A. Appraisal of Current Geoenvironmental Research, Education and Practice

Research initially has been driven significantly by environmental problems associated with uncontrolled waste disposal sites. Regulations and regulatory agencies had significant impact on the initial development of research programs and technologies investigated. Significant advances have occurred in waste containment field over the last few decades.

Containment Systems: Highly engineered systems have been developed for barrier layers (liners and covers) and also systems have been developed for effectively collecting and mitigating containment byproducts (leachate and gas collection systems) using natural and synthetic materials. Wastes have been classified and systems have been developed as a function of the hazard levels associated with wastes. Design and construction of containment systems have been optimized for the intended applications. Technologies highly protective of the environment have been developed that essentially eliminate hydraulic leakage and reduce mass transport in the short-term. While the effectiveness of these systems has been well-established for the short-term, long-term effectiveness of the systems has not been fully investigated.

Teaching

Most universities have geoenvironmental engineering components included in their curricula with several universities that offer well-developed specialty programs in this area. Series of courses have been developed to cover various aspects of waste containment applications. These courses and specialized programs are typically offered at the graduate level. While several undergraduate level course books include geoenvironmental topics, generally waste containment topics are not included at the undergraduate level. In addition to university programs, several short courses have also been developed for waste containment education. These courses have been offered regularly in the last two decades. Decline in the short course offerings and professional education opportunities have occurred in the last few years.

Geoenvironmental engineering education requires interdisciplinary training. Students take a variety of courses to fulfill the requirements of geoenvironmental engineering education. The nature of these courses and topics vary between different institutions. Programs are available that allow for education in a broad range of topics and programs
are available that include a wide range of topics with a requirement for focused study in a particular area.

Practice
Similar to the rapid progress in the waste containment research, there has been significant progress in the professional practice for waste containment. Various design and construction methodologies have been developed and used in waste containment practice. The designs and construction practices have been significantly affected by regulatory requirements. Generally the level of sophistication in designs has not been beyond regulatory requirements and development of innovative approaches has not been heavily pursued by practitioners. Knowledge and technology transfer from research studies to routine practice has not been fully accomplished.

B. Appraisal of Emerging and Future Issues in Geoenvironmental Research, Education and Practice
Research
Various emerging research areas have been identified within waste containment category. These include alternative landfilling technologies most notably bioreactor landfills; alternative waste containment materials including manufactured clays with varying properties, active (biologically or otherwise) liners, and new geosynthetic materials; nondestructive testing and monitoring of containment facilities; sensors and sensing technologies for containment facilities; reactive barriers; fate and transport of various chemicals (in particular organic chemicals) through liner systems; containment of various waste types such as radioactive wastes, mining wastes, agricultural wastes, and e-wastes, potential changes in waste streams; settlement of wastes and development of fundamental principles of waste settlement; and thermal aspects of containment facilities.

Two large-scale broad-based research efforts have been identified as priorities during the workshop meetings. These efforts are to be undertaken by multi-institution teams with contributions from multi-disciplinary units. These research areas are established in response to the long-term monitoring and model verification needs for assessment of the effectiveness of containment systems and sustainable waste containment needs that are identified as highest priority research areas during the workshop. The waste containment area has reached a level, where development of individual components of these systems are complete, yet the performance, in particular long-term performance, of integrated systems are not well-known:
National Geoenvironmental Research Programs – These are long-term research and development programs that include significant field components. Ultimate goal of these programs is establishing advanced waste containment systems that not only protect the environment now, but provide environmental protection for future generations. Significant outcomes of these programs are:

• Determination of long-term performance and effectiveness of containment systems using thematic areas of focused parameters.
• Establishing databases that contain the information gathered as well as provisions for transfer of data among participants of the programs and also outside researchers, regulatory agencies, and the general public.
• Determination of uncertainties and quantification of risks associated with containment systems.
• Assessment of existing predictive performance models as well as development of new models.
• Determination of various innovative aspects including innovative materials, innovative designs, new sensor technologies, new monitoring schemes, etc.
• Establishing better long-term stewardship including policy making.
• Providing higher level of technology and information exchange and transfer between researchers, educators, practitioners, and regulators.
• Assessment of energy production (gas and thermal) potential from waste containment facilities.
• Determination of environmental impacts of containment facilities on the global environment including effects of landfill gases on air quality as well as carbon balance in the environment.

It is recommended that these programs start with the analysis of various existing highly instrumented containment sites. Funding sources identified are NSF and joint sponsorship by NSF, EPA, and DOE as well as potential contributions from the industry. It is recommended to form a working group for further developing this research topic.

Sustainable Waste Management Systems – This research area includes development of sustainable containment approaches as well as sustainable containment materials. The two systems identified are: “walk-away” containment systems that are expected to be facilities that do not have any potential environmental impacts at the end of their service life, and continuously operating containment systems that can be used for waste containment for much longer periods of time compared with the service life of current containment facilities. The research includes analysis of waste materials and containment systems as well as various added topics including societal and economic factors. The Geoenvironmental Research Programs are expected to generate the necessary baseline investigation for this second research topic. The two identified topics are closely interrelated and the information obtained from these studies is mutually inclusive.

Education
Common topics to be included in geoenvironmental curricula are identified as containment principles, contaminant transport, and contaminant – containment material interactions. The workshop attendees believe that these areas are generally well covered within the geoenvironmental programs. An area that is identified as an emerging area within geoenvironmental engineering is biology and microbiology. Analysis of various containment systems and also remediation technologies require understanding of biological principles, which are typically not included in geoenvironmental programs. It is recommended to organize a workshop to identify basic biology principles that are applicable in geoenvironmental engineering and to develop courses and course series to be included in geoenvironmental engineering education. The workshop is to be
organized with participation from civil engineering departments and science departments. Lakshmi Reddi from Kansas State University will take the lead for developing the workshop.

A need for textbooks in waste containment area as well as overall geoenvironmental engineering field has been identified. There is a general need for books in the waste containment area.

**Practice**
The waste containment industry has developed significantly in the last several decades. Applicable design methods for containment systems are available. However, the design methods are not always properly applied in practice. Areas where problems are encountered include slope stability and erosion. It is also noted that these areas represent easily observed issues. There may be other problematic issues not readily observed over the short-term, but may become apparent in the long-term. Overall, there is need for better technology transfer from research to industry and regulatory agencies. There is also need for added involvement of researchers and practitioners in policy making.

For many containment applications, economic, social, and regulatory issues gain priority over technical issues and design considerations. The importance of technical issues in these applications has to be better stressed. It has been noted that common geoenvironmental engineering services have become commodity engineering with tight budgets and small profit margins. The level of sophistication and innovation in practice needs to be increased to elevate the state of the industry.