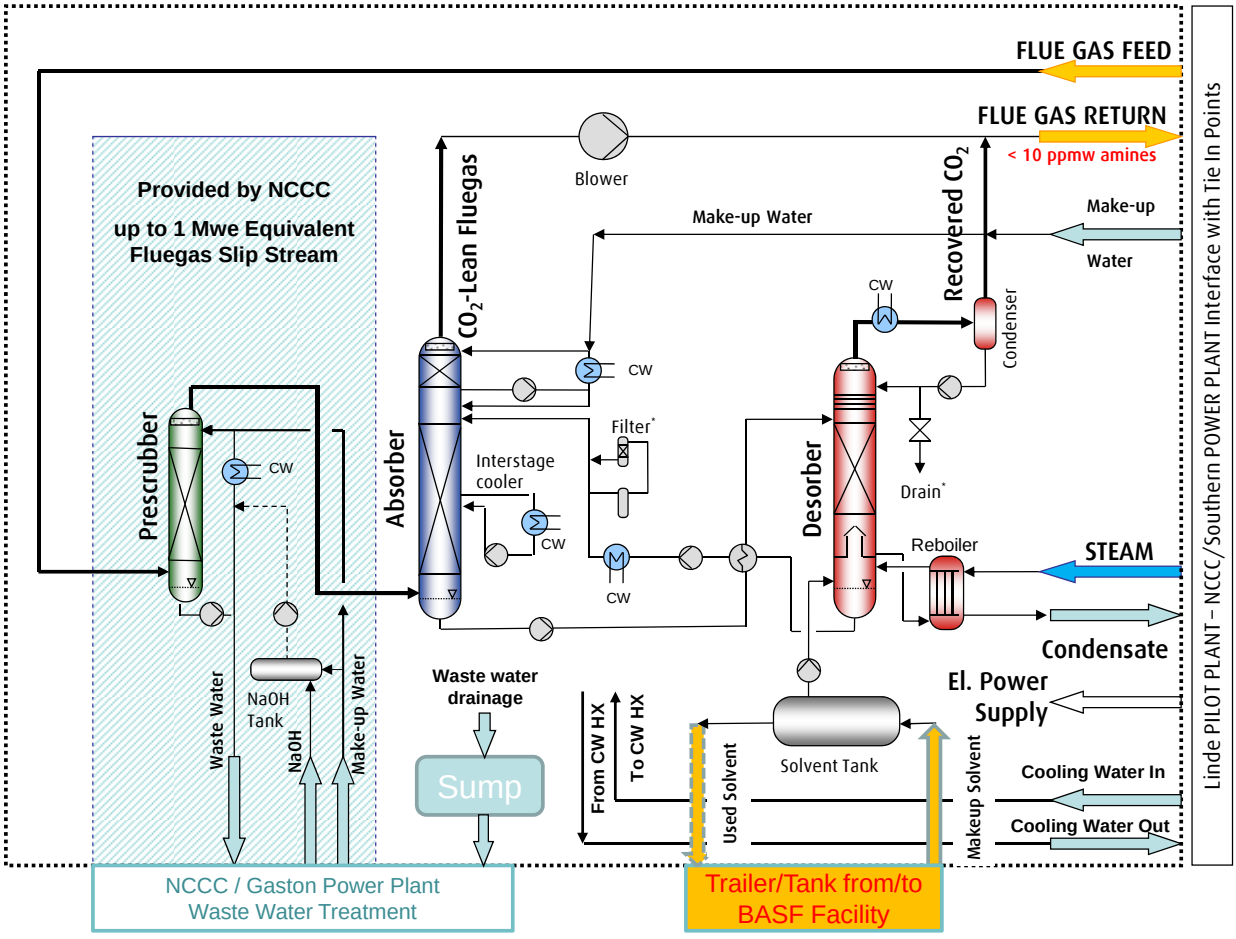

Figure 4. Integration of Linde-BASF Feed and Exhaust Streams with NCCC Utilities

The carbon dioxide (CO_2) lean flue gas stream downstream of the absorber is mixed with the recovered CO_2 stream downstream of the stripper before being returned to the Gaston Plant, upstream from the FGD unit. The emission control system (demisters and wash section) of the pilot plant is designed to completely avoid any amine component carry-over. During testing to establish limiting operations, the estimated maximum concentration of amine components in the returned flue gas stream from the pilot plant is below 10 ppmw. However, since the slipstream for the pilot tests is approximately 1/1000th of the flue gas from the Gaston power plant, the theoretical maximum concentration of the amines emitted with the flue gas through the stack of the power plant would be < 10 ppbw (parts per billion).

BASF's proprietary solvent will be supplied from a BASF facility in storage containers (currently anticipated to be in drums) to the NCCC site and subsequently trans-filled into a pair of dedicated solvent tanks. With a strictly-defined operating procedure, the solvent from these tanks are transferred to an intermediate solution storage tank and from there into the pilot units (absorber/stripper) during pilot plant start-up. Upon completion of all tests, the solvent from the pilot units will be discharged to the solvent storage tanks before being transferred to the storage containers. The storage containers will be transported out of the site for final analyses and disposal, as per BASF specifications for solvent handling.

The area sump is designated and intended to collect area wash down water, any condensate drainage from the pilot plant, rain water, as well as any accidental spills that might occur while taking analysis samples or performing maintenance. The amount of liquid in the waste tank is controlled with level control valves and dedicated pumps that automatically discharge the liquid into the NCCC's neutralization tank where analyses are performed, as per NCCC specifications and the wash liquid is then neutralized prior to transfer for appropriate handling. If neutralized waste water satisfies pre-determined criteria, it is discharged into a local run-off pond. Otherwise, it is transferred to tanker trucks, totes, or drums for further transport outside the site to a waste handling facility for disposal.

Process Safety (including environmental and health) Risk Assessment Methodology

As per Linde requirements for engineering and operations of pilot and commercial plants, a process safety review (PSR) methodology incorporating comprehensive check-lists has been adopted for this project EH&S risk assessment. In addition, as per DOE-NETL requirements, a National Environmental Policy Act (NEPA) environmental questionnaire has been completed for this project in conjunction with the host site organization (SCS/NCCC). The NEPA questionnaire has been signed off by the host site and reviewed and approved by DOE-NETL. Further, as standard procedures for all engineering and construction projects, a formal Hazop study has been completed and the actions from this either incorporated into updating the pilot plant design and procedures, or slated for implementation during the construction, commissioning, and operations/testing periods. Specific review of operations safety requirements has also been performed in order to incorporate the identified gaps into the engineering design.

The Linde PSR methodology is performed in five distinct stages of the project to identify issues and risks at the earliest possible time frame. The five PSR stages are: (1) project initiation and definition, (2) project award/start, (3) design, (4) construction, and (5) plant operations. Each PSR is performed by a team consisting of members with appropriate capabilities and subject matter expertise, and uses a systematic and comprehensive check-list to facilitate the review process. The check-lists are set up along key review topics, including: (1) safety management, (2) project definition, (3) legislation, (4) technology/design, (5) product delivery systems, (6) climate, (7) environment, (8) effluents, (9) hazard management, (10) site/plant layout, (11) utilities, (12) plant controls and shutdowns, (13) equipment, (14) site/plant construction, (15) construction, (16) property conservation, (17) commissioning, (18) materials stored on-site, and (19) operations/maintenance.

PSR stages 1 through 3 have already been completed for this project and pilot plant. PSR stage 4 will be performed in 2013 during the pilot plant construction timeframe and PSR 5 will be performed just prior to the pilot plant testing in 2014 following the commissioning and start-up of operations.

Following the completion of the basic design and engineering of the pilot plant, a Hazop study was performed in May 2012 for the pilot plant engineering, construction, operations and testing. The three-day Hazop study was led by a certified Hazop leader (Process Safety and Regulatory Manager for Linde Gases, North America) and was represented by project team members across multiple organizations with a broad array of required subject matter expertise. The purpose of the Hazop is to identify potential design errors and the hazards that result from these errors:

- To identify all hazards that result from the operation of the plant;
- To find adequate measures to mitigate these hazards if necessary; and
- To ensure the operability of the plant on a high-availability level.

This study followed the well-established guidelines for engineering and construction projects to identify hazards, risks, and mitigation factors in the design as was available at the time and how it fulfilled the planned pilot plant engineering, construction, operations, testing and maintenance needs. A summary of risk factors and mitigating actions was prepared and the design-related aspects were used to update the

pilot plant design and the corresponding process and instrumentation diagrams, the key document used for the Hazop study. The risk factors related to construction and operations have been assigned to the responsible team members for monitoring during the appropriate phase of the project.

Summary of EH&S Risks and Mitigating Approaches

The following tables summarize the major EH&S issues arising from operation of the BASF-Linde pilot plant, along with a list of related mitigation approaches and actions to satisfy all existing EH&S regulations and guidelines. Table 1 focuses on potential risks related to process effluent streams, while Table 2 addresses risks associated with pilot plant design, operation, and maintenance.

Table 1. EH&S Risks and Mitigation Approaches (Pilot plant exit streams)

Risk	Mitigation Approach	Comments (max. concentrations, exposures etc)
• Carry over of amines from Absorber and Stripper	• High efficiency water wash section • High efficiency demister • Effluent streams returned to the FGD unit of the power plant and diluted with the rest of flue gas	• None to negligible carry over of amines at normal operating conditions • Estimated max. concentration of amines in the absorber/stripper effluent < 10 ppmw • Max. concentration of amines in combined return stream to FGD < 2 ppmw • Max. concentration af amines from power plant stack to atmosphere < 3 ppbw (parts per billion) • Above max. emissions at off-design conditions are significantly lower than emissions from commercial, state-of-the-art solvent technologies
• Used solvent	• Handled by BASF for appropriate disposal off-site	• Up to 3,000 gallons (expected once a year for 2 years) of used solvent • BASF uses advanced techniques for decomposition of amines to CO_2, H_2O and N_2 species from their commercial solvent based plants around the world
• Accumulated heat stable salts (solids)	• Periodic replacement of mechanical and activated carbon filters installed within the solvent circulation loop • Disposal of used filters provided by filter suppliers	• Capacity of filters designed for at least six-month testing periods • Maximum two filter disposals anticipated within entire pilot testing period • Degradation products to be analyzed and solid waste appropriately disposed
• Waste water containing NaOH and $NaSO_3$ from pre-scrubber	• Processed by Southern Company in coordination with Gaston Power plant	• Perform neutralization of waste water if/when needed before final disposal • Alabama Power takes ownership of any waste generated at NCCC and will coordinate the off-site disposal, which may be characterized as “special waste” or “hazardous waste”
• Waste water from Linde-BASF pilot plant	• Curbed enclosed concrete pad (sealed containment design) with drain system connected with the sump	• Examples of waste water include wash down water, any condensate drainage from the pilot plant, rain water, as well as minor spills • Sump pumps will discharge waste water to either the Outside Boundary Limit (OSBL) “Neutralization Tank,” or to an OSBL “Runoff Pond” depending on the

		contamination of the recovered waste water.
• Residual flows of waste liquids and spent solvent containing unknown degradation products to be analyzed (potential hazardous substances)	• Collected by the solution storage tank and/or by the sump and subsequently transferred for further treatment and/or final disposal	• Examples include: significant quantities of 3wt% aqueous solution of potash (up to 2,700 gallons) discharged into sump during commissioning and further transferred to and handled by Southern Company, as well as complete drainage of used aqueous amine solution (up to 3,000 gallons) after completion of all tests while utilizing one dedicated solvent solution tank and two solution storage tanks before being handled by BASF for analysis and final decomposition, as commented above.

Table 2. EH&S Risks and Mitigation Approaches (Design, operations and maintenance)

Risk	**Mitigation Approach**
• Plant operations safety	• Applied Linde's comprehensive "Safety by Design" guidelines • Safety and operator training
• Safety issues arising from improper design and operations/maintenance requirements not identified at design	• Comprehensive Hazard and Operability study (HAZOP) • Comprehensive Process Safety Reviews (PSR)
• Process operations safety	• Safety instrumented systems • Flow restriction and safety interlocks • Automatic safe shutdown capability incorporated in pilot plant design • Emergency power supply
• Chemical exposure	• Multiple eye wash and emergency showers • Safe locations of vents and blow downs • Proper sizing of relief valve and similar devices • Catch pots for capturing any leaks during maintenance
• Solvent handling	• Rigorous operating procedures including mandatory usage of Personal Protection Equipment (PPE)
• Solvent storage (regulatory requirements)	• OSHA and EPA regulated chemicals with threshold storage volume for process safety management checked. Confirmed solvent is not part of the classified chemicals list with threshold volume.

Solvent properties and Toxicological effects

OASE® blue is BASF's advanced amine-based aqueous solvent technology solution designed and developed for energy-efficient CO_2 recovery from low-pressure flue gas streams. Manufacture of OASE® blue is in compliance with industry standards and EH&S regulations. While the family of BASF solvents are protected by several issued patents, the specifics of their chemical compositions and characteristics for PCC application constitute commercial trade secrets and are therefore not publishable. Consequently, a generalized summary of potential toxicological effects is shown in Table 3 based on published data for similar classes of commercially used amine solvents, such as MEA, MDEA etc.

It should be also noticed that OASE® blue is delivered as premixed aqueous solution of amines and used as such a mixture, and hence, the actual toxicological effects are significantly smaller than for corresponding pure substances.

Table 3. Solvent EH&S Risks

Property/Effect	**Solvent Data/Guidelines**
State of matter/Color/Odor	Liquid or solid (based on temperature), colorless, amine-like
Emergency overview/Precautions	- May cause eye damage - Severely irritating to eyes, skin, and respiratory tract - May be harmful if swallowed - May be harmful if absorbed through skin. - May cause sensitization by inhalation. - May cause sensitization by skin contact - Avoid contact with eyes, skin, and clothing - Avoid inhalation of mists/vapors
Potential health effects	**Primary routes of exposure:** Routes of entry for solids and liquids include eye and skin contact, ingestion and inhalation. Routes of entry for gases include inhalation and eye contact. Skin contact may be a route of entry for liquefied gases.
Degradation/Environmental fate	No data available concerning biodegradation
Flammability	Aqueous OASE® blue solution in storage tanks can be exposed to atmosphere (stable under air blanket; inert atmosphere not necessary)
Accidental release measures	**Personal precautions:** Avoid inhalation. Avoid contact with the skin, eyes, and clothing. **Environmental precautions:** Do not discharge into drains/surface waters/groundwater. **Cleanup:** Clean contaminated floors and objects thoroughly with water and detergents, observing environmental regulations. Collect waste in suitable containers, which can be labeled and sealed. Incinerate or take to a special waste disposal site in accordance with local authority regulations. For small amounts: Pick up with absorbent material (e.g. sand, sawdust, general-purpose binder). For large amounts: Pump off product.
Handling and storage	**Handling:** Ensure thorough ventilation of stores and work areas. **Storage:** Keep container tightly closed and in a cool place. Keep container dry. **Storage incompatibility:** Segregate from acids.

Temperature tolerance	25 to 80°C. It is not necessary to protect the packed product against exceeding the temperature indicated.
Exposure control and personal protection	**Personal protective equipment** **Respiratory protection:** Wear a NIOSH-certified (or equivalent) respirator as necessary. Observe OSHA regulations for respirator use (29 CFR 1910.134). **Hand protection:** Wear chemical-resistant protective gloves. Manufacturer's directions for use should be observed because of great diversity of types. **Eye protection:** Tightly-fitting safety goggles (chemical goggles). Wear face shield if splashing hazard exists.
General safety and hygiene measures	Handle in accordance with good industrial hygiene and safety practice. Females of childbearing age should not come into contact with the product. Avoid contact with skin. Avoid contact with eyes. Do not breathe spray. Eye wash fountains and safety showers must be easily accessible.
Stability and Reactivity	**Substances to avoid:** Acids **Hazardous reactions:** Evolution of heat under influence of acids. **Decomposition products:** Possible thermal decomposition products: carbon monoxide, carbon dioxide, ammonia, volatile organic compounds, nitrogen oxides, carbon oxides **Thermal decomposition:** No decomposition if stored and handled as prescribed/indicated. **Corrosion to metals:** Corrosive effects to metal are not anticipated. **Oxidizing properties:** Not fire-propagating
Toxicological Information	**Acute toxicity:** The inhalation of a highly-enriched/saturated vapor-air-mixture represents an unlikely acute hazard. Of low toxicity after single ingestion. Virtually nontoxic after a single skin contact. **Irritation / corrosion:** Irritating to skin. May cause severe damage to the eyes and skin. Corrosive to skin, eyes and respiratory system. **Sensitization:** May cause sensitization of the respiratory tract. Sensitization after skin contact possible. **Repeated dose toxicity:** After repeated exposure, the prominent effect is limited to local irritation. **Genetic toxicity**: In the majority of studies performed with microorganisms and in mammalian cell culture with similar class of substances, a mutagenic effect was not found. A mutagenic effect was also not observed in *in-vivo* tests. **Carcinogenicity:** No data available concerning carcinogenic effects. Under certain conditions trace compounds can form in the aqueous solution that are carcinogenic in animal studies. **Reproductive toxicity:** No reliable data are available concerning reproduction toxicity.
Aspiration Hazard	No aspiration hazard expected.
Ecological Information	**Aquatic toxicity:** The product itself has not been tested. However, based on the effects of the components on environmental species, which are generally well above 100 mg/L, the lack of bioaccumulation potential, and the biodegradability, the product OASE® blue is not likely to be toxic to environmental biota. **Environmental mobility:** The substance will not evaporate into the atmosphere from the water surface. Adsorption to solid soil phase is not expected.
Other adverse effects	Do not discharge product into the environment without control
Disposal considerations	**Waste disposal of substance:** Incinerate in suitable incineration plant, observing local authority regulations. **Container disposal:** Contaminated packaging should be emptied as far as possible; then it can be passed on for recycling after being thoroughly cleaned.
Other information	**NFPA Hazard codes:** Health: 3; Fire: 1; Reactivity: 0; **HMIS III rating:** Health: 3; Flammability: 1; Physical hazard: 0

Conclusion

The current project involving the design, engineering, construction, operation and testing of a 1 MWe post-combustion CO_2 capture pilot plant is nearing the end of the design and engineering phase (Budget Period 1). A preliminary but comprehensive EH&S (environmental, health and safety) risk assessment has been completed so that all possible risk mitigation factors can be applied during the early design and engineering phase for successful build and operations of the pilot plant. This topical report summarizes the key plant EH&S concepts and approach. Key EH&S risks are identified and the mitigating factors for management of the risks are summarized. The construction, operations and testing that will follow will take into account the risks and mitigating factors highlighted in order to safely implement the project. At the end of the operations phase, an updated EH&S report will be prepared highlighting the implementation of the EH&S factors in the project, as well as any additional lessons learned during implementation at pilot scale. In addition, the final EH&S report will focus on the risk assessment on the installation and operation of the Linde-BASF PCC plant at a full-scale power plant This is expected to provide a strong basis for EH&S risk handling in further scale-up and commercialization of the post-combustion capture technology.