



# QUALITY GUIDELINES FOR ENERGY SYSTEM STUDIES

## CO<sub>2</sub> Impurity Design Parameters

**Table 4: Global Economic Assumptions**

Parameter	Value
<b>TAXES</b>	
Income Tax Rate	38% (Effective 34% Federal, 6% State)
Capital Depreciation	20 years, 150% declining balance
Investment Tax Credit	0%
Tax Holiday	0 years
<b>CONTRACTING AND FINANCING TERMS</b>	
Contracting Strategy	Engineering Procurement Construction (EPC) assumes project risks for real assets of the owner
Type of Debt Financing	Non-Recourse (collateralized)
Repayment Term of Debt	15 years
Grace Period on Debt Repayment	0 years
Debt Reserve Fund	No
Capital Expenditure Period	ANALYSIS PERIOD
Operational Period	ANALYSIS PERIOD
Economic Analysis Period (IRROE)	ANALYSIS PERIOD

  

**Exhibit 2-3 Design Coal**

Rank	Bituminous	
Seam	Illinois No. 6 (Herrin)	
Source	Old Ben Mine	
Proximate Analysis (weight %) (Note A)		
	As Received	Dry
Moisture	11.12	0.00
Ash	9.70	10.91
Volatile Matter	34.99	39.37
Fixed Carbon	44.19	49.72
Total	100.00	100.00
Sulfur	2.51	2.82
HHV, kJ/kg	27,113	30,506
HHV, Btu/lb	11,666	13,126
		29,544
		12,712

  

January 2012

DOE/NETL-341/011212

## Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference therein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed therein do not necessarily state or reflect those of the United States Government or any agency thereof.

## 1 Overview

This section of the Quality Guidelines provides recommended impurity limits for CO<sub>2</sub> stream components for use in conceptual studies of CO<sub>2</sub> carbon capture, utilization, and storage systems. These limits were developed from information consolidated from numerous studies and are presented by component and application. Impurity levels are provided for carbon steel pipelines, sequestration through enhanced oil recovery (EOR), saline reservoir sequestration, and co-sequestration of CO<sub>2</sub> and H<sub>2</sub>S in saline reservoirs. This guideline is intended only for conceptual studies under a generic scenario and should not be used for actual projects, which are likely to have requirements that differ from the generic scenario assumed herein.

Exhibit 2-1 gives the recommended limits for CO<sub>2</sub> stream impurities required by the transportation pipeline, by EOR applications, and by saline reservoir. Each of the three design cases presents a design point and a range independent of the other design cases. For most impurities, the range indicates the maximum and minimum values found in the literature review and does not necessarily represent recommended limits; however, some represent an unofficial industry standard or the lack of information. In most cases, the design value matches the most restrictive constraint. Specific details of the design and range information can be found in the subsections below the table broken out by the given impurity.

The first set of data is for the compressed CO<sub>2</sub> transmission pipeline. Because it is assumed that the CO<sub>2</sub> stream to be sequestered remains at a constant 2,200 psig, the pipeline values are assumed to be independent of distance for EOR or SAS. However it may be worthwhile in future efforts to characterize the effect of potential pressure losses on recommended ranges for certain components.

EOR values are based on multiple EOR recommended specifications and current EOR operations. Certain impurity limits will change depending on the oil quality and location. Also, certain health and safety hazards govern the design limitations. Refer to the notes for each contaminant listed in Section 2 for further detail.

SAS, like EOR, has multiple sources of information including the experience at American Electric Power's (AEP) Mountaineer plant-- the first large scale carbon capture utilization and sequestration (CCUS) project.

Venting CO<sub>2</sub>, whether due to an upset condition in the plant or due to start-up of the CCUS system, can have detrimental effects, especially if certain impurities are present. The farthest column in Exhibit 2-1 indicates if the component could contribute to a hazardous or unlawful situation depending on the quantity and the plant's emissions permit.

Attachment A is a list of 43 different CO<sub>2</sub> specifications found during the literature review. Pipeline design guides, pipe transportation specifications, and recommendations from multiple sources were used to evaluate and recommend limits based on the CO<sub>2</sub> source such as plant type, air quality control systems, fuel used, gas transmission length, and other variables. This guideline does not attempt to tailor itself to every potential source variable, rather it is based on the pipe and destination (whether a saline reservoir or oil reservoir) parameters necessary for CO<sub>2</sub> to be handled safely, efficiently, and cost effectively.

## 2 Gas Stream Composition

Exhibit 2-1 below lists the recommended maximum (or minimum when noted) CO<sub>2</sub> impurities for EOR or saline reservoir CCUS.

**Exhibit 2-1 CO<sub>2</sub> Stream Compositions Recommended Limits**

Component	Unit (Max unless Otherwise noted)	Carbon Steel Pipeline		Enhanced Oil Recovery		Saline Reservoir Sequestration		Saline Reservoir CO <sub>2</sub> & H <sub>2</sub> S Co-sequestration		Venting Concerns (See Section 3.0)
		Conceptual Design	Range in Literature	Conceptual Design	Range in Literature	Conceptual Design	Range in Literature	Conceptual Design	Range in Literature	
CO <sub>2</sub>	vol% (Min)	95	90-99.8	95	90-99.8	95	90-99.8	95	20 – 99.8	Yes-IDLH 40,000 ppmv
H <sub>2</sub> O	ppm <sub>wt</sub>	300	20 - 650	300	20 - 650	300	20 - 650	300	20 - 650	
N <sub>2</sub>	vol%	4	0.01 - 7	1	0.01 - 2	4	0.01 - 7	4	0.01 – 7	
O <sub>2</sub>	vol%	4	0.01 – 4	0.01	0.001 – 1.3	4	0.01 – 4	4	0.01 – 4	
Ar	vol%	4	0.01 – 4	1	0.01 – 1	4	0.01 – 4	4	0.01 – 4	
CH <sub>4</sub>	vol%	4	0.01 – 4	1	0.01 – 2	4	0.01 – 4	4	0.01 – 4	Yes-Asphyxiate, Explosive
H <sub>2</sub>	vol%	4	0.01 - 4	1	0.01 – 1	4	0.01 – 4	4	0.02 – 4	Yes-Asphyxiate, Explosive
CO	ppm <sub>v</sub>	35	10 - 5000	35	10 - 5000	35	10 - 5000	35	10 - 5000	Yes-IDLH 1,200 ppmv
H <sub>2</sub> S	vol%	0.01	0.002 – 1.3	0.01	0.002 – 1.3	0.01	0.002 – 1.3	75	10 - 77	Yes-IDLH 100 ppmv
SO <sub>2</sub>	ppm <sub>v</sub>	100	10 - 50000	100	10 - 50000	100	10 - 50000	100	10 - 50000	Yes-IDLH 100 ppmv
NO <sub>x</sub>	ppm <sub>v</sub>	100	20 - 2500	100	20 - 2500	100	20 - 2500	100	20 - 2500	Yes-IDLH NO-100 ppmv, NO <sub>2</sub> - 200 ppmv

Component	Unit (Max unless Otherwise noted)	Carbon Steel Pipeline		Enhanced Oil Recovery		Saline Reservoir Sequestration		Saline Reservoir CO <sub>2</sub> & H <sub>2</sub> S Co-sequestration		Venting Concerns (See Section 3.0)
		Conceptual Design	Range in Literature	Conceptual Design	Range in Literature	Conceptual Design	Range in Literature	Conceptual Design	Range in Literature	
NH <sub>3</sub>	ppm <sub>v</sub>	50	0 - 50	50	0 - 50	50	0 - 50	50	0 - 50	Yes-IDLH 300 ppmv
COS	ppm <sub>v</sub>	trace	trace	5	0 - 5	trace	trace	trace	trace	Lethal @ High Concentrations (>1,000 ppmv)
C <sub>2</sub> H <sub>6</sub>	vol%	1	0 - 1	1	0 - 1	1	0 - 1	1	0 - 1	Yes-Asphyxiant, Explosive
C <sub>3</sub> +	vol%	<1	0 - 1	<1	0 - 1	<1	0 - 1	<1	0 - 1	
Part.	ppm <sub>v</sub>	1	0 - 1	1	0 - 1	1	0 - 1	1	0 - 1	
HCl	ppm <sub>v</sub>	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	Yes-IDLH 50 ppmv
HF	ppm <sub>v</sub>	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	Yes-IDLH 30 ppmv
HCN	ppm <sub>v</sub>	trace	trace	trace	trace	trace	trace	trace	trace	Yes-IDLH 50 ppmv
Hg	ppm <sub>v</sub>	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	Yes-IDLH 2 mg/m <sup>3</sup> (organo)
Glycol	ppb <sub>v</sub>	46	0 - 174	46	0 - 174	46	0 - 174	46	0 - 174	
MEA	ppm <sub>v</sub>	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	MSDS Exp. Limits 3 ppmv, 6 mg/m <sup>3</sup>
Selexol	ppm <sub>v</sub>	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	N.I.*	

\*Not enough information is available to determine the maximum allowable amount

Several of the contaminant design limits were developed to address specific potential issues common to several contaminants. Examples of these include:

- N<sub>2</sub>, CH<sub>4</sub>, and H<sub>2</sub> all have a lower critical temperature that would require increased pipe strength to minimize ductile fracture potential (4).
- Non-condensables (N<sub>2</sub>, O<sub>2</sub>, Ar, CH<sub>4</sub>, H<sub>2</sub>) should be limited to reduce the amount of compression work; total non-condensables should be limited to less than 4 volume % (6)

- Some of the limits are based on the toxicity of the component (CO, H<sub>2</sub>S), which become a concern because of the potential for inadvertent releases. Toxic components with Immediately Dangerous to Life and Health (IDLH) concentration set by the National Institute for Occupational Safety and Health (NIOSH) (1) are listed in Exhibit 2-1. The IDLH concentration is not a short-term exposure limit to be encountered under normal working conditions but a concentration from which escape may be made in 30 minutes without injury or irreversible health effects and without deleterious/severe impediment to escape
- EOR has some specific limitations on O<sub>2</sub> concentration due to potential unwanted exothermic reactions with the hydrocarbons and limitations on H<sub>2</sub>S and SO<sub>2</sub> as they can be reproduced at the pumping well when the CO<sub>2</sub> front breaks through

Additional information on specific contaminants is provided below.

## 2.1 CO<sub>2</sub>

Once all impurities in the gas stream are identified and measured, the CO<sub>2</sub> component is arrived at by difference. The range was determined from multiple sources and can be affected by co-sequestration and levels of impurities. The highest concentration listed as a design parameter in the literature search that didn't include food-grade specifications is 99.8% (2). The IDLH for CO<sub>2</sub> is 40,000 ppm (1).

## 2.2 H<sub>2</sub>O

Moisture content requirements vary widely and depend mostly on the amount of sulfur and other impurities in the gas stream. The lower range is typically for higher sulfur content and the higher range is for lower sulfur content. Improper combination of sulfur and water can form sulfuric acid, which corrodes standard piping. Many moisture content specifications in the literature were derived from instrument air standards producing an unnecessarily stringent requirement. A compromise value of 300 ppm<sub>wt</sub> was chosen among the multiple sources ranging from 20 ppm (3) and 30 lbs/MMSCF (650 ppm<sub>wt</sub>) (4).

## 2.3 N<sub>2</sub>

The design point for nitrogen was taken from multiple sources with the range being set by pipeline specification (4, 2). N<sub>2</sub> is a non-condensable species requiring additional compression work and has a concentration limit of typically less than 4 volume% (5) for most applications; however, it should also be noted that N<sub>2</sub> compression concentration could be as high as 7 volume% when coming from an oxycombustion system, but it is not recommended (3). As mentioned earlier, the presence of N<sub>2</sub> can also require increased transport pipe strength due to ductility issues. For EOR applications, N<sub>2</sub> increases the miscibility pressure, making it more difficult to recover oil, which requires the design limit to be reduced to 1 volume% (6).

## 2.4 O<sub>2</sub>

Oxygen is another non-condensable species requiring additional compression work and a concentration limit of less than 4 volume% (5) for most applications. Oxygen in the presence of H<sub>2</sub>O can increase cathodic reactions causing thinning in the CO<sub>2</sub> pipeline (7). Because of this,

the typical standard found for pipeline designs is 0.01 volume%; however, operating pipelines tend to be even more conservative in the 0.001 to 0.004 volume% range (3). The maximum oxygen content was set by specification (4), which is also used by the AEP Mountaineer project (8).

Oxygen can also cause the injection points for EOR to overheat due to exothermic reactions with the hydrocarbons in the oil well (9). In addition, high oxygen content can cause aerobic bacteria to grow in the reservoir and at the injection points (10). For these reasons, the oxygen contaminant design target and allowable range is lower for EOR (9).

## 2.5 Ar

Argon is another non-condensable species requiring additional compression work and a typical limit of less than 4 volume% (5). For EOR applications, Ar also increases the miscibility pressure, reducing its EOR limit to 1 volume% (6).

## 2.6 CH<sub>4</sub>

Methane (CH<sub>4</sub>) is another non-condensable species with a lower critical temperature requiring increased pipe strength due to ductility issues (4) and typically limited to concentrations of less than 4 volume% (6) as outlined earlier. The design point is taken from multiple sources. The methane range was set by pipeline specification (2) (4). Methane also increases the miscibility pressure, making it more difficult to recover oil, so the EOR limit is reduced to 1 volume% (6).

## 2.7 H<sub>2</sub>

Hydrogen is another non-condensable species with a lower critical temperature requiring increased pipe strength due to ductility issues (4) and is typically limited to concentrations of less than 4 volume% (6) as outlined earlier. The design point was taken from multiple sources. The range was set by pipeline specification (11) (3). Hydrogen also increases the miscibility pressure, making it more difficult to recover oil, so the EOR limit is reduced to 1 volume% (6).

## 2.8 CO

Carbon monoxide (CO) is toxic and is thus controlled more stringently due to fears of unintended release into the atmosphere. The Total Weighted Average (TWA) concentration limit, set by NIOSH, is 35 ppm. The TWA is the maximum allowable average concentration of a chemical in air for a normal 8-hour working day and 40-hour work week (2). The range is set by the previous National Energy Technology Laboratory (NETL) Systems Analysis Guidelines as the minimum and the maximum was derived from Vattenfall (2). Other specifications not addressing health hazards allow for concentrations in the 1000 – 5000 ppm range (12), (3). This toxic gas can also be a concern for EOR as it can be released at the pumping well when the CO<sub>2</sub> front breaks through. The IDLH concentration for CO is 1,200 ppm (1).

## 2.9 H<sub>2</sub>S

Hydrogen sulfide (H<sub>2</sub>S) is toxic and concentrations for non-sequestration applications are set at 0.01 vol% based on the IDLH concentration from NIOSH (1). As discussed earlier, the IDLH concentration is not a short-term exposure limit to be encountered under normal working conditions but a concentration from which escape may be made in 30 minutes without injury or

irreversible health effects and without deleterious/severe impediment to escape. The targeted value of 0.01 vol% falls between the TWA recommendation from NIOSH of 10 ppm, which would be extremely costly to obtain and the 200 ppm recommendation in reference (5). The 200 ppm recommended limit was established based on health and safety effects by applying a safety factor of 5 on the known maximum exposure limit of 1000 ppm (5). The maximum range limit of 1.3 vol% is from Vattenfall, one of the few references to specify a limit (2). The H<sub>2</sub>S co-sequestration limit is based on NETL's Carbon Sequestration Systems Analysis Technical Note 10 (13) with the highest concentration, 77%, taken from the literature review (14). Because of its toxicity, H<sub>2</sub>S can be a concern for EOR as it can be emitted at the pumping well when the CO<sub>2</sub> front breaks through.

## 2.10 SO<sub>2</sub>

The literature review indicates that a design level of 100 ppm for SO<sub>2</sub> is easily achievable with current air quality control systems (4) (5). Additionally, SO<sub>2</sub> is being investigated for co-sequestration with CO<sub>2</sub>. Preliminary reports predict that 5 volume% (50,000 ppmv) could be captured and have a negligible effect on the critical point of CO<sub>2</sub> (15). The IDLH for SO<sub>2</sub> is 100 ppm (1), therefore, this potentially toxic concentration can be a concern for EOR as it can be reproduced at the pumping well when the CO<sub>2</sub> front breaks through. Vattenfall is one of a few entities to set this limit so their value is used as the design target for SO<sub>2</sub> and the range's maximum amount (2).

## 2.11 NO<sub>x</sub>

The literature review indicates that a design level of 100 ppm for oxides of nitrogen (NO<sub>x</sub>) is easily achievable with current air quality control systems (11) (5). The NO<sub>x</sub> range was determined from a reference study that included the minimum and maximum values (2). This toxic gas at higher concentrations can be a concern for EOR as it can be reproduced at the pumping well when the CO<sub>2</sub> front breaks through. The IDLH limits for NO and NO<sub>2</sub> are 100 ppm and 200 ppm, respectively (1).

## 2.12 NH<sub>3</sub>

The allowed concentration at the AEP Mountaineer CCUS project is 50 ppmv. It is one of the few physical plants outlining an NH<sub>3</sub> concentration. Because of this, it was set as the design point and maximum amount. The IDLH for NH<sub>3</sub> is 300 ppm (1).

## 2.13 COS

This toxin can be a concern for EOR as it can be reproduced at the pumping well when the CO<sub>2</sub> front breaks through. Vattenfall is one of few entities to set this limit so their value is used as the design target for COS and the range's maximum amount (2). Although an IDLH has not been established for COS, it is known to be lethal at high concentrations (>1000 ppm)

## 2.14 HCN

These design parameters are established by Vattenfall (2). Further research is needed as no other references were found other than ones that allowed trace amounts. This is a toxic compound with an IDLH of 50 ppm (1).

### 2.15 C<sub>2</sub>H<sub>6</sub>

These design parameters are based on Dixon Consulting EOR, Dakota Gasification specification, and Strawman Composite (12). Although this is not a toxic compound, it is potentially explosive and might cause asphyxiation at high concentrations.

### 2.16 C<sub>3</sub>+

These design parameters are based on Dixon Consulting EOR, Dakota Gasification specification, and Strawman Composite (12).

### 2.17 Particulate

These design parameters are based on Dixon Consulting EOR, Dakota Gasification specification, and Strawman Composite (12).

### 2.18 HCl

Not enough information is available to determine the maximum allowable amount. Future research is needed. HCL is a toxic compound with an IDLH of 50 ppm (1).

### 2.19 HF

Not enough information is available to determine the maximum allowable amount. Future research is needed. HF is a toxic compound with an IDLH of 30 ppm (1).

### 2.20 Hg

Not enough information is available to determine the maximum allowable amount. Future research is needed. Hg is a toxic compound with an IDLH of 10 mg/m<sup>3</sup> for compounds and 2 mg/m<sup>3</sup> for organo mercury.

### 2.21 Glycol

Pipe specification limits were used because excess glycol carry-over can cause damage to seals and other components (4). The range here is a value of zero to the maximum value of 174 ppbv, which is listed in the IEA presentation referenced as an “Industrial Working Group Prelim Spec 2005” (12).

### 2.22 MEA

Not enough information is available to determine the maximum allowable amount. Future research is needed. Although monoethanolamine (MEA) is not an acute toxin and does not have an IDLH, MSDS 8 hour time weighted average (TWA8) exposure limits are 3 ppm (TWA8 ACGIH) and 6 mg/m<sup>3</sup> (TWA8 OSHA).

### 2.23 Selexol

Not enough information is available to determine the maximum allowable amount. Future research is needed.

### 3 Venting

Venting of CO<sub>2</sub> will occur during start-up of the CCUS system as well as during upset conditions of the plant. Standards for venting are complex and extremely area specific. Exhibit 2-1 outlines specific contaminants that could cause a hazard to the populous such as the hydrocarbons and sulfur components. Toxic contaminant IDLH levels are presented in Exhibit 2-1. In addition, M.W. Kellogg considered other items (16):

- Local, national and, international regulations
- Contaminants in the stream -- particularly NH<sub>3</sub> (ammonia slip), H<sub>2</sub>S, other sulfur components, and hydrocarbons -- and how they affect the plant's emissions permit
- Duration and frequency of venting
- Dispersion scenarios including a range of atmospheric conditions and proximity to population centers

M.W Kellogg also indicated that atmospheric dispersion is the largest safety concern. If the dispersion does not occur rapidly enough, a dense CO<sub>2</sub> plume could drop to grade level and might cause asphyxiation. In that event, the recommendation is to flare the gas by adding natural gas to disperse the dense mixture before igniting it.

### 4 CCUS Technology-Specific Contaminants

Some contaminants are specific to the CO<sub>2</sub> capture technology employed. Below is a list of specific concerns and major contaminants associated with pre-combustion, post-combustion, and oxycombustion technologies.

#### 4.1 Pre-Combustion

For the purposes of this guideline, pre-combustion capture from an integrated gasification combined cycle (IGCC) unit is assumed. Pre-combustion produces a fairly clean CO<sub>2</sub> stream. Organic impurities can still be present as complete combustion that may remove them does not take place prior to CO<sub>2</sub> separation. These include CH<sub>4</sub>, HCN, COS, and other sulfur compounds. These compounds can cause corrosion and formation of hydrates during CCUS. Some of these impurities are also toxic to humans (2).

Depending on how the physical process works, the Selexol or other acid gas removal solvents might be found in the gas stream; however, it is unknown what amount of Selexol will cause damage to the CCUS system or the reservoir itself (2).

#### 4.2 Post-Combustion

For the purpose of this guideline, a post-combustion MEA absorption system is assumed. CO<sub>2</sub> from a post-combustion process generally contains fewer numbers of different impurities than the other two technologies as some may be consumed during combustion, as mentioned above. Still, the obvious NO<sub>x</sub>, SO<sub>x</sub>, and particulate can be a problem if the system does not have a properly functioning FGD, SCR, and/or baghouse (17).

In addition, oxygen in the flue gas can lead to induced oxidative degradations of the MEA that can end up in the CO<sub>2</sub> product and cause corrosion. (18).

### 4.3 Oxycombustion

The CO<sub>2</sub> stream from an oxycombustion process contains the excess oxygen from the boiler. If no steps are taken to reduce O<sub>2</sub> content, it can exceed 3 vol%. Boiler air in-leakage increases the impurity concentrations by introducing non-condensables such as Ar and N<sub>2</sub> along with the oxygen that can become part of the CO<sub>2</sub> product (19).

## 5 Research Needs

Several areas of research have been identified to better understand the impact of contaminants in supercritical CO<sub>2</sub> and their effect on transport and underground sequestration systems.

Although there is a significant amount of information available on pure supercritical CO<sub>2</sub>, there is very limited data on mixtures with contaminants and water. Information/data needs have been identified in the following areas:

- Supercritical CO<sub>2</sub> Equations of State (EOS) for supercritical mixtures including speed of sound, entropy, enthalpy, viscosity, dew point
- Simpler/faster algorithms or lookup tables for supercritical CO<sub>2</sub> mixtures
- CO<sub>2</sub> data at 10-15 KSI at 400-700 K
- CO<sub>2</sub> corrosion and compressibility data with contaminants and H<sub>2</sub>O
- A better understanding of the supercritical CO<sub>2</sub> gas phase dynamics and contaminant impacts on phase diagrams at critical points
- A better understanding of CO<sub>2</sub> dehydration in order to reduce corrosion and methane hydrate formation

Additional areas of research have also been identified to determine the impact of impurities on the underground sequestration of CO<sub>2</sub> including:

- Impact on plume dispersion
- The effect on the physical properties of storage formation, including: the density and wettability of the rock; and the potential for contaminants to react in the formation, which may impact the functioning of the sequestration system
- The effect on potential anaerobes at injection depths and their potential for creating plugging and contamination issues
- Data on supercritical CO<sub>2</sub>-mixture storage in coal seams, including the effect on coal mechanical properties, swelling, CO<sub>2</sub> sorption and CO<sub>2</sub> permeation
- Solubility data of SO<sub>2</sub> and H<sub>2</sub>S in brine for saline reservoir storage

Information needs have also been identified to better understand the impact of supercritical CO<sub>2</sub> contaminants on the transport pipeline. These include:

- Impact of pipeline pressure drops and temperature excursions

- Potential of additives to passivate corrosion
- Data on the response of elastomers (seals and gaskets) to supercritical CO<sub>2</sub> mixtures
- Design/methods to mitigate potential of boiling liquid vapor explosion (BLEVE) risks

Additional information also needs to be developed concerning the potential carryover of capture system components (ammonia, amines) into the supercritical CO<sub>2</sub> stream.

## Works Cited

1. **(NIOSH), National Institute for Occupational Safety and Health.** Chemical Listings and Documentation. *Center for Disease Control and Prevention*. [Online] September 30, 2011. <http://www.cdc.gov/niosh/idlh/intridl4.html>.
2. **Vattenfall Utveckling AB.** *CO<sub>2</sub> Quality Requirement for a System with CO<sub>2</sub> Capture, Transport and Storage*. Stockholm, Sweden : Vattenfall Utveckling AB.
3. **Oosterkamp, Antonie.** *CO<sub>2</sub> Pipeline Transmission - a broad state of the art -* . s.l. : R&D Foundation Polytec, 2008. Presentation.
4. *CO<sub>2</sub> Transportation and EOR.* **Havens, Ken.** Houston, TX : Kinder Morgan CO<sub>2</sub> Company, 2007. INGAA.
5. **DYNAMIS.** *DYNAMIS CO<sub>2</sub> quality recommendations*. s.l. : European Commission, 2007. Project no: 019672.
6. **Global Oil Tools LLC.** Global Oil Tools - Enhanced Oil Recovery. *Global Oil Tools*. [Online] [Cited: January 24, 2011.] <http://www.globaloiltoolsllc.com/html/2009103010474301.html>.
7. *Capturing CO<sub>2</sub> from Oxy-Fuel Combustion Flue Gas.* **Shah, Minish.** Cottbus, Germany : Praxair Inc., 2005. Oxy-Fuel Combustion Workshop.
8. **Spitznogle, Gary O.** CO<sub>2</sub> Impurity Specification at AEP Mountaineer. [Email]. January 18, 2011.
9. **White, Vince.** *Purification of Oxyfuel-Derived CO<sub>2</sub> for Sequestration or EOR*.
10. **Interstate Oil & Gas Compact Commission.** *A Policy, Legal, and Regulatory Evaluation of the Feasibility of National Pipeline Infrastructure for the Transport and Storage of Carbon Dioxide*. Oklahoma City : Interstate Oil & Gas Compact Commission, 2010.
11. **Det Norske Veritas.** *Recommended Practice DNV-RP-J202; Design and Operation of CO<sub>2</sub> Pipelines*. Hovik, Norway : Det Norske Veritas, 2010.

12. **Santos, Stanley.** Summary Notes on What is the Implication of CO<sub>2</sub> Quality in its Design and Engineering of Pipeline Transport. Stockholm, Sweden : IEA Greenhouse Gas R&D Programme, October 2008.
13. **(NETL), National Energy Technology Laboratory.** *Carbon Sequestration Systems Analysis Technical Note 10.* Pittsburgh : NETL, 2007.
14. *Design Consideration for Acid Gas Injection.* **Carroll, John.** Norman, Oklahoma : Gas Liquids Engineering Ltd., 1999. Laurance Reid Gas Conditioning Conference.
15. *Dissolution Potential of SO<sub>2</sub> CO-Injected with CO<sub>2</sub> in Geologic Sequestration.* **Crandell, LE.** 2010, Environmental Science and Technology, pp. 349-355.
16. **Weeks, David.** *Processing Considerations for Carbon Capture & Storage.* s.l. : M. W. Kellogg. Kellogg Paper No. 2059.
17. *Pre-combustion, post-combustion and oxy-combustion in thermal power plant for CO<sub>2</sub> capture.* **Kanniche, Mohamed.** 30, 2010, Applied Thermal Engineering, pp. 53-62.
18. **University of Cincinnati and EPA.** *Impacts of Flue Gas Impurities in Sequestered CO<sub>2</sub> on Groundwater Sources: A Process Analysis and Implications for Risk Management.* Cincinnati : University of Cincinnati and EPA. Paper # 19.
19. **US Power Plant Laboratories.** Engineering Feasability and Economics of CO<sub>2</sub> Sequestration/Use on an Existing Coal-Fired Power Plant: A Literature Review. Windsor, Connecticut : s.n., January 31, 2000.
20. **Visser, Erika de.** *Towards Hydrogen and Electricity Production with Carbon Dioxide Capture and Storage.* s.l. : European Commission, 2007.
21. **(NETL), National Energy Technology Laboratory.** *Cost and Performance Baseline for Low-Rank Coal Fossil Energy Combustion Process Power Plants with and without CO<sub>2</sub> Capture.* Pittsburgh : s.n., February 2010.

ATTACHMENT A - QGESS Literature Search Spreadsheet

(Page 1)

QGESS Literature Search Results

Type Application Misc	NETL DESIGN BASIS		NON-NETL DESIGN BASIS		Generic		Generic		Generic		Generic		Generic	
	CCS	Remote dest.in, adjacent dest.in, adjacent dest.in, adjacent dest.in	CCS	Remote dest.in, adjacent dest.in, adjacent dest.in, adjacent dest.in	CCS	CCS	CCS	CCS	CCS	CCS	MEA	MEA	Selexol	Selexol
CO <sub>2</sub>	....	>95 vol%	not limited	not limited	99.7 mol%	89.019 mol%	91 vol%	90 vol%	99.8 vol%	97.8 vol%	96.6 vol%			
Water	233 K (40F) dew point	no free water	not limited	not limited	19800 ppmwt	19420 ppmwt	1400 ppmv							
N <sub>2</sub>	<300 ppmv	<40000 ppmv	not limited	not limited	328000 ppmwt	10800 ppmwt	6100 ppmv	6000 ppmv	300 ppmv	300 ppmv	300 ppmv			
O <sub>2</sub>	<40 ppmv	<100 ppmv	<100 ppmv	<100 ppmv	16800 ppmwt	16800 ppmwt	16800 ppmv	16800 ppmv	30 ppmv	unknown	unknown			
Ar	<10 ppmv	<10 ppmv	not limited	not limited	0.9 mol%	4.281 mol%	5.7 vol%	5.6 vol%	0.021 vol%	0.045 vol%	0.045 vol%			
CH <sub>4</sub>	uncertain	<0.8 vol%	<0.8 vol%	<0.8 vol%	0.9 mol%	uncertain	uncertain	uncertain	uncertain	350 ppmv	350 ppmv			
H <sub>2</sub>	<10 ppmv	<10 ppmv	not limited	not limited	200 ppmwt	200 ppmwt	uncertain	uncertain	10 ppmv	1700 ppmv	1700 ppmv			
H <sub>2</sub> S	<1.3 vol%	<1.3 vol%	<75 vol%	<75 vol%	1600 ppmwt	2300 ppmwt	760 ppmv	15000 ppmv	10 ppmv	0.01 vol%	2.3 vol%			
SO <sub>2</sub>	<40 ppmv	<40 ppmv	30000 ppmv	30000 ppmv	2500 ppmwt	500 ppmwt	2500 ppmv	2400 ppmv	20 ppmv	unknown	unknown			
NO	uncertain	uncertain	uncertain	uncertain	0.03 mol%	440 ppmwt								
TOTAL Hydrocarbons	<5 vol%	<5 vol%	<5 vol%	<5 vol%	not limited	not limited	trace	trace	trace	trace	trace			
NH <sub>3</sub>	<10 ppmv	<10 ppmv	not limited	not limited			trace	trace	trace	trace	trace			
HCl							trace	trace	trace	trace	trace			
HF							trace	trace	trace	trace	trace			
HCN							trace	trace	trace	trace	trace			
CO <sub>2</sub>							trace	trace	trace	trace	trace			
TOTAL Sulfur							trace	trace	trace	trace	trace			
C <sub>2</sub> H <sub>6</sub>							trace	trace	trace	trace	trace			
C <sub>3</sub> H <sub>8</sub>							trace	trace	trace	trace	trace			
C <sub>4</sub> H <sub>10</sub>							trace	trace	trace	trace	trace			
C <sub>2</sub> +C <sub>3</sub> +C <sub>4</sub> +C <sub>5</sub> +C <sub>6</sub>							trace	trace	trace	trace	trace			
volatile hydrocarbons							trace	trace	trace	trace	trace			
TOTAL Inerts							trace	trace	trace	trace	trace			
Hg							trace	trace	trace	trace	trace			
Metals							trace	trace	trace	trace	trace			
Particulate							trace	trace	trace	trace	trace			
Glycol							<1 ppm							
MEA							unknown	unknown	unknown	unknown	unknown			
Selexol Delivery Pressure	152 bar													
Selexol Delivery Temperature														

# ATTACHMENT A - QGESS Literature Search Spreadsheet

(Page 2)

QGESS Literature Search Results

Type Application	PIPE SPECIFICATIONS														
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Misc	Kindergarten Pipeline Specification For EOR (Koch, Oxygen CO <sub>2</sub> Company, 2003)	FOOR Ball Creek Pipeline Specification for EOR Coal Fired, Post Combustion (DNV-RR-202 recommend practice by DNV 2010)	FOOR Ball Creek Pipeline Specification for EOR Coal Fired, Pre Combustion (DNV-RR-202 recommend practice by DNV 2010)	FOOR Ball Creek Pipeline Specification for EOR Gas Fired, Post Combustion (DNV-RR-202 recommend practice by DNV 2010)	FOOR Ball Creek Pipeline Specification for EOR Gas Fired, Post Combustion (DNV-RR-202 recommend practice by DNV 2010)	FOOR Ball Creek Pipeline Specification for EOR Gas Fired, Post Combustion (DNV-RR-202 recommend practice by DNV 2010)	FOOR Ball Creek Pipeline Specification for EOR Gas Fired, Post Combustion (DNV-RR-202 recommend practice by DNV 2010)	FOOR Ball Creek Pipeline Specification for EOR Gas Fired, Post Combustion (DNV-RR-202 recommend practice by DNV 2010)	Diem Consulting EOR August 2001 (AIF Products presentation at 2006 gasification conference)	Dynamics for spore concentration limits as presented at the CCS conference (Osterkamp Trendheim in 2007)	RAD Foundation Polytec Pipeline Specification (Osterkamp Presentation 2008 R&D Foundation Polytec)	RAD Foundation Polytec Pipeline Specification (Osterkamp Presentation 2008 R&D Foundation Polytec)	RAD Foundation Polytec Pipeline Specification (Osterkamp Presentation 2008 R&D Foundation Polytec)	Industry working group Preliminary Specification 2005	
CO <sub>2</sub>	>85 vol%														
Water	654 ppm														
N <sub>2</sub>	<4000 ppm	100 ppm	300 - 6000 ppm	37000 ppm	13000 ppm	13000 ppm	<42000 ppm	<40000 ppm	<2.0% N <sub>2</sub> & H <sub>2</sub>	<0.17 vol%	70000 ppm	6000 ppm	30000 ppm	<4000 ppm	
O <sub>2</sub>	<10 ppm	100 ppm	300 - 6000 ppm	37000 ppm	13000 ppm	13000 ppm	<41000 ppm	<41000 ppm	<2.0 ppm	<100 ppm	<30000 ppm	trace	2 ppm	100 ppm max	
Ar		0.01 vol%	0.03-0.6 vol%	3.7 vol%	0.01 vol%	0.01 vol%	<41000 ppm	<41000 ppm		trace	<5 vol%	<0.05 vol%			
CH <sub>4</sub>		0	0.01 vol%	0	0	0	0	0	<1.0%	<100 ppm	trace	350 ppm	<1%		
H <sub>2</sub>		0	0.8-2.0 vol%	0	0	0	0	0	<1.0%	trace	trace	<3 vol%	<1%		
CO		0	300-4000 ppm	0	0	0	0	0	<1.0%	trace	trace	4000 ppm	5000 ppm	1000 ppm	
H <sub>2</sub> S	<20 ppm	0	0.01-0.6 vol%	0	0	0	0	0	<100 ppm	trace	trace	<3.4 vol%	10-200 ppm TBD	10-200 ppm Max	
SO <sub>2</sub>		100 ppm	0	5000 ppm	100 ppm	0	100 ppm	50000 ppm	<100 ppm	<10 ppm	25000 ppm	...	50000 ppm		
NO		100 ppm	0	100 ppm	100 ppm	0	100 ppm	100 ppm	100 ppm	<50 ppm	2500 ppm	...			
TOTAL Hydrocarbons	<5 vol%														
NH <sub>3</sub>															
HCl															
HF															
HCN															
COS															
TOTAL Sulfur															
C <sub>2</sub> H <sub>6</sub>															
C <sub>3</sub> H <sub>8</sub>															
C <sub>4</sub> H <sub>10</sub>															
C <sub>5</sub> H <sub>12</sub>															
C <sub>6</sub> H <sub>14</sub>															
volatile hydrocarbons															
TOTAL Inerts															
Hg															
Metals															
Particulate															
Glycol	46 ppbv														
MEA															
Solexol															
Delivery Pressure													2,220 psig	2,000 psia	
Delivery Temperature													120F max	120 F Max	

# ATTACHMENT A - QGESS Literature Search Spreadsheet

## (Page 3)

QGESS Literature Search Results

Type Application	Operating Pipelines													MISC		
	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	
Currently Operated Pipelines	Canyon Reef Carinas (Osterkamp Presentation 2008 R&D Foundation Polytec)	Central Basin Pipeline (Osterkamp Presentation 2008 R&D Foundation Polytec)	Sheep Mountain (Osterkamp Presentation 2008 R&D Foundation Polytec)	Bravo Dome Source (Osterkamp Presentation 2008 R&D Foundation Polytec)	Cortez Pipeline (Osterkamp Presentation 2008 R&D Foundation Polytec)	Weyburn (Osterkamp Presentation 2008 R&D Foundation Polytec)	Jackson Dome (Osterkamp Presentation 2008 R&D Foundation Polytec)	McElmo Dome (WorleyParsons paper, "CO <sub>2</sub> Specifications for Pipeline Transportation")	Currently Operated Pipelines (TX) Natural Gas (WorleyParsons paper, "CO <sub>2</sub> Specifications for Transportation")	AP Mountaineer CCS project	CO <sub>2</sub> Norway Compression Station (CO <sub>2</sub> Norway)	Canyon Reef Project Specification (Doctor and Palmer)	Dakota Gasification Company CO <sub>2</sub> experience (Riley and Bacon, 2005)	Acid Gas Injection (Carroll and Maddocks, 1989)	Typical Food Grade CO <sub>2</sub> Specification (Tromont Process Systems)	
CO <sub>2</sub>	85-98%	98.50%	98.8-97.4%	99.70%	95%	96%	98.7-99.4%	>98%	95%	99.5 vol%	99.5 wt%	98 wt%	22-30 vol% (w water free basis)	99.95 vol%		
Water	50 ppmwt	240 ppmwt	120 ppmwt	3000 ppm	240 ppmwt	20 ppm vol	trace	218 ppm	5000 ppm	245 ppm wt	4800 ppm	60 ppmwt	No free water	8 ppm		
N <sub>2</sub>	500 ppm	13000 ppm	9000 ppm	3000 ppm	<40000 ppm	<300 ppm	trace			100 ppm	4800 ppm	6000 ppmwt	No free water	40 ppm		
O <sub>2</sub>		<10 ppm spec				<50 ppm				10 ppm	<10 ppm	300 ppmwt		9 ppm		
Ar														20 ppm		
CH <sub>4</sub>	2-15% OBH4	0.20%	1.70%		1-5%	0.70%	trace		5%			0.3 wt%	0.4 vol% (w water-free basis)	30 ppm		
H <sub>2</sub>																
CO						1000 ppm										
H <sub>2</sub> S	<200 ppm	<20 ppm spec			0.002%	0.90%	trace		100 ppm			1 wt%	10-77 wt% (water free basis)	0.5 ppm		
SO <sub>2</sub>														2 ppm		
NO														2.5 ppm		
TOTAL Hydrocarbons														2.5 ppm		
NH <sub>3</sub>														2.5 ppm		
HCl														2.5 ppm		
HF														2.5 ppm		
HGN														2.5 ppm		
COS														2.5 ppm		
TOTAL Sulfur														2.5 ppm		
C <sub>2</sub> H <sub>6</sub>														2.5 ppm		
C <sub>3</sub> H <sub>8</sub>														2.5 ppm		
C <sub>4</sub> +	0.3-0.6%				trace	2.30%								2.5 ppm		
C <sub>2</sub> +														2.5 ppm		
volatile hydrocarbons														2.5 ppm		
TOTAL Inerts														2.5 ppm		
Hg														2.5 ppm		
Metals														2.5 ppm		
Particulate														2.5 ppm		
Glycol														2.5 ppm		
MEA														2.5 ppm		
Solxol Delivery Pressure														2.5 ppm		
Delivery Temperature														2.5 ppm		