The most promising approach to solve the carbon problem involves widespread implementation of zero-emission power plants. These are likely to be fossil fuel-based plants with carbon capture and storage (CCS) technology. Low-emission electricity has the secondary advantage of allowing for electrification of the transportation sector, and as such can lead to very large reductions in CO2 emissions if implemented at the global scale. While a variety of storage options are being studied, geological storage appears to be most viable. Injection of captured CO2 into deep geological formations leads to a fairly complex flow system involving multiple fluid phases, a range of potential geochemical reactions, and mass transfer across phase interfaces. General models of this system are computationally demanding, with the problem made more difficult by the large range of spatial scales involved, and the importance of local features for both fluid flow and geochemical reactions. An especially important local feature involves leakage pathways, with one example being abandoned wells associated with the century-long legacy of oil and gas exploration and production. Such pathways also have large uncertainties associated with their properties. Therefore, inclusion of leakage in the storage analysis requires resolution of multiple scales, and incorporation of large uncertainties. Taken together, these render standard numerical simulators ineffective due to their excessive computational demands. A series of simplifications to the governing equations can reduce computational demands, and ultimately render the system solvable by analytical or semi-analytical methods. These solutions, while restrictive in their assumptions, allow for large-scale analysis of leakage in a probabilistic framework. An example from Alberta, Canada will be used to demonstrate the utility of these solutions.