APPENDIX D
RISK ASSESSMENT METHODOLOGY

There are numerous human-health and ecological issues associated with the construction and operation of any large coal-fueled electric power generation facility. The FutureGen Project would represent a technological advancement in power generation that integrates advanced coal gasification technology, the production of hydrogen from coal, electric power generation, and carbon dioxide (CO_2) capture and geologic storage. Carbon capture and storage technology is an innovative method for reducing greenhouse gas emissions, but the new technology comes with added design and operational complexities and potential health, safety and environmental risks. The FutureGen Project Risk Assessment (TetraTech, 2007) addressed the potential human-health and environmental effects associated with the capture of CO_2 and other trace gases at the power plant, gas transportation via pipeline to the geologic storage site, and subsurface storage. The risk assessment was conducted to support the preparation of an Environmental Impact Statement (EIS) for the FutureGen Project. The technical approach and methodology employed in this risk assessment are described below.

The approach to risk analysis for CO_2 capture and sequestration in geologic formations is still evolving. However, a substantial amount of information exists on the assessment and management of releases associated with the geologic storage of CO_2 from natural-gas storage, deep injection of hazardous waste, and the injection of either gaseous or supercritical CO_2 in hydrocarbon reservoirs for enhanced oil recovery. There are also numerous projects underway at active CO_2 injection sites to determine the long-term fate of CO_2 injected into deep geological formations. The FutureGen Project Risk Assessment relied heavily on the technical approaches and findings from these previous and ongoing projects. However, the FutureGen Project Risk Assessment was based largely on site-specific information. The risk assessment also utilized a common set of performance characteristics and hazard scenarios to provide a basis for comparing the four candidate sites.

The risk assessment was conducted according to a work plan reviewed by a panel of carbon capture/storage and risk assessment experts. The approved work plan provided a detailed description of the approach applied to the analysis of the identified pre- and post-injection risk issues. There were five primary elements outlined in the risk assessment:

- Conceptual Site Models (CSMs)
- Toxicity Assessment
- Risk Evaluation for the Capture and Transport of Gaseous Emissions (Pre-Injection)
- Risk Evaluation for the Storage of CO_2 and Hydrogen Sulfide (H_2S) in Subsurface Reservoirs (Post-Injection)
- Risk Screening and Performance Assessment

A central task in the FutureGen Project Risk Assessment was the development of the conceptual site models (CSMs) for the four proposed locations. Potential exposure pathways of gas release during capture, transport and storage were identified. The chemicals involved in the capture and sequestration process and their potential short-term and long-term health effects were identified and discussed. Then, detailed descriptions for each of the four candidate sites were provided. These descriptions included population and community characteristics, general surface features, aquatic and terrestrial ecology, and the geologic features that were critical to the determination of the feasibility of subsurface injection and sequestration of gaseous emissions from the power plant.

A toxicity assessment was conducted to review chemical toxicity data and to identify chemicals of potential concern that could cause adverse human-health and environmental effects. These data provided the basis for the comparison of estimated exposures and the assessment of potential risks. CO_2 was the main chemical in this analysis, but toxicity data were also compiled and evaluated for other chemicals, including H_2S, carbon monoxide, methane, mercury, and cyanide. The most important outcome of this analysis was the selection of benchmark concentrations for chemicals of potential concern. These benchmarks, developed for each potential exposure scenario and several different effect levels, served as the basis for the evaluation of potential risk to human populations and identified ecological receptors.

The risks associated with the capture and transport of gaseous emissions, prior to injection into the geologic reservoirs, were evaluated separately from the post-injection or subsurface phases of the FutureGen Project. The surface portion of the risk assessment evaluated the potential risks associated with the plant and aboveground facilities for separating, compressing and transporting CO_2 to the injection site. Failures of the engineered system evaluated included: pipeline rupture, pipeline puncture (i.e., releases through a small hole), and rupture of the wellhead injection equipment. Accidental releases from the pipeline or wellhead, although expected to be infrequent, could potentially affect the general public in the vicinity of a release. The carbon dioxide pipeline failure frequency was calculated based on data contained in the on-line library of the Office of Pipeline Safety (http://ops.dot.gov/stats/IA98.htm). Accident data from 1994-2006 indicated that 31 accidents occurred during this time period. DOE chose to categorize the two accidents with the largest carbon dioxide releases (4000 barrels and 7408 barrels) as rupture type releases, and the next four highest releases (772 barrels to 3600 barrels) as puncture type releases. For comparison, 5 miles (8 km) of FutureGen pipeline would contain about 6500 barrels, depending on the pipeline diameter. Based on data in Gale and Davison (2004), the rupture and puncture failure frequencies were calculated to be 5.92×10^{-5}/(km-yr) and 1.18×10^{-4}/(km-yr), respectively, assuming the total length of pipeline involved was approximately 1616 miles (2600 km). The annual pipeline failure frequencies used in this assessment were calculated based on the site-specific pipeline lengths. The failure rate of wellhead equipment during operation was estimated as 2.02×10^{-5} per well per year based on natural gas injection-well experience from an IEA GHG Study (Papanikolau et al., 2006).

Simulation models were used to estimate the emission of CO_2 for the aboveground release scenarios when the gas is in a supercritical state. The SLAB model developed by the Lawrence Livermore National Laboratory and approved by U.S. EPA was used to simulate denser-than-air gas releases for both horizontal jet and vertically elevated jet scenarios. The model simulations were conducted for the case with CO_2 at 95 percent and H_2S at 100 parts per million by volume (ppmv). The state of the contained captured gas prior to release is important with respect to temperature, pressure, and the presence of other constituents. Release of CO_2 under pressure would likely cause rapid expansion and then reduction in temperature and pressure, which can result in formation of solid-phase CO_2, as explained in Appendix C-III of the risk assessment. The estimated quantity of solid-phase formed was 26 percent of the volume released; therefore 74 percent of the volume released from a pipeline rupture or puncture was used as input to the SLAB model for computing atmospheric releases of CO_2 and H_2S. Carbon dioxide is heavier than air and subsequent atmospheric transport and dispersion can be substantially affected by the temperature and density state of the initially released CO_2. The meteorological conditions at the time of the release would also affect the behavior and potential hazard of such a release.

The potential effects of CO_2 and H_2S releases from pipeline ruptures and punctures were evaluated using an automated "pipeline-walk" analysis. The "pipeline-walk" analysis was developed to determine impacts of pipeline accidents along the entire length of the proposed CO_2 pipelines. The analysis examined each pipeline at 300-meter (984-foot) intervals, starting at the power plant and ending at the injection site. Site specific meteorological data were applied and an accident (rupture or puncture) computer simulation model (SLAB model) was run for 112 defined atmospheric states to determine the potential impact zone. At each 300-meter interval, population density information from the 2000 Census was applied to each of the impact zones to provide a weighted-average or expected number of persons affected. The total number of persons reported as affected by a release at each interval was determined by multiplying the number of individuals in each segment of the impact zone by the proportion of time (relative importance) of each of the 112 atmospheric states. The methodology is described in detail in Section 4.4.2 and Appendix C-IV of the risk assessment) The predicted concentrations in air were used to estimate the potential for exposure and any resulting impacts on plant workers, nearby residents, sensitive receptors, and ecological receptors.

The post-injection risk assessment presents the analysis of potential impacts from the release of CO_2 and H_2S after the injection into subsurface reservoirs. A key aspect of this analysis was the compilation of a database that included the site characteristics and results from studies performed at other CO_2 storage locations, and from sites with natural CO_2 accumulations and releases.

The analog-site database includes information on leakage of CO_2 from existing injection sites and natural releases. Information has been obtained on four existing injection sites, 16 natural CO_2 sites in sedimentary rock formations, and 17 sites in volcanic or geothermal areas. The types of information collected include: description of the zone with CO_2, physical characteristics of the primary and secondary seals and secondary porous zone (if present), information on shallow groundwater and surface water, nearby faults, numbers of nearby wells, the amount of CO_2 released from leakage or a natural event, the conditions present at that time, and any known effects. Not all information was pertinent for a given site and not all the information could be obtained.

This database was used for characterizing the nature of potential risks associated with surface leakage through cap-rock seal failures, faults, fractures or wells. CO_2 leakage from the target reservoirs was estimated using a combination of relevant industry experience, natural analog studies, modeling, and expert judgment. Both qualitative and quantitative analyses were conducted to evaluate risks from potential releases. A qualitative risk screening of the four candidate sites was presented based upon a systems analysis of the site features and scenarios portrayed in the CSM. Risks were qualitatively weighted and prioritized using procedures identified in a health, safety, and environmental risk screening and ranking framework for geologic CO_2 storage site selection. More detailed evaluations were conducted by estimating potential gas emission rates and durations from the analog database for a series of release scenarios and using the results of model simulations of subsurface leakage presented in the final Environmental Information Volumes.

Three scenarios could potentially cause acute effects: upward leakage through the CO_2 injection wells; upward leakage through the deep oil and gas wells; and upward leakage through undocumented, abandoned, or poorly constructed wells. Six scenarios could potentially cause chronic effects: upward leakage through caprock and seals by gradual failure; release through existing faults due to effects of increased pressure; release through induced faults due to effects of increased pressure (local over-pressure); upward leakage through the CO_2 injection wells; upward leakage through the deep oil and gas wells; and upward leakage through undocumented, abandoned, or poorly constructed wells. For the chronic-effects case for the latter three well scenarios, the gas emission rates were estimated to be at a lower rate for a longer duration. The atmospheric transport of released gas from these potential post-injection releases was estimated through modeling using a U.S. Environmental Protection Agency-approved screening model. The predicted concentrations in air were used to estimate the potential for exposure and any resulting impacts on workers, nearby residents, sensitive receptors, and ecological receptors. Other scenarios including catastrophic failure of the caprock and seals above the sequestration reservoir and fugitive emissions were discussed, but not evaluated in a quantitative manner.

The risk screening and performance assessment section of the risk assessment presents comparisons for each site to appropriate health-effects criteria for CO_2 and H_2S. Risk ratios (i.e., the ratio between the predicted atmospheric gas concentration and the benchmark health-effects criteria) were calculated for both human and ecological receptors. A risk ratio less than one indicates that the effect is unlikely to occur. Higher risk ratios generally represent the potential for higher levels of health concern, although regulatory derived toxicity values include safety factors to ensure protection of sensitive individuals. Probabilities for each of the identified exposure scenarios were calculated from the best data presently available for annual frequencies and for site-specific factors that affect the outcomes at each site. A range of probabilities associated with the identified exposure scenarios was presented and discussed.

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References:

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