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Optimizing Alabama's CO_2 Storage in Shelby County (Project OASIS) - Risk Assessment

Report Type:

Deliverable Task 7

DOE Award Number:

DE-FE0032267

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Submission Date:

7-1-2025

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INTRODUCTION

The "Optimizing Alabama's CO_2 Storage in Shelby County: Project OASIS" CarbonSAFE Phase II Project seeks to build on regional data sets that demonstrate that the subsurface within Shelby County, Alabama has the potential to store commercial volumes of CO_2 safely, permanently, and economically. The primary target CO_2 Storage Complex is the deep Ketona Dolomite located within a 140 square mile area of the Valley and Ridge Region of Alabama. This deep saline reservoir is beneath a confining system encompassing at least 6,500 ft of shales and other low permeability sediments. Project OASIS drilled a deep stratigraphic test well to confirm the geological properties of the confining system and storage reservoir(s) within the Storage Complex. The geological data was incorporated into numerical models to establish the areal extent of the CO_2 plume and help design the storage site and its monitoring system.

The project is managed by the Southern States Energy Board (SSEB), an interstate compact organization consisting of governors and state legislative leaders from sixteen southern states, Puerto Rico, and the U.S. Virgin Islands, as well as an appointee by the President of the United States. The organizational compact provides it with access to state government organizations and legislatures. The Board also maintains an Associate Members program comprised of energy resource companies, utilities, trade groups, academic R&D science and technology experts and energy consultants. Further, the SSEB staff is experienced in managing and coordinating complex energy and environmental programs, from research programs to full-scale design and demonstrations of new and innovative technologies. Project OASIS is a public-private partnership of six entities with multiple principal investigators (PIs). SSEB's Lead PI and Co-PI are responsible for all aspects of project performance in accordance with the DOE-NETL Cooperative Agreement. SSEB has issued subgrants to Advanced Resources International, Inc., Alabama A&M University, Auburn University, Crescent Resource Innovation, and Oklahoma State University. Advanced Resources International, Inc., issued subgrants to Baker Hughes and Loudon Technical Services for field services

An organizational chart depicting the contractual flow down to Subrecipients and Vendors, personnel, and the scope assignment(s) per entity are provided in Figure 1 below.

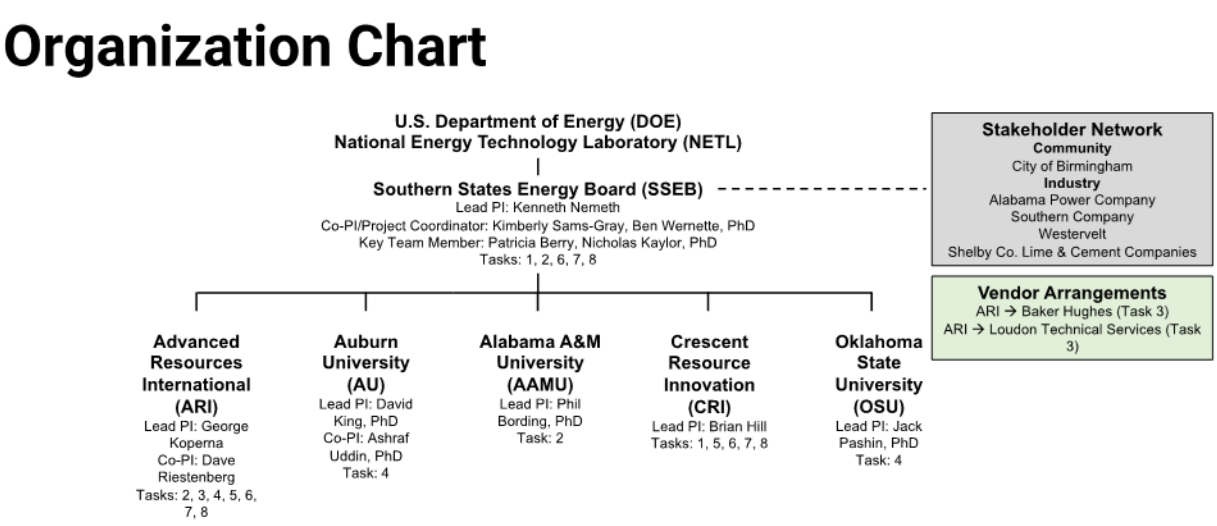

Figure 1: Project OASIS Contractual Organization Chart

RISK ASSESSMENT

The Project team conducted several multi-disciplinary risk assessment workshops to compile and then update the risk registry which identifies and evaluates the risks associated with field activities as well as some future potential risks associated with commercial-scale capture, transport, and storage at the site. The updates incorporated new site-specific information and used a semi-quantitative risk management approach (Figure 2) to analyze the data (e.g., likelihood and consequence severity values). Risks were updated or closed out in the project management plan (PMP) (Figure 3), Project OASIS drilling risk matrix (Figure 4) which was part of Task 3.4, and finally the workshop held April 29, 2025, identified potential risks for future development phases of capture, transport, and storage (Figure 5). The unique geology of the Valley and Ridge geological province in central Alabama presents the greatest challenges for potential carbon capture, utilization, and storage (CCUS) development. This region contains a thick sequence of carbonate units and chaotically bedded shales, which form the basis of the potential storage complex. Unlike the larger, more developed CCUS initiatives in Alabama's Coastal Plain, this region remains largely untapped and is geographically isolated from major pipeline networks. The stratigraphic test well was successful in evaluating the subsurface lithology and structure with collected core, sidewall core plugs, and electronic well logs as well as the 2D seismic survey and later licensed vintage regional 2D seismic lines to extend formation mapping across a broader area. A key limitation encountered during the stratigraphic

drilling phase was the inability to collect connate formation fluid samples due to low porosity and permeability. As a result, fluid composition and compatibility remain uncertain and will require direct testing in subsequent phases. Despite this, the project has made substantial progress in defining geologic risks and formulating mitigation strategies which are reviewed in the following sections of this document.

SUMMARY OF FUTURE DEVELOPMENT RISK AND MITIGATION

The risks identified for future development with a rating above medium are highlighted in yellow. These risks fall mostly in the geologic category such as confining unit does not provide adequate seal, a fracture pressure lower than expected reducing maximum injection pressure and injection rate, insufficient lateral continuity of the reservoir properties, limiting overall storage capacity, USDW deeper than expected causing redesign of project. The mitigation strategy for these risks is further characterization of the project area via subsurface testing, data collection, modeling and exploration. The highest rated operational risk is public opposition to project construction such as a pipeline, the mitigation strategy for this is early outreach to the community and education on the benefits CO_2 sequestration to the public. The two highest non-technical risks are (1) UIC Class VI permitting time-lines which the project teams would minimize by responding quickly and thoroughly to EPA Request for Additional Information (RAI), and (2) the site host or other major partner pulls out of project which would be mitigated by the project team by diversifying the project partner portfolio and finding alternative funding sources.

Figure 2: Illustration of the semi-quantitative risk methodology used in risk registry.

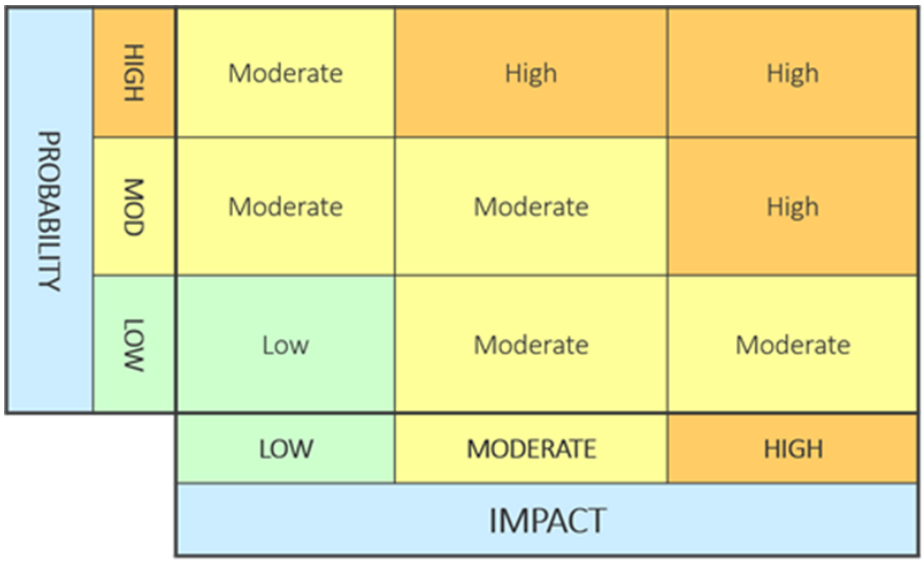

Figure 3: PMP Perceived Risks and Mitigation Strategies

Perceived Risk	Risk Rating (Low, Med, High)			Mitigation/Response Strategy Probability
	Probability	Impact	Overall	
Financial Risks:				
Delays in project start	Low	Low	Low	The projected workload will not require unacceptable pre-award commitments
Cost share not harmonized with federal spend rate	Low	Low	Low	Cost share commitment meets or exceeds required percentage and will be monitored by SSEB with each invoice submitted to NETL
Technical/Scope Risks:				
Delays due to lack of availability of key technical services/equipment	Medium	Low	Low	Field service providers and site preparation crews will be scheduled with advance notice
Unforeseen events requiring significant scope change	Low	Low	Low	The SOPO is designed to provide technical approach to the tasks while allowing flexibility in terms of specifics in order to prevent the need for significant scope change – changes in response to January 28, 2025 memorandum impacting CBP, expecting underspend for CBP tasks
Change in vendor prices increase dramatically	Low	Medium	Low	Schedule activities early, purchase long-lead items early, and consider local suppliers – tariff and inflation may impact future efforts
Wellbore stability challenges while drilling	Low	High	Medium	The new drilling program will be informed by past efforts and will include the use of rotary steerable drill bit, a larger rig, and intermediate casing to prevent sloughing of the Floyd-Parkwood shale.
Wellbore deviation complicates downhole data acquisition	Low	Medium	Medium	The Project Team will use an intermediate casing to prevent wellbore stability issues.
Management, Planning, and Oversight Risks:				
Delays in completion due to excessive staff workload	Low	Low	Low	Participants are experienced in handling multiple projects.
Delayed or late reports	Low	Low	Low	Reporting requirements and milestones are manageable and not constrained by any single participant or event – some delays but communicated to FPM in advance of deadline

Key person replacement	Medium	Low	Low	Maintain work distribution. A formal succession plan is in place for SSEB's Senior Management.
Delays in approving Foreign Nationals access	Medium	Medium	Medium	Pre-screen potential team members and provide necessary credentials to NETL for approval.
ES&H Risks:				
Environmental impacts to air, land and water resources and potential impacts of waste production	Low	Medium	Low	A comprehensive assessment for the integrated project will identify risks, mitigation plans, and ownership. The EIV also will address potential impacts to air, land, and water resources, and potential impacts of waste production.
Health and Safety risks to investigators	Low	Medium	Low	Partners will comply with host site and operations oversight have numerous HSE plans that will be adopted in the site access agreement
Health and Safety risks to investigators	Medium	Low	Low	Field activities and unique events should not increase workplace risk or exposure if applicable COVID-19 protocols are followed when meeting in person.
External Factor Risks:				
Delays due to actions required by non-project parties	Medium	Low	Low	Field service providers and site preparation crews will be scheduled with advance notice – engagement DOE-NETL has been limited as of Jan 2025 which may lead to issues
Public opposition to project may damage organizational reputation impacting ability/desire to complete future phases of project	Medium	Medium	Medium	Active engagement with local communities, decision makers, and other rights-holders throughout the project
New requirements for EJ are evolving and may impact project timeline or operations for future Phase III development	Low	Low	Low	Monitor government requirements to ensure compliance with new EJ regulations/requirements that may impact operations – EJ requirements are evolving and potentially removed from scope

Figure 4: Project OASIS drilling risk matrix

Perceived Risk	Risk Rating			Mitigation/Response Strategy
	Probability	Impact	Overall	
	(Low, Med, High)			
Financial Risks:				
Delays in project start	Low	Low	Low	Project OASIS is on the drill rig schedule and project team maintains frequent communication
Change in vendor prices (increase dramatically)	Low	Medium	Low	Where appropriate multiple bids will be collected to ensure competitive pricing
Cost overruns	Low	High	Medium	Costs and invoicing will be updated and checked against budget on a regular basis – **Update: Underspent, funds used elsewhere (to expand regional assessment)**
Insufficient government funding	Low	Medium	Medium	The budget will be closely monitored and tracked against spend throughout the field program
Government Shut Down	Medium	Medium	Medium	Funds are available through ASAP, which requires no federal approval prior to drawdown
Technical/Scope Risks:				
Delays due to lack of availability of key technical services/equipment	Medium	Low	Low	Field service providers and site preparation crews will be scheduled with advance notice, frequent communication with vendors and drill rig
Schedule slippage due to inadequate availability of resources	Low	Low	Low	Field service providers and crews are scheduled in advance reducing probability
Potential complications arising from NEPA determination or other environmental considerations	Low	Low	Low	A NEPA categorical exclusion has been received for the location; potential changes in NEPA will be evaluated throughout performance and communicated where necessary

Wellbore stability challenges while drilling	Low	High	Medium	The new drilling program is informed by past efforts and will include the use of rotary steerable drill bit, a larger rig, and intermediate casing to prevent sloughing of the Floyd-Parkwood shale; a wellbore diagnostic study conducted by Baker will be used to optimize mud weights, etc. – **Lesson Learned: Directional drilling, drilling program, etc. worked as planned; lessons learned from other efforts.**
Wellbore deviation complicates downhole data acquisition	Low	Medium	Medium	The Project Team will use an intermediate casing to prevent wellbore stability issues – **Lesson Learned: see above, minimal mushwad. However, we did meet our intended goal of drilling the entire repeat section of the Knox Group or even to the MOHO!!!**
Structural complexity complicates drilling program	Medium	Medium	Medium	2D seismic surveys have provided broad understanding of structural elements though some uncertainty remains – **Lesson Learned: regional SEI data may provide insight into other areas for drilling or where the C section is shallower (such as an anticlinal structure); gaping porosity play is not likely something that can pursued in any meaningful way (not sure how far afield these networks persist)**
Complications in updating the existing host site access agreement in order to conduct field data collection activities	Low	Low	Low	The site access agreement is in place – **Note: Westervelt was a good partner**
Budget overruns due to excessive costs	Low	Medium	Medium	ARI, vendor, and contractor experience from prior DOE drilling projects – **Lesson Learned: ROP issues, more rig days didn't really make sense, other delays relating to tripping, bits, mobilization (Note: Phase II budget may need increased to support well drilling and other activities sufficiently)**
Complications in formulating a timeline of field activities	Low	Low	Low	Timeline is prepared; long lead items (rig, casing) prepaid – **Lesson Learned: location delayed call out for field services**
Technical issues associated with drilling/completion of the characterization wells impacting schedule/budget.	Low	Medium	Medium	Structurally complex area; internally deformed/fractured units; mitigated by directional drilling and improved fluids plan

Failure to obtain well drilling permits in a timely manner	Low	Low	Low	ADEM NPDES permit in place; No AOGB permit required, NEPA categorical exclusion is in place – **Update: no issues to document**
Difficulty in managing a large team consisting of several organizations can result in delays and rework	Low	Medium	Medium	Communications organization chart in place
Inadequate project definition and/or clarity of work plan could lead to mistakes, rework, or project failure	Low	Low	Low	Project scope in place, compliant with CarbonSAFE Phase II requirements
Unavailability of project site	Closed	Closed	Closed	Closed; site access agreement is in place with Westervelt
Hung / Lost Tools	Medium	Medium	Medium	Structurally complex area; internally deformed/fractured units; mitigated by directional drilling and improved fluids plan – **Lesson Learned: Purchase tool insurance**
Poor Sidewall Core Recovery	Medium	Low	Low	Planning on whole core – **Lesson Learned: issues with whole recovery however sidewall coring was successful**
Borehole collapse	Medium	Medium	Medium	Structurally complex area; internally deformed/fractured units; mitigated by directional drilling and improved fluids plan – **Lesson Learned: Still a concern in the MUSHWAD, but not other lithologies**
Poor cement job on production casing string	Closed	Closed	Closed	Closed; no long-string (production string) casing
Casing leak	Low	Low		No hydrocarbon shows anticipated; not running long string casing
Deficiencies in Site Closure Demonstration	Low	Low	Low	Close site in accordance with Westervelt requirements as outlined in site access agreement – **grass growing, no issues to report**
Potential need for significant site restoration or other environmental impacts resulting from fieldwork	Low	Low	Low	Close site in accordance with Westervelt requirements; site was previously logged – **Update: Closed the site according to Westervelt agreement**
Management, Planning, and Oversight Risks:				

Operations status unclear due to limited reporting	Low	Low	Low	Field team is experienced and maintains a daily reporting protocol to keep the broader team informed of field activities – **Lesson Learned: Good contacts with company man, ARI management, recurring operations calls suggested**
Decision structure challenges	Low	Low	Low	Project Team has long history of collaborating and field management team keeps personnel on site -
ES&H Risks:				
Environmental impacts to air, land and water resources and potential impacts of waste production	Low	Medium	Low	All state regulations will be followed including ADEM NPDES permit requirements including the construction of berms, etc. -
Health and Safety risks to field team	Low	Medium	Low	Partners will comply with host site and operations oversight have numerous HSE plans that will be adopted in the site access agreement; PPE will be required for all personnel on location – **Update: No reported incidents**
Mobilization and equipment related safety risks	Medium	Medium	Medium	PPE will be required; frequent communication before activities and during via radio
Potential for hazardous conditions or other safety and health issues	Medium	Low	Medium	Well drilling best management practices in place; ARI has HSE plans; experienced onsite drilling supervisor
External Factor Risks:				
Delays due to actions required by non-project parties	Medium	Low	Low	Field service providers and site preparation crews have been scheduled with advance notice – **no community protests**
Stakeholder interest leads to crowded location	Medium	Low	Low	Schedule stakeholder site visits in advance with rig team and management; limit size of stakeholder groups – **Lesson Learned: managed well by those on site by staging groups, log in sheets, appropriate PPE, etc.**
Unauthorized personnel on location	Low	Low	Low	Gate personnel manage traffic and keep log of personnel on location

Public opposition to project	Medium	Medium	Medium	Active engagement with local communities, decision makers, and other rights-holders throughout the project; project is sited on privately held land and site access agreement has been executed – **Lesson Learned: need to be out in front of well drilling with public notice, but no real issue to report for OASIS**

Figure 5: Future development phases of capture, transport, and storage

Perceived Risk	Risk Rating (Low, Medium, High)			Mitigation/Response Strategy
	Probability	Impact	Overall	
Geologic Risk:				
Confining unit does not provide adequate seal	Medium	High	High	Update geomechanical model, site characterization, locate secondary units
Connate water is more saline than expected resulting in reduced CO_2 solubility	Low	Low	Low	
Fracture pressure lower than expected reducing maximum injection pressure and injection rate	Medium	High	High	Stress testing in additional characterization well
Natural fractures exist in the storage units leading to enhanced injectivity resulting in an extended CO_2 plume and limit the storage capacity of the reservoir	Low	Medium	Medium	Geologic characterization, FMI logging, coring, periodic monitoring and model evaluation
High permeability layers exist in storage units where they are not expected resulting in an extended CO_2 plume and limit the storage capacity of the reservoir	Low	Low	Low	Detailed whole core and log characterization, geophysical and petrophysical data coupling to ascertain porosity and permeability
Insufficient lateral continuity (or spatial distribution) of the reservoir properties, limiting overall storage capacity	High	High	High	Exploration program, multiple wells drilled throughout the region
Pressure is too low to have supercritical CO_2 causing larger than expected CO_2 plume	Low	Low	Low	
USDW deeper than expected causing redesign of project	Medium	High	High	Site characterization, logging data and fluid sampling data to determine salinity
New or Existing Wellbore Risk:				
CO_2 or brine leaks through a legacy well impacting a USDW or reaching the atmosphere	Low	Low	Low	Aeromag used to look for orphan wells. Investigate AOGB well databases.

CO_2 leaks through a fault or fracture impacting a USDW or reaching the atmosphere	Medium	High	High	Determine maximum injection pressure based on stress state modeling. Collect seismic data. Monitoring.
CO_2 leaks through a project well impacting a USDW or reaching the atmosphere	Low	Low	Low	Robust well design. Monitoring. CBL, MIT, Pressure tests.
Future oil and gas exploration causes CO_2 to migrate out of the storage unit	Low	Low	Low	Report project wells and AoR to regulator
Unreported/unknown legacy well location.	Low	Low	Low	Aeromag used to look for orphan wells. Investigate AOGB well databases.
Wellbore Construction Risk:				
Continuous monitoring equipment failure	Low	Low	Low	Design adequate redundancy wherever applicable, preventive maintenance plans (QASP).
Borehole collapses during cementing/casing	Low	Low	Low	Detailed borehole geomechanical modeling. Minimize time borehole is open
Cement doesn't reach surface during pumping	Low	Low	Low	Design proper cementing, staged cement job. Run caliper log before running casing
Drilling program results in poor hole rugosity/washouts	Medium	Low	Low	Pre-job planning, geologic characterization, caliper logs, CBL
Drilling results in deviated wellbore	Medium	Low	Low	Deviation surveys. Identify acceptable deviation as part of pre-job planning
Fluid injected during testing or completion reacts with formation water causing reduced injectivity	Low	Low	Low	Use KCL as needed
Geological difficulties cause drilling delays and increase costs	Low	Low	Low	
Lack of available service providers	Low	Low	Low	Identify vendors - have MSAs w/ multiple vendors. Preplanning and redundant tools on site.
Loss of well control during workover leading to CO_2 reaching the atmosphere	Low	High	Low	Pre-job planning. Have kill string in well. Maintain a stakeholder engagement plan. CO2 monitoring during workover. Require robust HSE plan for crew
Lost circulation zone requires remedial action	Low	Low	Low	Consider use of LCM in drilling fluid. Do formation tests.
Mechanical difficulties cause drilling delays and increase costs	Low	Low	Low	Rig provider selection, maintenance plan, have allowable down time in contract.
Mobilized hydrocarbons may migrate to the near-surface environment impacting USDWs or the surface.	Low	Low	Low	Trace amounts of hydrocarbons
Off depth perforation	Low	Low	Low	Pre-job planning. Verify depths prior to perf-Ing. Use right starting elevations (KB). Gamma ray & CCL.

Stuck drill pipe	Medium	Medium	Medium	Pull up to shoe during nightly shutdown. Project plan (mud hydraulic, twice daily mud checks, etc.). Realtime drilling analysis.
Poor core recovery requires additional coring runs or change of core plan	Medium	Medium	Medium	Pre-project planning. Plan for data redundancy. Allow appropriate stand by time, proper coring tools for geology
Significant micro-annuli/channeling detected in cement sheath	Medium	Low	Low	Caliper, centralizers, excess cement. Pre-job lab testing of cement slurry.
Operations - Injection/Storage Risk:				
Responsibility for Long-Term CO2 liability - Uncertainty on potential financial responsibility/impact for leakage post closure	Low	Low	Low	mechanism at state level
Injection tubing string develops a leak	Low	Low	Low	monitor pressure, early detection, use CRA
Monitoring program unable to identify CO_2 plume	Low	Moderate	Low	multiple monitoring mechanisms, robust monitoring plan
Post injection pressure plume does not stabilize as expected and applied for in the permit	Low	Low	Low	Rigorous monitoring program and modeling. Rigorous site characterization.
Increased reservoir pressure creates induced seismic event causing injection to be halted	Medium	Medium	Medium	Monitoring plan. Injection pressures remain below fault reactivation threshold.
Temperature changes during injection cause micro annulus	NA	NA	NA	
Higher than expected injection pressure causes hydraulic fracture in seal	Low	Medium	Low	pump-in test to confirm frac gradient
Operations - Capture/Transport Risk:				
Preferred pipeline route crosses an environmentally protected area	Medium	Low	Low	Environmental survey and site identification
Preferred pipeline route crosses through a populated area	Low	Low	Low	Route planning
Public opposition to pipeline construction	High	High	High	Early Outreach and education
Theft/damage of surface equipment (SCADA) results inability to collect monitoring data	Medium	Low	Low	Fence in sites
Design basis for CO_2 stream entering pipeline is delayed	Low	Low	Low	Ensure system is design for CO2 design compatibility
Operations - Business Risk:				
Inability/delay in securing project financing - Project Ownership and strength of participants will impact how the project is financed. Inability to acquire financing could delay project timing	Medium	Medium	Medium	Early interaction with banks and other financial institutions to describe project and revenue streams. Early interaction may provide opportunities to adjust the project to meet lender requirements.

Business plan for operations post 45Q - Project economics may be lower if 45Q is not increased or extended	Medium	Medium	Medium	Monitor possible state incentives as well as voluntary credit markets
Capture and Transmission Risk:				
Design basis for pipeline route changes	Medium	Medium	Medium	Planning
Capture system fails to provide required pressure at wellhead	Low	High	Low	Drill characterization well (site specific information) collaborate with subsurface team. Assessing equipment and testing. Maintenance program.
CO_2 composition changes affect fluid phase behavior and consequent injectivity	Low	Low	Low	Proper contractual arrangements
CO_2 volume changes requiring permit modification	Low	Low	Low	Communications with potential additional emitters. Permit with the potential maximum volumes to allow for upside rates.
CO_2 stream contaminants compromise injection well class	NA	NA	NA	CLOSED
Cyber security risk	Low	Low	Low	Proper MFA, cybersecurity protocols, analog backups
Insufficient electric load from grid	Low	Medium	Medium	Proper communication and procedures for loss of electrical load
Leaks in compression system and transport.	Low	Low	Low	Regular maintenance and inspections
Uncontrolled Discharge in pipeline	Low	High	High	Regular maintenance and inspections, first responder education, pipeline design
Plant shutdown	Low	Medium	Medium	Communication and planning, schedules and procedures
Transportation disruption causes supply issues	Low	Medium	Medium	Communication and planning, schedules and procedures
Capture and pipeline not operational when injection operations are ready	Low	Medium	Medium	Communication and planning, schedules and procedures
Injection operations are not ready to receive CO2 when capture and pipeline are completed	Low	Low	Low	Permit early
Inflation increases construction costs and reduces potential for FID	Medium	Medium	Medium	Order long lead items as quickly as possible. Account for more contingency.
Tarriff costs for components and/or parts not made in USA result in higher costs reducing economic viability for the project	Medium	Medium	Medium	Order long lead items as quickly as possible. Account for more contingency.
Uncertainty around potential Tarriff costs reduces corporate confidence in projected construction costs and reduces potential for FID	Medium	Medium	Medium	Order long lead items as quickly as possible. Account for more contingency.
Legal and Logistical Risk:				
Access to pore space is unattainable	Low	Medium	Medium	State of Alabama has unitization at 66%

Accident on site results in serious human injury	Low	Medium	Medium	Emergency response plans for facility. HSE plan for well construction. Contractual requirements for training and experience.
Changes/updates to EPA requirements related to construction of Injection and monitoring wells may result in increases to project costs and/or delays	Medium	Medium	Medium	Planning, communication with regulator
Limited availability of US produced well pipe resulting in increased costs and/or delays in construction sourcing necessary pipe	Medium	Medium	Medium	long lead time to source tubulars
Clas VI Permit takes longer to acquire than expected	High	High	High	early submittal, respond to RAIs quickly
State of Alabama pursuing Class VI primacy - final regulations/timing unknown and could impact project timing and/or development	Medium	Medium	Medium	monitor AL primacy process, position project to adjust, keep AL regulators in communication
Cannot get access to legacy wells for proper P&A	Low	High	Low	confirm status of legacy well(s), physical accessibility
Similar projects with problems cause objection to our project (public shift in perception)	Medium	Medium	Medium	Public outreach, good planning
Site Host or other major partner pulls out of Project	Medium	High	High	Diversify project partner portfolio, alternative funding sources