CCS – Preliminary Storage Risk Log – Notes to the Reader

FOLLOW-UP NOTE ADDED AFTER NOVEMBER 1 WORKSHOP:
There were some important suggested changes to this risk log that are going to be incorporated in a second version for another round of responses. Those changes include the following general itesm:
1. Correcting the time estimated in each stage based on practical project experience
2. Shifting some tasks and the related risks to different stages. In particular, some of the actions and risks proposed in Stage 2 below will be moved to Stage 1
3. Clarifying language so that even the abbreviated titles for risk related to the risk itself and not the cause or pathway
4. Additional input to the descriptions to improve their use.

Since those changes were not made to the version included below through which we collected information for the November 1, 2007 workshop, we a resharing it in its entirety but offer a strong caveat about necessary/useful changes.

The purpose of this risk log is to provide a vehicle for ranking the risks potentially associated with Carbon Storage (CS) projects in order to facilitate discussion of options for addressing the long term liability associated with carbon storage. This document is not meant to be used for any other purpose and it should be noted that the risks associated with any particular CS project are going to be contingent on site and project specific details.

The risk log contains four tables. The first two are going to be used by the reader in filling out the prioritization of the risks.

Table 3 presents an overview of the stages of a CS project, the related activities and a list of the defined areas of risk that we are going to explore.

Table 4 presents a detailed description of each area of risk list in Table 3 and asks the reader to indicate their estimate of the level of prioritization and cost associated with mitigating the described risk. Table 4 is very long – you will see the stage indicated in the header and each column represents a numbered risk identified in Table 3.

Directions: We are using this approach to develop a priority ranking of the risks potentially associated with CS projects so that ultimately we can focus discussion on the highest priority areas for which there are not readily available mitigation options. Please look at the risks and using the rankings in Table 1 and 2 below indicate your best estimate of the priority ranking and potential cost associated with each risk. Please note, we are interested in compiling a ranking for the entire table, but the focus of this effort is on the areas of long term risk found in stages 5 and 6. If you are uncomfortable indicating a ranking on one or more risks, please leave them blank. Also, please feel free to offer comments in the space indicated for each risk. Please send responses to Sarah Wade (swade@ajwgroup.com) and John Venezia (jvenezia@wri.org) by close of business Monday September 24, 2007.

We are asking those who participated in the June workshop to complete table 4 and we are also circulating this to outside experts. We will compile the results and synthesize them into a presentation for the fall workshop. Again, the focus is on the areas of long term risk – stages 5 and 6 – but we would like to obtain feedback on the entire range of areas of potential risk. Each of these scales is discussed and then presented below in Tables 1 and 2.

Overall Ranking: We are trying to identify the most important areas of risk from the following list for discussion purposes. This is going to require that you accept, for purposes of this ranking effort, certain limitations. Most importantly, there is no such thing as a generic risk associated with CCS. The potential for any of the following risks is going to be highly dependent on the specifics of the site and the project. There is also no such thing as a generic cost. Projects will vary in size, proximity to populations and other sensitive receptors and will have other features that impact the potential cost of potential mitigation or remediation activities.

We would like to ask people to consider a generic case that is based on a presentation by Vello Kuuskraa of Advanced Resources International (found online at: http://www.westcarb.org/pdfs_ab1925/Kuuskraa%20_mitigation.pdf). This case would involve a sequestration project sized for a typical 1000 MW IGCC plant that emits 6 million tons per year for 30 years and monitors for an additional 20 years (total of 50 year operation). The CS portion of the project would involve 20 injection wells, each with capacity to inject 1,000 tons per day. After 50 years, it is anticipated that the plume would extend under an area of about 50 square miles. The presentation describes monitoring and initial maintenance and mitigation activities that might be expected for such a project and it estimates the cost of such activities. We also point to the IPCC CCS report estimates of total CCS project costs of roughly $70 per ton (so a generic project as described above would have a total cost of $12.6 billion). For purposes of this assessment assume that efforts were made to site, plan construct and operate a good and safe project. Based on this scenario, please indicate the area of expertise that informs your judgment and your assessment of your level of knowledge of the potential probability of the following risks and the potential cost of mitigating impacts if they arise. Then please indicate your assessment of the priority ranking (Table 1) and cost (Table 2) in the spaces provided in the bottom rows of Table 4. We also invite you to comment on the language in the tables or to use the “Comment” row to indicate important nuances in your rankings.

Respondent Background:

1. Industry or field of expertise: (circle, underline or highlight all that apply)

Legal Insurance Finance Environment Energy Production CCS Industry

Other Industry Other (please indicate):________________________________

2. Based on your level of background knowledge of CCS are your answers about the priority ranking based more on: (Circle one)

Perception Reading / exposure in conferences and the like Concrete experience in CCS research or operation

3. Based on your level of background knowledge of CCS are your answers about mitigation costs based more on: (Circle one)

Perception Reading / exposure in conferences and the like Concrete experience in CCS research or operation

Table 1. Priority Ranking Scales

Scale	Priority	Description
1	Very Low	A risk that is very easy to prevent and/or would be very unlikely to occur under standard operating conditions
2	Low	A risk that is easy to prevent and/or would be unlikely to occur under standard operating conditions
3	Medium	A risk that can be prevented and/or would be as likely as not to occur under standard operating conditions
4	High	A risk that requires careful controls to prevent occurrence and/or would be likely to occur without controls/safeguards
5	Very High	A risk for which it is uncertain that prevention is absolutely possible or for which more research will be needed to assure prevention is possible and/or would be almost certain to occur without significant safeguards

Table 2. Cost Scales

Scale	Cost	Description
1	Very Low	Negligible impacts (Costs managed through budget shifts – cost <$20M in generic case above)
2	Low	Minor impact on project time, cost or quality (Requires some additional funding – costs between $21-50M in generic case above)
3	Medium	Notable impact on project time, cost or quality (Requires significant additional funding –costs between $61-75M in generic case above)
4	High	Substantial impact on project time, cost or quality (Requires significant allocation of company funds – costs between $76-100M in generic case above)
5	Very High	Threatens the success of the project (costs > 2-5% of total project costs - >$100M in generic case above)

Table 3. Risk Identification

Stage	1. Siting	2. Construction	3. Operation	4. Closure	5. Post Closure	6. Full Closure
Timing	6-12 months	6-12 months	1-30 years +	2-12 months	Time limit or Performance driven	Indefinite post closure
Typical actions/ activities during the phase	- Site characterization studies (including seismic survey, core sampling, data analysis, etc) - Plan/design project specifications - Develop subsurface model -Establish baseline parameters - Public involvement - Develop Contingency Mitigation Plan (CMP) - Acquire land use and reservoir rights	- Complete acquisition of land use and reservoir rights - Obtain permits - Site prep - Drilling - Well construction - Install MMV network - Complete model - Complete baseline - Connect to CO source -Corrective action at ID'd boreholes / abandoned wells	- Obtain and inject CO (plus other chemical constituents if any?) - Periodic (annual) reporting / demonstration of compliance w/ permit - Ongoing MMV for well integrity, reservoir integrity, plume tracking - Periodic MMV to calibrate model	- Plan (plug / cements, MMV plan) - Permits - Construction of plug - Site completion and/or restoration	- MMV - Amend CMP for post/full closure period	- Periodic MMV - Possible well rework
Potential Areas of Risk	1.1 Worker safety 1.2 Damage to private property 1.3 Failure to collect or analyze important data about potential leakage pathways (incompatible geology, undetected abandoned wells) leading to selection of an inappropriate site 1.4 Public is not favorable to project causing project delays and difficulty in getting financing (delays)	2.1 Worker safety 2.2 Damage to private property 2.3 Damage to confinement zone (by fracturing a cap for example) 2.4 Contractor delays / cost over-runs 2.5 Poor well construction 2.6 Failure to obtain injection permit (Delay) 2.7 Failure to adequately correct old wells/boreholes 2.8 Technical challenges around plant construction and integration 2.9 Drilling a "dry hole" - no CCS potential 2.10 Failure to acquire land use and/or reservoir rights	3.1 Worker safety – OSHA 3.2 Worker safety – CO_2 exposure 3.3 Groundwater: CO_2 and geochemical reaction products 3.4 Groundwater: brine or gas displacement 3.5 Confinement zone failure 3.6 Property damage (mineral rights) 3.7 Ecosystem degradation (terrestrial or aquatic) 3.8 Public exposure to sudden CO_2 release (surface pipeline leak, borehole, well blow out) 3.9 Public exposure to slow leak accumulation (basements) 3.10 Atmospheric release (loss of credits / compliance) 3.11 Business interruption (BI) 3.12 Contingent BI (CO_2 source interrupted) 3.13 Induced seismicity 3.14 Land subsidence or heave 3.15 Lawsuits	4.1 Worker safety 4.2 Failure to fully close well (borehole leaks) 4.3 Failure to adequately install MMV system 4.4 Quality problems with materials	5.1 Groundwater: CO_2 and geochemical reaction products 5.2 Groundwater: brine or gas displacement 5.3 Groundwater: Confinement zone failure 5.4 Subsurface property damage (mineral rights) 5.5 Ecosystem degradation (terrestrial or aquatic) 5.6 Public exposure to sudden CO_2 release (borehole leak) 5.7 Public exposure to slow leak accumulation (basements) 5.8 Land subsidence / heaves 5.9 Atmospheric release (loss of credits / compliance) 5.10 Lawsuits 5.11 Inadvertent CO_2 extraction	6.1 LT unanticipated groundwater: CO_2 and geochemical reaction products 6.2 LT unanticipated groundwater: brine or gas displacement 6.3 LT unanticipated confinement zone failure 6.4 LT unanticipated property damage (mineral rights) 6.5 LT unanticipated ecosystem degradation (terrestrial or aquatic) 6.6 LT unanticipated public exposure to sudden CO_2 release (borehole leak) 6.7 LT unanticipated public exposure to slow leak accumulation (basements) 6.8 LT unanticipated land subsidence 6.9 LT unanticipated atmospheric release (loss of credits / compliance) 6.10 LT lawsuits 6.11 LT inadvertent CO_2 extraction 6.12 Seismicity 6.13 Regulatory Uncertainty

			3.16 Inadvertent CO_2 extraction 3.17 MMV technicians negligence orMMV equipment failures		5.12 Seismicity 5.13 Regulatory Uncertainty	

Table 4. Risk Log – Stage 1.0 Siting

ID	1.1 Worker safety	1.2 Damage to private property	1.3 Failure to collect or analyze important data	1.4 Public is not favorable to project
Description	Industrial accidents involving workers during seismic survey, drilling for core samples or doing other site characterization work in the field; traffic related accidents doing same	Trucks and equipment used in seismic survey or core sampling cause damage on or en route the locations for field activities	Either through negligence or oversight, key data (about potential leakage pathways, incompatible geology, undetected abandoned wells, etc) is omitted from site characterization leading to selection of an inappropriate/marginal site	Opposition leads to increased costs, delays and potentially inability to move forward with project
Timescale	Risk most prevalent during the actual implementation of field activities (days or weeks at a time)	Risk most prevalent during the actual implementation of field activities (days or weeks at a time)	Ramifications for entire life of project	Ramifications for entire life of project
Potentially Involved Parties	Contractors (survey or drilling crews) Operators?	Contractors (survey or drilling crews) Operators?	Contractors (survey or drilling crews) Operators? Potentially anyone who has an unreported	Operator
Preventive Action	Hire reputable firm, require them to be insured, emergency response plan	Hire reputable firm, require them to be insured, emergency response plan; obtain approval from land owners as needed	Hire reputable firm, require them to be insured, emergency response plan; obtain approval from land owners as needed	Outreach, engagement with local community
Mitigation Response	Medical treatment?	If feasible repair damage, pay damages if/as required	No mitigation at this stage, may require modification to well design or operation; may require preventive mitigation; could lead to need to close well	Continued outreach and engagement
Residual Risk	None likely, lawsuits possible	None	May be difficult to go back and collect info such as baseline	
Warning Signals	Reputation of contractor; terrible field conditions	Reputation of contractor; bad field conditions	Reputation of contractor; extensive private/proprietary information about proximate drilling activities	Public reaction to early outreach, press reaction
Interdependence / Risk Coupling	None	None	Critical link to future well integrity and leak prevention	Could lead to bad relations, frivolous lawsuits
Priority Ranking				
Mitigation Cost				
Comments				

Table 4. Risk Log -- Stage 2.0 Construction

ID	2.1 Worker safety	2.2 Damage to private property	2.3 Damage to confinement zone (by fracturing a cap for example)	2.4 Contractor delays / cost over-runs
Description	Industrial accidents involving workers during drilling and construction of well	Setting up site creates ancillary damage – run off from land clearing, truck traffic problems	Drilling crew errors or poor rock strength lead to unplanned fracturing of the caprock	Poor weather, bad conditions underground and/or high demand on scheduling drilling crews could lead to significant delays and cost over-runs; potentially could have permit implications?
Timescale	Risk most prevalent during the actual drilling activity (days or weeks at a time)	Risk most prevalent during the actual drilling activity (days or weeks at a time)	Risk most prevalent during the actual drilling activity (days or weeks at a time)	Most likely to occur during drilling stage
Potentially Involved Parties	Drilling crew Operators?	Drilling crew Operators?	Drilling crew Operators?	Contractor, operator
Preventive Action	Hire reputable firm and require them to be insured; emergency response plan	Obtain approval and/or permit from knowledgeable state agency for drilling; obtain approval from land owners; hire reputable firm and require them to be insured; emergency response plan	Obtain approval and/or permit from knowledgeable state agency for drilling; obtain approval from land owners; hire reputable firm and require them to be insured; emergency response plan	Planning, contract provisions (incentives and/or penalties)
Mitigation Response	Medical treatment?	If feasible repair damage	Consider modifications to well design, other preventive action (if) as needed to prevent groundwater problems	Unknown
Residual Risk	None	None likely – could lead to bad relations with neighbors	Potentially significant if not caught – could lead to leaky well	Unknown
Warning Signals	Reputation of contractor; terrible field conditions	Reputation of contractor; terrible field conditions and/or weather	Feedback / issues arising during drilling process	Early small problems with project
Interdependence / Risk Coupling	None	None	Related to quality of site characterization	None identified
Priority Ranking				
Mitigation Cost				
Comments				

Table 4. Risk Log -- Stage 2.0 Construction (continued)

ID	2.5 Poor well construction	2.6 Failure to obtain injection permit	2.7 Failure to adequately correct old wells/boreholes	2.8 Technical challenges around plant construction and integration
Description	Failure to properly design and construct well leads to known or unknown well flaws that could lead to leakage or failure to pass MIT concerns	New information appears or Regulatory agency finds inadequate well completion / integrity and does not allow injection to take place	Wells are not indicated in old records, are overlooked or are not considered to be in zone of influence, or identified old wells are not properly closed, leading to potential leakage pathways	Either there is not enough space to construct necessary physical plant and/or there is inadequate CO_2 supply resulting in less valuable / inoperable site
Timescale	Would take place during well construction but might not be detected until time of MIT test or after injection has begun	Biggest risk is once construction is completed but before well has passed integrity tests and received final approval for injection	Problem could take place during site characterization/ construction but persist throughout life of project	Would become apparent during construction
Potentially Involved Parties	Drilling and well construction crews, operator	Operator, drilling crews	Site characterization team, operator, construction team	Project design and construction team
Preventive Action	Detailed site characterization, careful planning and execution of well construction, oversight by operator, strong financial incentives / penalties for construction crew	Planning	Thorough site characterization, conservative estimate of zone of influence based on SOA modeling of plume movement	Detailed and thorough site characterization and planning
Mitigation Response	Reworking the well before or after injection begins	Rework or close well	Monitoring to prevent leaks, rework old wells,	By adjacent land, stop project
Residual Risk	If undetected until later date, could result in significant cost / leakage	None	Significant – old wells with weak plugs could become leakage pathways in future	None – unless key equipment left out
Warning Signals	Routine MIT, area monitoring, annulus pressure monitoring	If problem with area (akin to a dry hole) should show up in core sampling before well construction	Monitoring should show unexpected movement of plume, changes in pressures, groundwater sampling should show signs of leakage	Should be determined during design phase
Interdependence / Risk Coupling	Injection/operation procedures could trigger leak in a poorly constructed well	None	Linked to groundwater contamination	None
Priority Ranking				
Mitigation Cost				
Comments				

Table 4. Risk Log Stage 2.0 – Construction (continued) and Stage 3.0 Operation

ID	2.9 Drilling a "dry hole"	3.1 Worker safety (OSHA)	3.2 Worker safety (CO_2 exposure)	3.3 Groundwater Contamination (CO_2 and geochemical reaction products)
Description	Drilling reveals that injectivity is not acceptable where well is planned; project is not viable	Industrial accidents leading to conventional injuries of workers	Industrial accident leads to worker exposure to high concentrations of CO_2. Possibly leading to significant respiratory stress or death	Groundwater contamination due to geochemical reaction of CO_2 in brine/rock formations potentially resulting in impacts on (3.3.1) drinking water and water used for (3.3.2) agricultural purposes.
Timescale	Should be indicated during site characterization or well drilling	Could occur once workers begin working on site	Could happen once CO_2 is being brought onto site. Would stop with closure of pipeline and well(s)	This risk could start to occur anytime after injection begins if there is leaky well but would more likely not occur until a significant amount of CO_2 had been injected
Potentially Involved Parties	Site characterization team, well construction team, operator	Operator, possibly construction team if accident reveals problem with construction	Operator	Site selection team, CO_2 provider, Operator, CCS Fund, Fed or State Entity
Preventive Action	Careful site selection	Adopt procedures and incentives aimed at avoiding accidents, no tolerance policy for failure to comply	Implement standard operating procedures to prevent accidents, conduct routine MMV of CO_2 delivery systems	Use MMV to insure well integrity and to ID plume movement before it becomes a problem
Mitigation Response	Drill to new horizon, if still no viable options, plug first well, drill another or move to a new location and drill new well	Have emergency response plan in place	Have emergency response plan in place including response for human health and remediation of leak	Mitigation: Stop (or contain) CO_2 leak (rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal.
Residual Risk	If dry hole not well plugged, could become leakage pathway in the future	Possibly long-term health claims from injured workers or their families	Possibly long-term health claims from injured workers or their families	Mitigation or remediation could lead to problem of disposing of large volumes of produced brines
Warning Signals	Core samples, seismic survey and other site characterization tests of porosity and permeability, extent of reservoir	Small problems arising	Corrosion or other signed of weakness in CO_2 delivery system, use of untrained workers	Problems with MIT tests, unplanned movement of CO_2 plume
Interdependence / Risk Coupling	None	Most likely none – though could signal failure to carefully adhere to injection plan suggesting potential for future problems	Mostly likely none	Potentially related to quality of site characterization and well construction
Priority Ranking				
Mitigation Cost				
Comments				

Table 4. Risk Log -- Stage 3.0 Operation (continued)

ID	3.4 Groundwater Contamination (brine or gas displacement)	3.5 Groundwater Contamination (confinement zone failure)	3.6 Subsurface property damage	3.7 Ecosystem degradation
Description	Groundwater contamination due to displacement of brine or gas from injection zone into groundwater zone potentially resulting in impacts on (3.4.1) drinking water and water used for (3.4.2) agricultural purposes.	Groundwater contamination due to failure of the confinement zone either from unmapped abandoned wells or over-pressurization of the formation potentially resulting in impacts on (3.5.1) drinking water and water used for (3.5.2) agricultural purposes.	Plume migration impacts subsurface rights of a party that has not previously signed them over to operator potentially resulting in loss of use.	CO_2 seeps to surface or just below surface and buildup potentially damaging terrestrial or aquatic systems.
Timescale	This risk could start once a meaningful amount of CO_2 has been injected	This risk could start once a meaningful amount of CO_2 has been injected	This risk could start once a meaningful amount of CO_2 has been injected and extend out past closure	This risk could start once a meaningful amount of CO_2 has been injected and extend out past closure
Potentially Involved Parties	Operator, CCS Fund, Fed or State Entity	Site selection team, operator, CCS Fund, Fed or State Entity	Operator, site selection team, CCS Fund, Fed or State Entity	Site selection team, operator, CCS Fund, Fed or State Entity, equipment manufacturers
Preventive Action	Use MMV to ID plume and/or brine movement before it becomes a problem	Accurately determine frac pressure and ID old wells. Implement an MIT and other MMV program to prevent serious problems	Develop robust plume migration model, design injection plan accordingly, acquire rights in defined zone of impact, use MMV to ID and mitigate plume movement that could potentially become a problem	Use MMV to ID and mitigate plume movement before it becomes a problem
Mitigation Response	Mitigation: Stop (or contain) CO_2 injection and/or leak (rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal.	Mitigation: Stop (or contain) CO_2 injection and/or leak (rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal.	Acquire additional subsurface property rights; if trespass not considered damage, then may not require mitigation.	Mitigation: Stop (or contain) CO_2 injection and/or leak (rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal
Residual Risk	Mitigation or remediation could lead to problem of disposing of large volumes of produced brines	May require removal of significant amounts of injected CO_2 if other means of mitigating leaks not viable. Mitigation or remediation could involve produced brines.	Could substantially increase project costs associated with legal fees and rights acquisition. Mitigation or remediation could lead to produced brine issues; Issue of potential future new mineral rights	Decline in property values, potential loss of business productivity, lawsuits, long term MMV requirements, decreased value of any carbon credits
Warning Signals	"Reports" of brine leakage to surface in old wells, etc; unplanned movement of CO_2 plume	Strange pressure readings from well, unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume
Interdependence / Risk Coupling	Related to modeling and quality of other site characterization activities; to extent reactions catalyzed by leak, dependent on construction	Strongly dependent on quality of site characterization	Strongly dependent on quality of site characterization and construction	Strongly dependent on quality of site characterization and construction
Priority Ranking				
Mitigation Cost				
Comments				

Table 4. Risk Log -- Stage 3.0 Operation (continued)

ID	3.8 Public exposure to sudden CO_2 release	3.9 Public exposure to slow leak accumulation	3.10 Atmospheric release	3.11 Business interruption (BI)
Description	CO_2 builds up in a confined space and then is suddenly released above the surface in a way that potentially exposes the public to high concentration of CO_2. (3.8.1 well blowout, 3.8.2 CO_2 seeps into a subsurface area at high concentration such as a coal mine)	CO_2 seeps to the surface and collects in pockets above ground such as a basement, a natural hollow potentially causing impacts ranging from respiratory stress to death	CO_2 leaks to surface and is emitted to the atmosphere, countering the climate change benefits	Problems with the injection operation force facility to stop accepting CO_2 for injection, causing significant business interruption (and potentially liability for the CO_2)
Timescale	This risk could start to occur once a meaningful amount of CO_2 has been injected	This risk could start to occur once a meaningful amount of CO_2 has been injected.	This risk could start to occur once a meaningful amount of CO_2 has been injected	This risk could occur any time after CO_2 is being brought to the site
Potentially Involved Parties	Site selection team, operator, CCS Fund, Fed or State Entity, equipment manufacturers	Site selection team, operator, CCS Fund, Fed or State Entity, equipment manufacturers	State or National Inventory, CCS Fund, Fed or State Entity, Other?	Construction team, operator
Preventive Action	Use MMV to ID plume movement before it becomes a problem	Use MMV to ID plume movement before it becomes a problem, use alarms/detectors in sensitive receptors	Use MMV to ID plume movement before it becomes a problem, use surface MMV as needed	Utilize operating protocols to maintain and check operating systems, develop a back up well (?), develop alternate plans for managing CO_2 delivered to facility in event injection must be halted for a period of time
Mitigation Response	Mitigation would involve ventilation and repair of CO_2 leak	Remediation would include ventilation as well as reduction of source of CO_2.	If movement likely, determine whether to mitigate by replacing emitted CO_2 (through options including discounted credits, offsets, markets, etc) and/or stopping the leak.	Repair systems, make alternate arrangements for CO_2
Residual Risk	Long term MMV requirements, claims of future health problems / lawsuits, decreased value of any carbon credits	Decline in property values, future lawsuits, LT MMV requirements, decreased value of any carbon credits	If needed, remediation could lead to problem of disposing of large volumes of produced brines; could create perception issues for other CCS CO_2 credits.	Potentially any problems associated with the injection well(s) could lead to LT concerns about well integrity
Warning Signals	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume, surface monitors/alarms triggered	Unplanned movement of CO_2 plume	If not doing routine maintenance, then possibly none
Interdependence / Risk Coupling	Dependent on site characterization and construction	Dependent on site characterization and construction	Dependent on quality site characterization, construction and following operating plans	None
Priority Ranking				
Mitigation Cost				
Comments				

Table 4. Risk Log – Stage 3.0 Operation (continued)

ID	3.12 Contingent Business Interruption	3.13 Induced seismicity	3.14 Land subsidence or heave	3.15 Lawsuits
Description	CO_2 delivery system fails – accidental leak, terrorism, other interruption, causing facility to stop injection – could prevent facility from delivering carbon credits	CO_2 injection induces seismic activity leading to subsurface or surface property damage	CO_2 modifies structure of subsurface potentially resulting in sink holes or ground heaves	Someone files a lawsuit for real or perceived damages
Timescale	Could occur anytime after CO_2 delivery system is establish	Could occur any time after CO_2 injection begins	This risk could start to occur during operational phase or anytime thereafter.	This is a project risk
Potentially Involved Parties	CO_2 owner, operator	Site characterization team, operator	Site selection team, operator, CCS Fund, Fed or State Entity	CCS Fund, Fed or State Entity, ?
Preventive Action	Back-up plans, financial risk mitigation regarding delivery of reductions	Use modeling to determine safe injection pressures	Use MMV to ID plume movement before it becomes a problem	Tort reform, statutory liability limitations
Mitigation Response	Seek new sources of CO_2 if necessary, enforce contract provisions	Modify and/or stop injection	Modify and/or stop injection, Repair damage	Good documentation
Residual Risk	None likely	May require enhanced monitoring to ensure no other related problems develop	Remediation could lead to problem of disposing of large volumes of produced brines; reduced property values, could lead to structural damage in buildings, roads, etc	If suits are successful or settled, could encourage others.
Warning Signals	None likely	Pressure monitoring results?	Unplanned movement of CO_2 plume	Stakeholder opposition
Interdependence / Risk Coupling	None likely	None likely		
Priority Ranking				
Mitigation Cost				
Comments				

Table 4. Risk Log – Stage 3.0 Operation (continued)

ID	3.16 Inadvertent CO_2 extraction	3.17 MMV technicians negligence
Description	Someone drills a deep well in the area of the plume and provides a leakage pathway for CO_2	MMV equipment improperly or poorly installed and/or maintained leads to failure to detect problems at early stages
Timescale	Could start to happen anytime after plume begins to build, but more likely to occur further away from injection point after a few years or more of migration	Could happen at any point in project
Potentially Involved Parties	Operator, regulatory agency, property owner	Construction team, operator
Preventive Action	Deed or other property restrictions in certain areas, coordination with other agencies permitting deep wells including NG storage, Class I and Class II UIC, nearby states / countries	Careful MMV planning, implementation of robust MMV testing and maintenance program
Mitigation Response	Correctly plug new well, undertake remediation if necessary	Correct (or reinstall) MMV system
Residual Risk	Lawsuits, damages	Potentially none if MMV problems found before any concerns about CO_2 migration
Warning Signals	Unchecked / uncoordinated growth – suggesting weak enforcement of AOR protocols	Model calibration based on early MMV results not showing expected results?
Interdependence / Risk Coupling	None	If MMV not working properly, could prevent detection of more serious problems
Priority Ranking		
Mitigation Cost		
Comments		

Table 4. Risk Log - Stage 4.0 Closure

ID	4.1 Worker safety	4.2 Failure to fully close well (borehole leaks)	4.3 Failure to adequately install MMV system	4.4 Quality problems with materials
Description	Industrial accidents leading to conventional injuries of workers and/or CO_2 exposure	The cement bond or other sealing mechanism is not properly installed leaving the plug weak or with small leaks	MMV components either are rendered inoperable because of installation issues, or they are not located as planned and therefore miss key signals of leakage or movement	Systems designed to last decades, last only 10 years or degrade under the installation conditions more rapidly than expected
Timescale	Could occur once workers begin closing the well and last duration of activity	Would take place during closure but might not be manifested for some time afterwards	Problem would take place during the actual phase of closure but might not be realized until well after closure is complete	Could happen anytime after installation
Potentially Involved Parties	Operator	Operator, team constructing the plug / closing the well	Closure team, project planning team, Operator	Operator, MMV design team
Preventive Action	Adopt procedures and incentives aimed at avoiding accidents, no tolerance policy for failure to comply	Careful planning of plug, integrity tests for the seal, MMV	Design a sound MMV system and plan for installing it, get plan approved by regulators in advance; hire reputable installation firm	Test materials under conditions of the specific well – temp, chemical nature of brine and injectate, etc
Mitigation Response	Have emergency response plan in place	Rework plug; if leakage occurs, potentially address leakage impacts	Rework MMV systems around well if needed; install new equipment if needed	Re-install new MMV equipment as needed
Residual Risk	Possibly long-term health claims from injured workers or their families	Risk of leakage in future	Could be significant if MMV fails to detect unplanned movement of plume	If equipment not lasting as long as planned, will be more costly to maintain and require more frequent testing to insure integrity of results
Warning Signals	None	MMV results	Questionable MMV results in testing, signs of movement not detected by MMV – such as salt water movement, etc	Erratic MMV results, testing
Interdependence / Risk Coupling	Most likely none – though could signal failure to properly plug well	None likely	If system appears to be working but is not, then could allow real problems to arise before prevention could take place	If undetected could lead to unplanned plume movement
Priority Ranking				
Mitigation Cost				
Comments				

Table 4. Risk Log- Stage 5.0 Post Closure

ID	5.1 Groundwater Contamination (CO_2 and geochemical reaction products)	5.2 Groundwater Contamination (brine or gas displacement)	5.3 Groundwater Contamination (confinement zone failure)
Description	Groundwater contamination due to geochemical reaction of CO_2 in brine/rock formations potentially resulting in impacts on (5.1.1) drinking water and (5.1.2) water used for agricultural purposes.	Groundwater contamination due to displacement of brine or gas from injection zone into groundwater zone potentially resulting in impacts on (5.2.1) drinking water and (5.2.2) water used for agricultural purposes.	Groundwater contamination due to failure of the confinement zone either from unmapped abandoned wells or over-pressurization of the formation potentially resulting in impacts on (5.3.1) drinking water and (5.3.2) water used for agricultural purposes.
Timescale	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter. MMV should detect these risks before significant contamination occurs.
Potentially Involved Parties	Site selection team, CO_2 provider, operator, CCS Fund, Fed or State Entity	Operator, CCS Fund, Fed or State Entity	Site selection team, construction team, operator, CCS Fund, Fed or State Entity
Preventive Action	Use MMV to ID plume movement and/or water quality issues before they become a problem	Use MMV to ID plume movement and/or water quality issues before they become a problem	Use MMV to ID plume movement and/or water quality issues before they become a problem
Mitigation Response	Mitigation: Notify local water agency. Stop (or contain) CO_2 leak (rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal.	Mitigation: Notify local water agency. Stop (or contain) CO_2 leak (rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal.	Mitigation: Notify local water agency. Stop (or contain) CO_2 leak (rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal.
Residual Risk	Mitigation or remediation could lead to problem of disposing of large volumes of produced brines	Mitigation or remediation could lead to problem of disposing of large volumes of produced brines	May require removal of significant amounts of injected CO_2 if other means of mitigating leaks not viable. Mitigation or remediation could involve produced brines.
Warning Signals	Unplanned movement of CO_2 plume,	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume
Interdependence / Risk Coupling	Contingent on successful Stages 1-4(siting, construction, operation, closure)	Contingent on successful Stages 1-4	Contingent on successful Stages 1-4
Priority Ranking			
Mitigation Cost			
Comments			

Table 4. Risk Log - Stage 5.0 Post Closure (continued)

ID	5.4 Subsurface Property Damage	5.5 Ecosystem Degradation	5.6 Public Exposure to CO_2
Description	Plume migration impacts mineral rights of a party that has not previously signed them over to operator potentially resulting in loss of use.	CO_2 seeps to surface or just below surface with potential damages to terrestrial or aquatic systems.	CO_2 builds up in a confined space and then is suddenly released above the surface in a way that potentially exposes the public to high concentration of CO_2. (5.6.1 well blowout, 5.6.2 CO_2 seeps into a subsurface area at high concentration such as a coal mine)
Timescale	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.
Potentially Involved Parties	Operator, CCS Fund, Fed or State Entity	Site selection team, operator, CCS Fund, Fed or State Entity	Site selection team, operator, CCS Fund, Fed or State Entity, equipment manufacturers
Preventive Action	Use MMV to ID plume movement and/or water quality issues before they become a problem	Use MMV to ID plume movement and/or changes in vegetation / soil before it becomes a problem	Use MMV to ID plume movement before it becomes a problem, implement emergency response plan
Mitigation Response	Acquire pore space and/or mineral estate rights; if trespass not considered damage, then may not require mitigation.	Mitigation: Notify local authorities. Stop (or contain) CO_2 leak (rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal, vegetation replanting.	Mitigation: Notify local authorities. Remediation: ventilation as well as reduction of source of CO_2.
Residual Risk	Mitigation or remediation could lead to problem of disposing of large volumes of produced brines; If property owner discovers new mineral (or pore space) rights in the future, could leave door open to future lawsuits	Decline in property values, potential loss of business productivity, lawsuits, long term MMV requirements, decreased value of any carbon credits	Long term MMV requirements, claims of future health problems / lawsuits, decreased value of any carbon credits
Warning Signals	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume, surface detection of CO_2	Unplanned movement of CO_2 plume
Interdependence / Risk Coupling	Contingent on successful Stages 1-4	Contingent on successful Stages 1-4	Contingent on successful Stages 1-4
Priority Ranking			
Mitigation Cost			
Comments			

Table 4. Risk Log - Stage 5.0 Post Closure (continued)

ID	5.7 Public Exposure to CO_2	5.8 Land Subsidence / Heaves	5.9 Atmospheric Release of CO_2
Description	CO_2 seeps to the surface and collects in pockets above ground such as a basement, a natural hollow potentially causing impacts ranging from respiratory stress to death	CO_2 modifies structure of subsurface potentially resulting in sink holes or ground heaves	CO_2 leaks to surface and is emitted to the atmosphere, resulting in loss of the climate change benefits
Timescale	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.
Potentially Involved Parties	Site selection team, operator, CCS Fund, Fed or State Entity, equipment manufacturers	Site selection team, operator, CCS Fund, Fed or State Entity	Operator, CO_2 owner, site MMV team, site selection team
Preventive Action	Use MMV to ID plume movement before it becomes a problem, use alarms/detectors in sensitive receptors	Use MMV to ID plume movement before it becomes a problem, equipment manufacturers	Use MMV to ID plume movement before it becomes a problem
Mitigation Response	Mitigation: Notify local authorities. Remediation: ventilation as well as reduction of source of CO_2.		Replace leaked CO_2. Potentially stop leak and/or remove and/or reinject CO_2
Residual Risk	Decline in property values, future lawsuits, LT MMV requirements, decreased value of any carbon credits	Remediation could lead to problem of disposing of large volumes of produced brines; reduced property values, could lead to structural damage in buildings, roads, etc	Could create perception issue for other CCS CO_2 credits (that impact credit price)
Warning Signals	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume
Interdependence / Risk Coupling	Contingent on successful Stages 1-4	Contingent on successful Stages 1-4	Contingent on successful Stages 1-4
Priority Ranking			
Mitigation Cost			
Comments			

Table 4. Risk Log - Stage 5.0 Post Closure (continued)

ID	5.10 Lawsuits	5.11 Inadvertent CO_2 Extraction (Well)	5.12 Seismicity (natural)
Description	Someone files a lawsuit for damages resulting in expenses and possibly other requirements	Once field is closed, someone drills a well that pierces confinement zone resulting in groundwater contamination, property damage, human exposure or CO_2 release	Natural seismic event causes a change in geologic formation either modifying the movement path of CO_2 or resulting in leak to surface
Timescale	This risk could start to occur during operational phase or anytime thereafter.	This risk could start anytime after closure.	This is an ongoing and permanent risk
Potentially Involved Parties	Operator – others?	Zoning / permitting officials (?) Operator/ driller of new well	?
Preventive Action		Use MMV to track plume, ensure permitting agencies aware of hazard through communication among appropriate agencies	
Mitigation Response	Good documentation, tort reform, statutory limitations on liability	Rework/close well to create functioning seal, remediate any damages from leaked CO_2.	Mitigation: Potentially ventilation, containment of CO_2, replace leaked CO_2 or reduce CO_2 credits.
Residual Risk	If suits are successful or settled, could encourage others	Remediation could lead to problem of disposing of large volumes of produced brines	Stability of geology might be permanently impacted
Warning Signals	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume
Interdependence / Risk Coupling			
Priority Ranking			
Mitigation Cost			
Comments			

Table 4. Risk Log - Stage 6.0 Full Closure

ID	6.1 LT Groundwater Contamination (CO_2 and geochemical reaction products)	6.2 LT Groundwater Contamination (brine or gas displacement)	6.3 LT Groundwater Contamination (confinement zone failure)
Description	Groundwater contamination due to geochemical reaction of CO_2 in brine/rock formations	Groundwater contamination due to displacement of brine or gas from injection zone into groundwater zone	Groundwater contamination due to failure of the confinement zone either from unmapped abandoned wells or over-pressurization of the formation
Timescale	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.
Potentially Involved Parties	CCS Fund, Fed or State Entity, ?	CCS Fund, Fed or State Entity, ?	CCS Fund, Fed or State Entity,?
Preventive Action	Use MMV to ID plume movement before it becomes a problem	Use MMV to ID plume movement before it becomes a problem	Use MMV to identify any additional abandoned wells that may be impacted as plume moves and ID plume movement before it becomes a problem
Mitigation Response	Mitigation: Notify local water agency. Stop (contain) CO_2 leak (Rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal	Mitigation: Notify local water agency. Stop (contain) CO_2 leak (Rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal	Mitigation: Notify local water agency. Stop (contain) CO_2 leak (Rework wells, correct abandoned wells, remove CO_2 or change movement path). Remediation: could include water treatment and related disposal
Residual Risk	Remediation could lead to problem of disposing of large volumes of produced brines.	Remediation could lead to problem of disposing of large volumes of produced brines	May require removal of significant amounts of injected CO_2 if other means of mitigating leaks not viable. Remediation could involve produced brines.
Warning Signals	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume
Interdependence / Risk Coupling	Contingent on successful Stages 1-5. Evidence of secondary trapping reduces probability.	Contingent on successful Stages 1-5. Evidence of secondary trapping reduces probability.	Contingent on successful Stages 1- 5
Priority Ranking			
Mitigation Cost			
Comments			

Table 4. Risk Log - Stage 6.0 Full Closure (continued)

ID	6.4 Property Damage	6.5 LT Ecosystem Degradation	6.6 LT Public Exposure to CO_2
Description	Plume migration impacts mineral rights of a party that has not previously signed them over to operator	CO_2 seeps to surface or just below surface and buildup causes damage to terrestrial or aquatic systems	CO_2 builds up in a confined space and then is suddenly released above the surface in a way that potentially exposes the public to high concentration of CO_2. (6.6.1 – CO_2 seeps into a subsurface area such as a coal mine)
Timescale	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.
Potentially Involved Parties	CCS Fund, Fed or State Entity, ?	CCS Fund, Fed or State Entity,?	CCS Fund, Fed or State Entity,?
Preventive Action	Use MMV to ID plume movement before it becomes a problem	Use MMV to ID plume movement before it becomes a problem. Evidence of secondary trapping could suggest low probability.	Use MMV to ID plume movement before it becomes a problem
Mitigation Response	Mitigation: Stop (contain) CO_2 leak causing damage; acquire impacted property rights Remediation: Could include clean up	Mitigation might involve stopping leak and/or removing CO_2. Remediation might involve cost of damages, clean up at surface, replanting vegetation.	Mitigation would include ventilation, stopping (or containing) CO_2 leak. Remediation might involve cost of damages.
Residual Risk		Decline in property values, potential loss of business productivity, lawsuits, long term MMV requirements, decreased value of any carbon credits	Long term MMV requirements, claims of future health problems / lawsuits, decreased value of any carbon credits
Warning Signals	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume
Interdependence / Risk Coupling	Contingent on successful Stages 1-5. Evidence of secondary trapping reduces probability.	Contingent on successful Stages 1- 5. Evidence of secondary trapping reduces probability	Contingent on successful Stages 1- 5. Evidence of secondary trapping reduces probability.
Priority Ranking			
Mitigation Cost			
Comments			

Table 4. Risk Log - Stage 6.0 Full Closure (continued)

ID	6.7 LT Public Exposure to CO_2	6.8 LT Subsidence	6.9 LT Atmospheric Release of CO_2
Description	CO2 seeps to the surface and collects in pockets above ground such as a basement, a natural hollow	CO2 modifies structure of subsurface resulting in sink holes or ground heaves	CO2 leaks to surface and is emitted to the atmosphere, countering the climate change benefits.
Timescale	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.	This risk could start to occur during operational phase or anytime thereafter.
Potentially Involved Parties	CCS Fund, Fed or State Entity, ?	CCS Fund, Fed or State Entity,?	State or National Inventory, CCS Fund, Fed or State Entity, CO_2 owner
Preventive Action	Use MMV to ID plume movement before it becomes a problem, use alarms/detectors in sensitive receptors	Use MMV to ID plume movement before it becomes a problem	Use MMV to ID plume movement before it becomes a problem
Mitigation Response	Mitigation would include ventilation, stopping (or containing) CO2 leak. Remediation might involve cost of damages, acquisition of surface rights (property)	Mitigation would include stopping (or containing) CO_2 leak. Remediation might include surface repairs and clean up.	If movement likely, determine whether to mitigate by replacing emitted CO2 (through options including discounted credits, offsets, markets, etc) and/or stopping the leak.
Residual Risk	Decline in property values, future lawsuits, LT MMV requirements, decreased value of any carbon credits	Remediation could lead to problem of disposing of large volumes of produced brines; reduced property values, could lead to structural damage in buildings, roads, etc	Remediation could create perception issue for other CCS CO2 credits.
Warning Signals	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume	Unplanned movement of CO_2 plume
Interdependence / Risk Coupling	Contingent on successful Stages 1- 5. Evidence of secondary trapping reduces probability.	Contingent on successful Stages 1- 5.	Contingent on successful Stages 1- 5.
Priority Ranking			
Mitigation Cost			
Comments			

Table 4. Risk Log - Stage 6.0 Full Closure (continued)

ID	6.10 Lawsuits (Frivolous)	6.11 Inadvertent CO_2 Extraction	6.12 Seismicity
Description	Someone files a lawsuit for damages	Once field is closed, someone drills a well that pierces confinement zone resulting groundwater contamination, property damage, human exposure or CO_2 release	Natural seismic event causes a change in geologic formation either modifying the movement path of CO_2 or resulting in leak to surface
Timescale	This risk could start to occur during operational phase or anytime thereafter.	This risk could start anytime after closure.	This is an ongoing and permanent risk
Potentially Involved Parties	CCS Fund, Fed or State Entity, ?	Zoning Officials / Officials who permit new wells	?
Preventive Action	Tort reform, statutory liability limitations	Use MMV to track plume, ensure permitting agencies aware of hazard.	
Mitigation Response	Good documentation	Rework well to create functioning seal, remediate any damages from leaked CO_2. Put notification on property deeds	Mitigation: Potentially ventilation, containment of CO_2 Remediation: might involve cost of damages?
Residual Risk	If suits are successful or settled, could encourage others.		Stability of geology might be permanently impacted
Warning Signals			National tracking of seismic activity might suggest impending activity
Interdependence / Risk Coupling			
Priority Ranking			
Mitigation Cost			
Comments			