Chapter 5: Site Bank Assessment Geologic Data Report, Round 2, 2008

Brandon C. Nuttall, David C. Harris, John B. Hickman, and Michael P. Solis

The coal industry is important to Kentucky as a source of jobs, revenue, and electric-power generation. Current technology and the likelihood of a carbon-emissions-constrained future suggest the state needs to be proactive in identifying candidate sites for industrial development that include the potential for local, long-term carbon storage (sequestration). The Commonwealth of Kentucky requested nominations of potential locations for development of coal to liquids or integrated gasification combined-cycle electricity-generating utilities and requested an assessment of carbon-storage possibilities. Nineteen original sites were proposed and assessed in October 2007; these sites are superficially addressed in this report. In December 2007, an additional 26 sites were nominated for evaluation and inclusion in the site bank discussed in this report. Of the 26 sites nominated for this assessment, three were not evaluated because of lack of location data (assumed withdrawn). Twenty-three sites were evaluated by the Kentucky Geological Survey to assess geologic criteria for storage potential for the sites (Fig. 5.1). Sites 2.06 and 2.25 are substantially similar to the previously nominated sites "R" and "F," respectively.

In general, most sites have a potential for carbon storage in at least one deep saline reservoir, often the Ordovician Knox Formation. In addition, other deep formations often underlie a site, but the lack of specific and detailed subsurface and reservoir data constrain primary reliance on these zones. For Knox reservoirs, the primary seal is likely the impermeable carbonates of the Knox itself and Middle and Upper Ordovician shales (Maquoketa). The Devonian New Albany, Ohio, and Chattanooga black shales represent a secondary seal across much of the state.

Final site scores will include nongeologic factors evaluated by other contractors (transportation network, electricity and gas transmission, water supply and transportation issues, and other factors). This report does not incorporate those final scores.

Evaluation Process

Geospatial analysis was accomplished with ArcMap, a geographic information system software from ESRI. Buffers with radii of 5, 10, 15, and 20 mi were constructed for each nominated site to represent various areas of review. For the 10-, 15-, and 20-mi radii, the Kentucky portion of the area enclosed by the circle was determined. Sites with substantial portions of their areas of review in surrounding states will require interstate assessments for which the Kentucky Geologi-

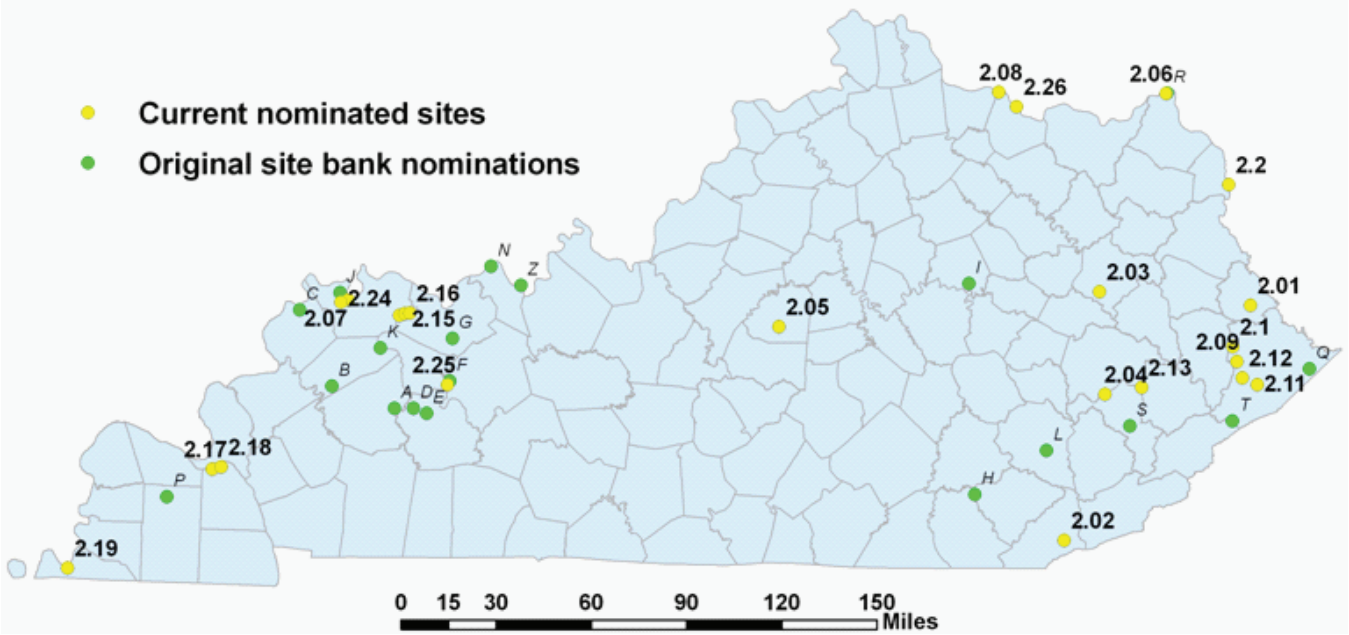

Figure 5.1. Locations of proposed sites.

cal Survey lacks sufficient data. Table 5.1 summarizes the percentage of each area of review that lies within Kentucky.

For each site, a location map was compiled to show the proposed site bounded by a 15-mi area of review. The maps show surface faults mapped at 1:24,000 scale and the oil (green shading) and gas (red shading) fields (Fig. 5.2). Individual well locations are shown where the existing oil and gas field outlines do not adequately represent recent oil and gas development or where well data are sparse. Wellbores may represent potential leakage pathways for stored CO_2 to be released to the surface. To qualitatively assess this potential, two stratigraphic intervals were selected: the Devonian black shale (Ohio–Chattanooga–New Albany), a regional seal and potential storage target; and the Ordovician Knox Dolomite, a potential regional deep saline reservoir. Figure 5.3 is an example histogram showing total depth for oil and gas wells within 10 mi of the nominated Martiki site (shown in Figure 5.2). The histogram also shows the distribution of penetrations with respect to the average depth to the top of the Devonian shale (red line) and Knox Dolomite (green line). To facilitate a future site-specific assessment, the existing deep wells were identified and reported.

Potential storage zones for each site were identified by compiling a series of structure maps showing the elevation of the Precambrian basement, Cambrian Mount Simon and Rome Sandstones, Cambrian-Ordovician Knox carbonates, Ordovician Rose Run and St. Peter Sandstones, Devonian Ohio–Chattanooga–New Albany black shale, and deep Pennsylvanian coals (assumed unmineable), in feet with respect to sea level. For example, the structure map on top of the Mount Simon in Figure 5.4 suggests that the Mount Simon is absent at the Martiki site. Other reservoir and seal intervals for each site are summarized in Table 5.2. The availability of nearby seismic-reflection survey data for investigation of the deep geology was considered in the assessment, although no seismic data were interpreted.

Figure 5.5 is an earthquake hazards map based on expected peak ground acceleration (g) with 10 percent probability of being exceeded in 50 yr (U.S. Geological Survey, 2008).The peak ground acceleration is an indicator of the shaking force that a surface structure (pipeline, coal-to-liquids plant, or other facility) might experience with a given probability (10 percent) over a specified time. The expected hazard at a particular site increases with increasing ground motion, increasing probability of occurrence, and decreasing time intervals. It should be noted that the 2008 U.S. Geological Survey hazard model was used to maintain consistency with earlier site-bank assessments; new earthquake hazard assessments and seismic risk maps are being compiled by the Kentucky Geological Survey (Wang, 2009).

Table 5.1. Percentage of area of review in Kentucky for each site.

Site ID	*5 mi %*	*10 mi %*	*15 mi %*	*20 mi %*
2.01	100	88	76	71
2.02	95	78	70	64
2.03	100	100	100	100
2.04	100	100	100	100
2.05	100	100	100	100
2.06	44	32	28	28
2.07	83	81	74	66
2.08	51	44	42	45
2.09	100	100	100	99
2.10	100	100	100	99
2.11	100	100	86	77
2.12	100	100	98	89
2.13	100	100	100	100
2.14	100	100	90	79
2.15	100	99	86	77
2.16	100	97	84	77
2.17	97	87	86	86
2.18	100	91	88	88
2.19	67	49	37	33
2.20	44	44	43	44
2.24	93	81	74	67
2.25	100	100	100	100
2.26	51	53	56	56

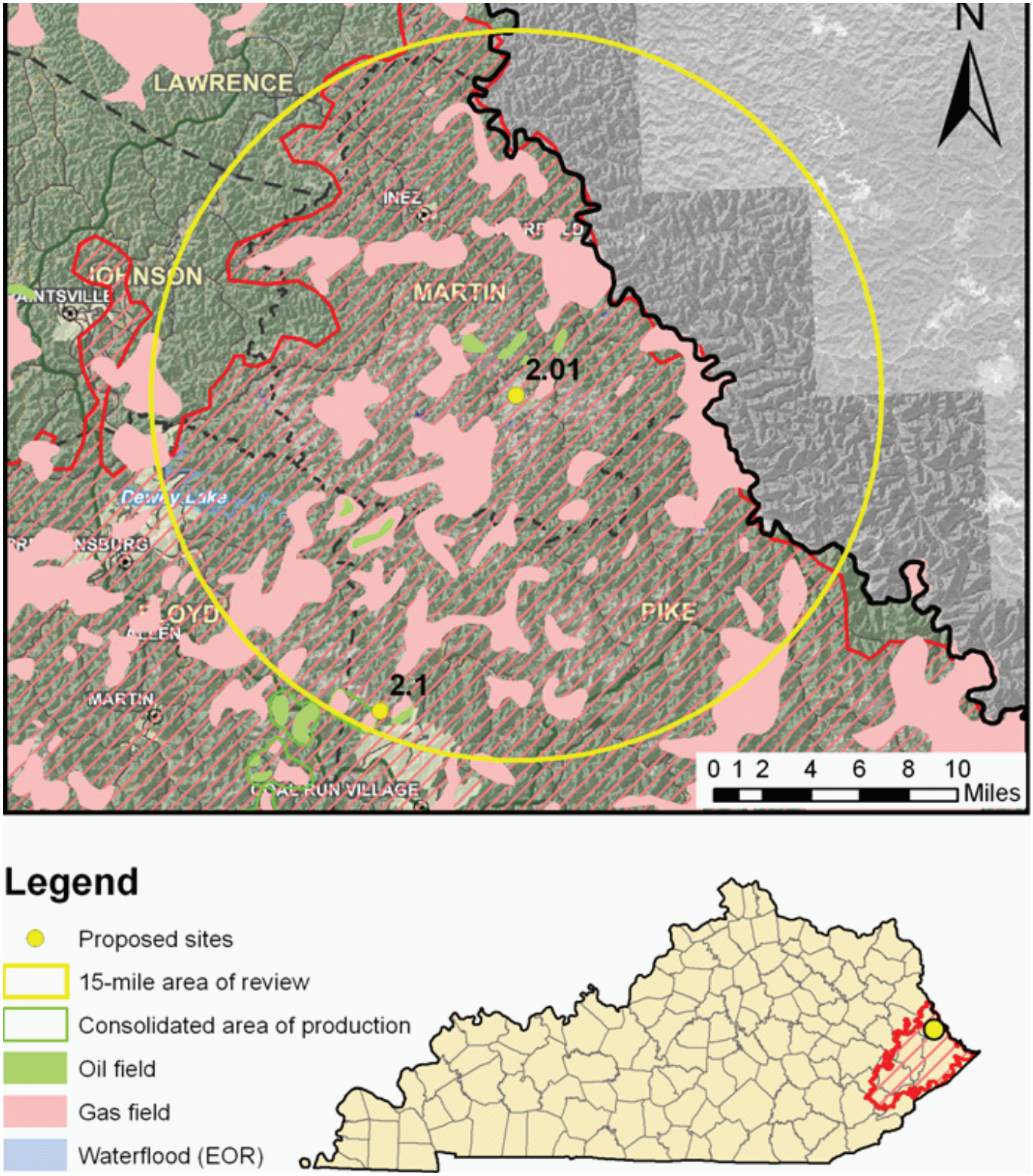

Figure 5.2. Location of site 2.01, Martiki, showing oil and gas fields in vicinity.

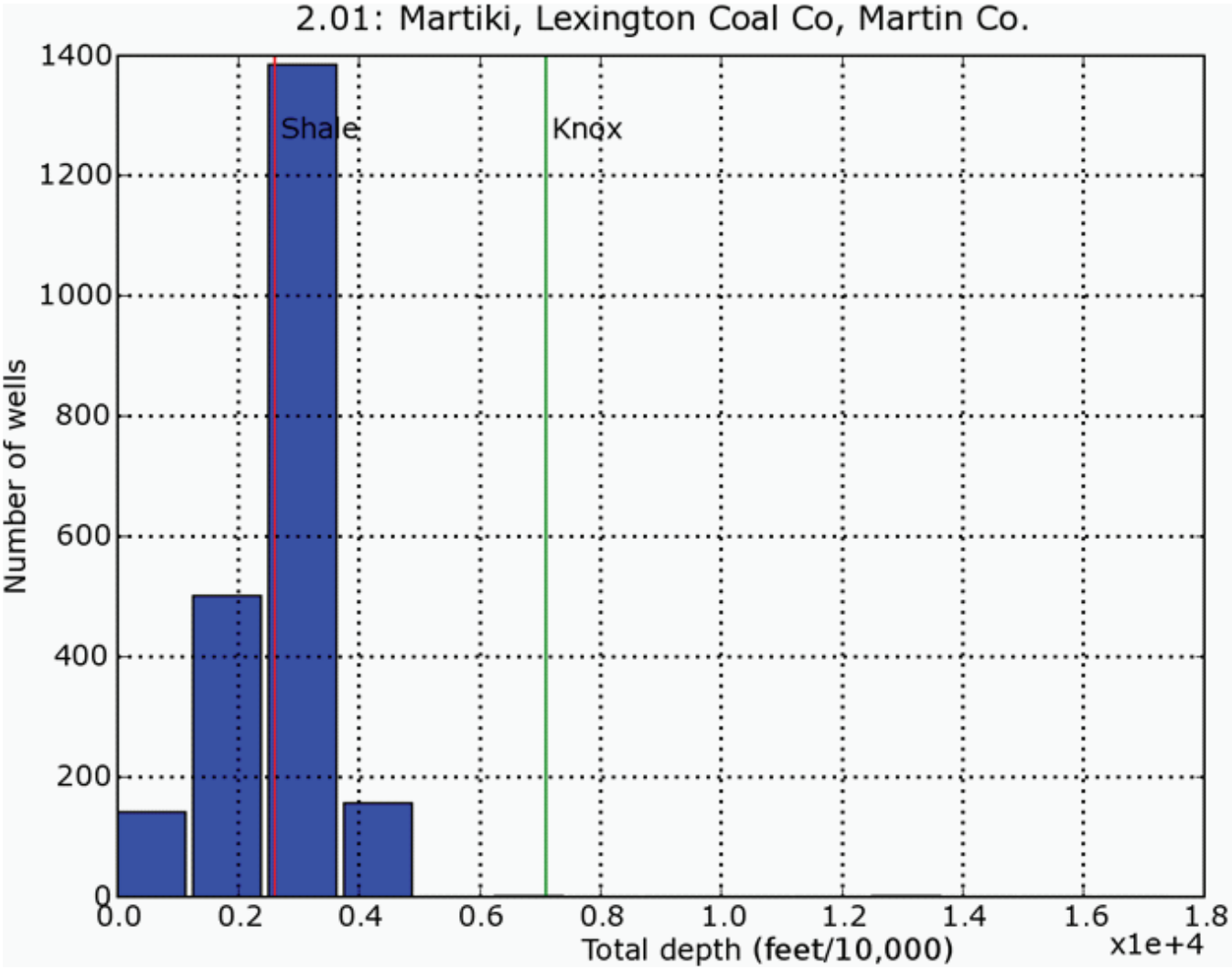

Figure 5.3. Histogram of total depth for oil and gas wells within 10 mi of the Martiki site (Fig. 5.2).

A decision matrix for scoring and ranking sites was compiled. Table 5.3 shows the criteria, the definition, and scoring rationale for ranking each of the sites. For each site, additional criteria were assessed by staff of the Smith Management Group, and the overall site scores will be included in their final report and are not provided here.

Summary

- Kentucky has a selection of sites across the state that have the potential for geologic storage of CO_2.
- Key assessment parameters include the proximity to earthquake hazard areas and the likelihood of deep saline reservoirs underlying or within a reasonable distance of the site.
- Proposed sites along Kentucky's borders require additional assessment details to incorporate interstate data.
- A full site assessment includes a variety of infrastructure and environmental factors not included in this geologic assessment. See the complete site bank assessment reports online:
  - August 2007, www.energy.ky.gov/NR/rdonlyres/05D4C7EA-51A9-4034-9021-A526A850F2FA/0/SiteBankReport.pdf (sites not addressed in this current report)
  - June 2008, www.energy.ky.gov/NR/rdonlyres/4CEFFE45-23D2-4BA6-AB48-473ADC00D582/0/SiteBankII.pdf (sites addressed in this report)

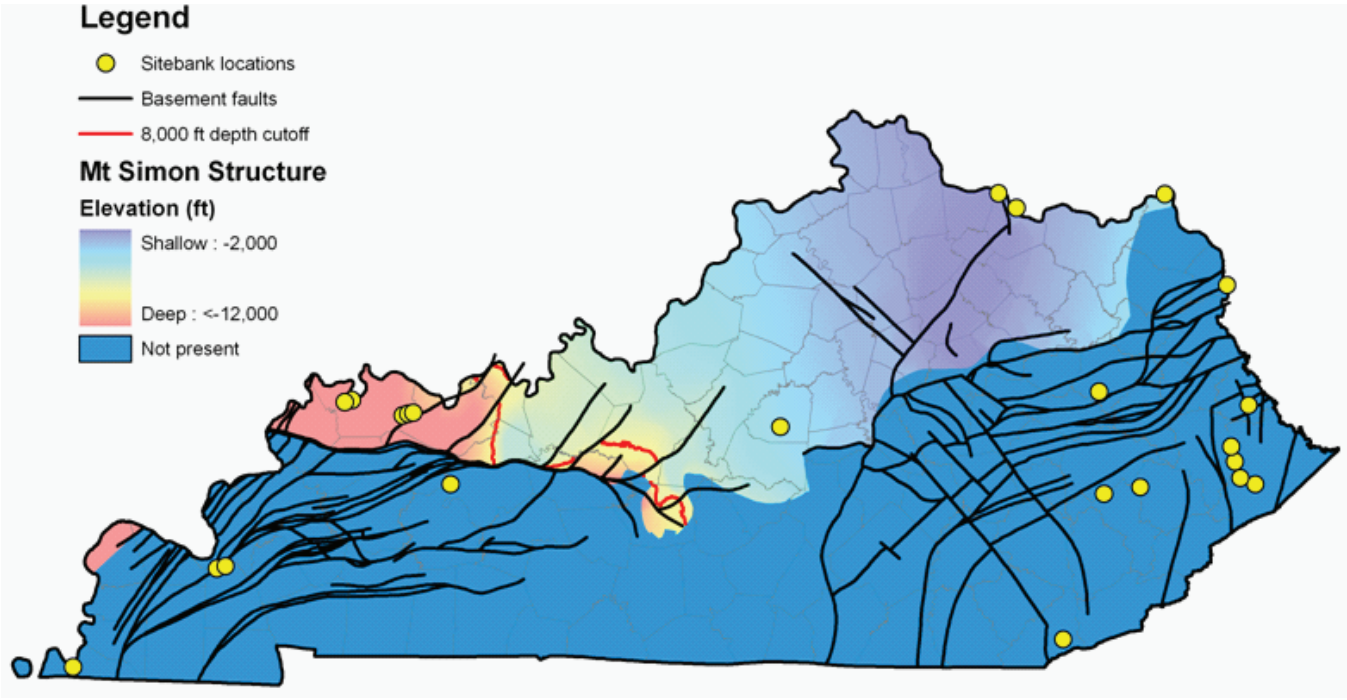

Figure 5.4. Structure on the top of the Cambrian Mount Simon Sandstone (preliminary), a potential deep saline reservoir, showing the 8,000-ft drilling-depth cutoff.

References Cited

U.S. Geological Survey, 2008, National seismic hazard maps: U.S. Geological Survey, gldims.cr.usgs.gov/website/nshmp2008/viewer.htm [accessed 5/27/2009].

Wang, Z., 2009, Earthquakes and other geologic hazards: Kentucky Geological Survey, www.uky.edu/KGS/geologichazards/ [accessed 12/22/2009].

Table 5.2. Deep saline reservoirs, primary storage targets, and primary seals that underlie proposed sites.

ID	*Company*	*Site*	*County*	*Basal Sand*	*Mount Simon*	*Rome, Conasauga, Eau Claire*	*Rose Run*	*Knox*	*St. Peter*	*Primary Seal*	*Wells Through Seal*	*Seismic Line*	*Average Top of Devonian Shale*	*Average Top of Knox*
2.01	Lexington Coal Co.	Martiki	Martin	yes	absent	yes	yes	**primary**	yes	Black River, Ordovician shales	1	none	2,600	7,100
2.02	Cumberland Valley Area Development District	Pine Mountain Regional Industrial Park	Bell	absent	absent	?	yes	**primary**	absent	Black River, Ordovician shales	8	none	3,500 (approximate base of thrust sheet)	6,600
2.03	Morgan County Government	Ky. 205 & Mountain Parkway.	Morgan	< 10% sandstone with > 4% porosity	absent	yes	yes	**primary**	yes	Black River, Ordovician shales	22	31-1a	1,200	3,600
2.04	Pine Branch Coal Sales	Pine Branch	Perry	< 10% sandstone with > 4% porosity	absent	yes	yes	**primary**	yes	Black River, Ordovician shales	5	31-1b	2,300	5,100
2.05	Hal Goode	Springfield-Washington County Commerce Center	Washington	absent	**primary**	yes	yes	**primary**	absent	Black River, Ordovician shales	4	none	shale not present in subsurface	1,200
2.06	George Arrington	South Shore	Greenup	absent	**primary**	yes	yes	yes	?	Conasauga	1	none	450	3,200
2.07	Henderson County Port Authority	Henderson County Riverport	Henderson	absent	yes	yes	absent	**primary**	yes	Maquoketa, Black River	0	231	4,100	8,200
2.08	Maysville-Mason County Industrial Development Authority	Dover, Ky., industrial site	Mason	absent	**primary**	yes	yes	yes	absent	Black River, Ordovician shales	2	none	shale not present in subsurface	1,100

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2.09	Summit Engineering Inc.	Big Shoal	Pike	< 10% sand-stone with > 4% porosity	absent	yes	yes	**primary**	yes	Black River, Ordovician shales	3	none	3,000	6,700
2.10	Summit Engineering Inc.	airport	Pike	yes?	absent	yes	yes	**primary**	yes	Black River, Ordovician shales	3	none	2,800	6,700
2.11	Summit Engineering Inc.	Hopkins Branch	Pike	< 10% sand-stone with > 4% porosity	absent	yes	yes	**primary**	absent	Black River, Ordovician shales	2	none	3,200	7,200
2.12	Summit Engineering Inc.	Marion Branch	Pike	< 10% sand-stone with > 4% porosity	absent	yes	yes	**primary**	absent	Black River, Ordovician shales	2	none	2,900	7,200
2.13	Summit Engineering Inc.	Knott County Industrial	Knott	< 10% sand-stone with > 4% porosity	absent	yes	yes	**primary**	yes	Black River, Ordovician shales	1	none	2,600	5,550
2.14	Penn Virginia Resource Partners	Area A	Henderson	absent	yes	yes	absent	**primary**	yes	Maquoketa, Black River	0	FAY-635, FAY-639, FAY-640	3,700	6,900
2.15	Penn Virginia Resource Partners	Area B	Henderson	absent	yes	yes	absent	**primary**	yes	Maquoketa, Black River	0	FAY-635, FAY-640	3,700	6,500
2.16	Penn Virginia Resource Partners	Area C	Henderson	absent	yes	yes	absent	**primary**	yes	Maquoketa, Black River	0	FAY-635, FAY-640	3,500	6,000
2.17	Mike Miller	Marshall County–Calvert City	Marshall	?	absent	yes	absent	**primary**	yes	Maquoketa, Black River	2	none	800	4,700
2.18	Bailey Port Inc.	Bailey Port	Marshall	?	absent	yes	absent	**primary**	yes	Maquoketa, Black River	1	none	800	4,700

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ID	*Company*	*Site*	*County*	*Basal Sand*	*Mount Simon*	*Rome, Conasauga, Eau Claire*	*Rose Run*	*Knox*	*St. Peter*	*Primary Seal*	*Wells Through Seal*	*Seismic Line*	*Average Top of Devonian Shale*	*Average Top of Knox*
2.19[1]	Tennessee Valley Authority	Hickman Property	Fulton	?	absent	yes	absent	**primary?**	absent	Knox carbonates?	3	DOW-2, DOW-2a	shale not present in subsurface	1,950
2.20	George Arrington General Coal Services, LLC	Big Sandy River	Boyd	yes	**primary**	yes	yes	yes	yes	Black River, Ordovician shales	5	N43D-1	1,900	5,700
2.21	Greater Owensboro Economic Development Corp.	Addison	Breckinridge	not assessed; no location provided										
2.22	Greater Owensboro Economic Development Corp.	Newman	Daviess	not assessed; no location provided										
2.23	Greater Owensboro Economic Development Corp.	W.R. Grace at Baskett	Henderson	not assessed; no location provided										
2.24	Greater Owensboro Economic Development Corp.	Tri-State at Geneva	Henderson	absent	yes	yes	absent	**primary**	yes	Maquoketa, Black River	0	none	4,200	8,000
2.25	Green River Area Development District	Big Rivers	Ohio	absent	yes	yes	absent	**primary**	**yes**	Maquoketa, Black River	6	IBK-92	3,000	6,200
2.26	Maysville–Mason County Industrial Development Authority	Maysville	Mason	absent	**primary**	yes	yes	yes	absent	Black River, Ordovician shales	3	none	shale not present in subsurface	900

[1]As of the date of this report, there were insufficient subsurface data (boreholes) to project potential storage and seals below the Ordovician Knox Formation for site 2.19, Fulton County. Interpretation of available seismic data was beyond the scope of this assessment

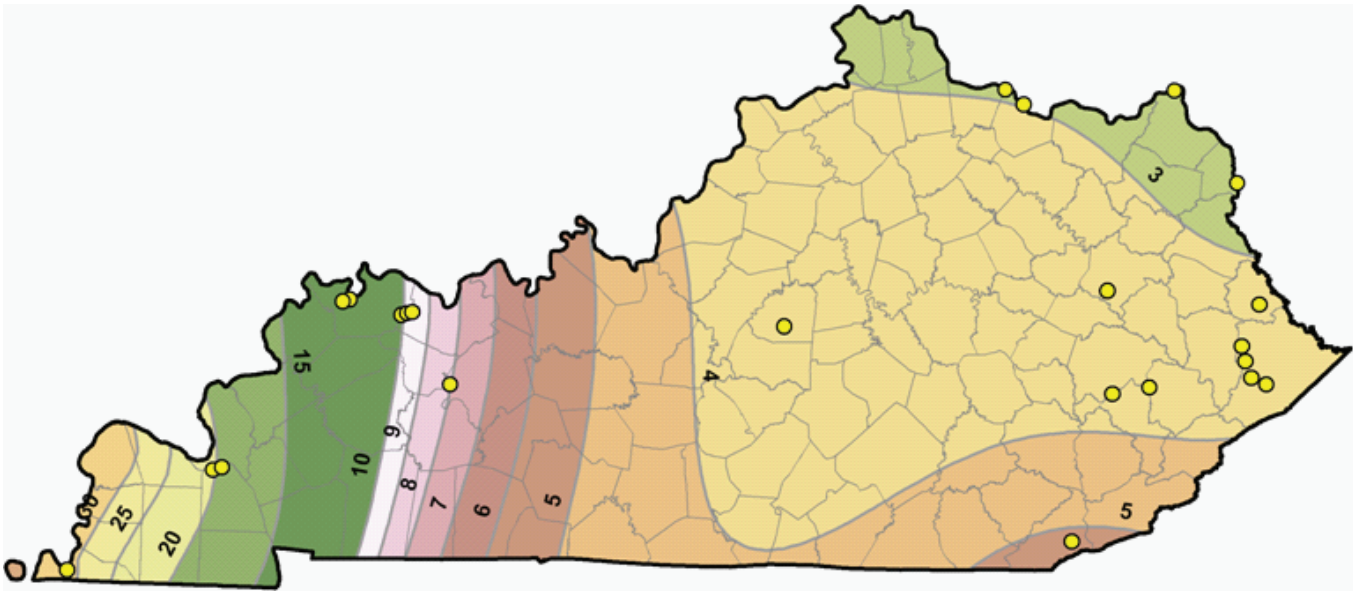

Figure 5.5. Earthquake hazard map of Kentucky showing expected ground acceleration (g) with 10 percent probability of being exceeded in 50 yr (U.S. Geological Survey, 2008).

Table 5.3. Criteria description and scoring used in decision matrix for site assessment.

Criteria	*Description*	*Qualifying Criteria*	*Rationale for Criteria*
2.1	Seismic stability	The proposed site must have low risk from significant seismic events. Proven by supporting geologic data and calculations demonstrating peak ground acceleration less than 20 percent g, with a 10 percent chance of being exceeded in 50 yr. Peak ground acceleration is the most appropriate seismic-hazard criterion because of pipeline infrastructure and other shallow subsurface facilities associated with the Site Bank Project. MCE indicates the maximum credible earthquake and is defined as included in this discussion.	See seismic risk map. 5 – 0.05 g MCE 4 – 0.10 g MCE 3 – 0.20 g MCE 0 – 0.30 g MCE 0 – 0.50 g MCE
2.2.1	Oil fields (immiscible EOR potential)	One or more oil fields within 20 mi and less than 2,500 ft depth.	CO_2 injection is a demonstrated technology for enhanced oil recovery. Storage of CO_2 when combined with recovery of additional resources is mutually beneficial. 5 – One or more oil fields within 20 mi and less than 2,500 ft depth 0 – No oil fields within 20 mi and less than 2,500 ft depth

Table 5.3. Criteria description and scoring used in decision matrix for site assessment.

Criteria	*Description*	*Qualifying Criteria*	*Rationale for Criteria*
2.2.2	Oil fields (miscible EOR potential)	One or more oil fields within 20 mi and 2,500 ft or more in depth.	CO_2injection is a demonstrated technology for enhanced oil recovery. Storage of CO_2 when combined with recovery of additional resources is mutually beneficial. Miscible flooding operations using supercritical CO_2 will sequester greater quantities of carbon than gaseous (immiscible) projects because of the density difference. 5 – One or more oil fields within 20 mi and greater than 2,500 ft depth 0 – No oil fields within 20 mi and greater than 2,500 ft depth
2.2.3	Proximity to proposed target formation	Although it is not necessary for the target formation to immediately underlie the proposed site for the Site Bank Project facility, it should be close to the proposed site in order to facilitate construction of pipelines or reduce transportation costs. It is preferable for cost and construction considerations for the proposed site and the proposed target formation to be as close to each other as possible.	5 – Target formation beneath proposed plant site 3 – Target formation within 5 mi 1 – Target formation farther than 5 mi
2.3	Other geologic factors	Comment on other geologic factors that might influence the site.	
2.3.1	Faults	Presence of mapped fault(s) within 10 mi.	Faults can be transmissive or sealing and will require further investigation. 5 – No faults within 10 mi 0 – Fault(s) within 10 mi of the site
2.3.2	Organic-rich black shale (speculative)	Known shale gas production within 10 mi, at depths of more than 1,000 ft.	In addition to acting as a reservoir seal, gas-prone areas of shale (particularly the Devonian Ohio–New Albany–Chattanooga black shale) preferentially adsorb CO_2, potentially displacing natural gas. This may provide a method of offsetting the cost of storage using enhanced gas recovery. 5 – Deep shale gas production within 10 mi 0 – No deep shale gas production within 10 mi
2.3.3	Unmineable coals	Known coal beds within 10 mi, at depths of more than 1,000 ft.	CO_2 injection into coals for enhanced coalbed methane (natural gas) recovery has been demonstrated. This may provide a method of offsetting the cost of storage using enhanced gas recovery. 5 – Deep coal beds within 10 mi 0 – No deep coal beds within 10 mi

Table 5.3. Criteria description and scoring used in decision matrix for site assessment.

Criteria	*Description*	*Qualifying Criteria*	*Rationale for Criteria*
A 2.1	Deep saline reservoir (proven)	Well or core *within 1 mi* of the proposed site that demonstrates suitable thickness, porosity, and permeability, that is 2,500 to 10,000 ft in depth, and has at least one demonstrated overlying seal at least 20 ft thick.	Current best practice indicates that deep saline formations are likely to have the largest capacity for long-term storage of CO_2 as a supercritical fluid. This criteria is intended to demonstrate the presence and utility of such a zone in the immediate vicinity of the proposed site. 5 – Well or core within 1 mi 0 – No well or core within 1 mi
A 2.2	Deep saline reservoir (probable)	A well or core that is *1 to 15 mi* away from the proposed site demonstrates the likelihood of suitable porosity or permeability between 2,500 and 10,000 ft depth and indicates 20 ft or more of impermeable seals in the overlying strata.	Current best practice indicates that deep saline formations are likely to have the largest capacity for long-term storage of CO_2 as a supercritical fluid. This criteria is intended to indicate the probable presence and utility of such a zone as demonstrated by one or more wells a reasonable distance from the proposed site. 5 – Well or core between 1 and 15 mi 0 – No well or core between 1 and 15 mi
A 2.3	Deep saline reservoir (speculative)	A well or core that is *15 to 25 mi* away from the proposed site indicates that a porous and permeable zone between 2,500 and 10,000 ft depth and with 20 ft or more of impermeable seals in the overlying strata can be inferred to be underlying the proposed site.	Current best practice indicates that deep saline formations are likely to have the largest capacity for long-term storage of CO_2. This criteria is intended to indicate the presence of such a zone is likely, but no well data within a reasonable distance from the proposed site are available on which to base an assessment. 5 – Well or core within 15 to 25 mi 0 – No well or core within 15 to 25 mi
A 2.4	Demonstrated closure	Sufficient data to show structural closure on primary saline reservoir target *within 15 mi*	Current best practice indicates the presence of a structural closure will limit migration of injected CO_2. 5 – Structural closure on primary target 0 – Insufficient closure on primary target
A 2.5	Multiple deep saline reservoirs	Two or more *proven* or *probable* saline reservoirs as defined above.	Multiple stacked intervals increases the likelihood of sufficient capacity for storage. 5 – Two or more saline reservoirs 0 – Fewer than two saline reservoirs
A 2.6	Demonstrated closure	Sufficient data to show structural closure on one or more of the available oil reservoirs for storage (miscible or immiscible) *within 15 mi.*	Structural closure will limit migration of injected CO_2. Additional analysis is required to determine the volume of the closure to its spill point. 5 – One or more available reservoirs 0 – No structural closure on available reservoirs

Table 5.3. Criteria description and scoring used in decision matrix for site assessment.

Criteria	*Description*	*Qualifying Criteria*	*Rationale for Criteria*
A 2.7	Subsurface activity/ access	The presence of oil and gas fields, underground coal mines, or limestone/aggregate quarries within *10 mi.*	Need to assess potential issues with respect to mining health and safety, ownership and leases of the mineral estate, and potential subsurface access conflicts. 5 – No sites within 10 mi 0 – Sites within 10 mi
A 2.8	Well penetrations into primary seal	Number of penetrations through the primary seal of the main target formation within a *10-mi area of review.*	Wellbores represent potential migration pathways for CO_2 leakage into underground sources of drinking water or to the surface. Need to assess integrity of the seal with respect to the density (number) of wellbores, their depths, and the possibility of unlocated holes to ensure CO_2 does not leak. 5 – Zero to three well penetrations within 10 mi 3 – Three to six well penetrations within 10 mi 0 – More than six well penetrations within 10 mi
A 2.9	Availability of seismic-reflection data	Seismic lines within *5 mi* of the site	Seismic-reflection data are essential for use in assessing the nature and potential integrity of a unit for storage and modeling the geometry of the area of pore space to be contacted by CO_2. 1 – Seismic lines available within 5 mi 0 – No seismic lines available within 5 mi