Energy Laboratory
Massachusetts Institute of Technology

PROSPECTUS

CARBON SEQUESTRATION INITIATIVE

January 2000
Background and Motivation

Over the past ten years, the focus of the climate change debate has been changing. We are moving away from arguments over whether the “greenhouse theory” is valid, to discussions about the magnitude of the problem and the appropriate political and technical responses. Industry has led this change in focus, as more and more companies echo the sentiment “climate change cannot be ignored.” Industry also realizes that there is still considerable uncertainty, making it imprudent to implement costly greenhouse gas emissions reduction technologies at present. However, the time is right to explore the technology options. In order to help industry in this task, the MIT Energy Laboratory is proposing to lead a consortium of companies in exploring the potential for carbon sequestration technologies.

Carbon sequestration, sometimes referred to more broadly as carbon management, is a way to reduce greenhouse gas emissions while still enjoying the benefits of fossil fuel use. Taken together with improved energy efficiency, this strategy represents an alternative to the large-scale replacement of fossil fuels with non-carbon energy sources. Interest has been increasing in the carbon management option because it is very compatible with the large energy production and delivery infrastructure now in place and because non-fossil energy sources face large barriers -- renewables are very expensive and nuclear has public acceptance problems.

Carbon sequestration was mentioned in the literature as early as 1977 in a paper by Cesare Marchetti of the International Institute for Applied Systems Analysis (IIASA), however it has only been in the last ten years that significant research efforts have been undertaken. The MIT Energy Laboratory has been one of the pioneering organizations at the forefront of this field (see Attachment A - Research into Carbon Management at the MIT Energy Laboratory). We have worked closely with the U.S. Department of Energy (DOE) on assessing the potential for these technologies, identifying research priorities, and conducting research projects. In the past few years, there has been more and more industrial interest and participation. As we head into the second decade of significant activity, research that has consisted primarily of theoretical or laboratory studies is ready to be augmented with field studies and even demonstration projects.

Sequestration covers technologies that capture carbon at its source and direct it to non-atmospheric sinks, as well as processes that increase the removal of carbon from the atmosphere by natural processes (e.g., forestation). Our past efforts at the Energy Laboratory have focussed on direct capture and storage technologies and we expect that would also be the focus of the
proposed consortium. However, we do have some expertise in enhancing natural processes and, while not the major thrust of the consortium, we can address some issues in that field.

On November 17, 1999, we held a planning meeting to help outline the objectives and scope of this carbon sequestration initiative. Companies attending included Norsk Hydro, Electricité de France, BP Amoco, Statoil, Kawasaki Heavy Industries, American Electric Power, Peabody Group, Mobil, Texaco and General Motors. We have used input from that meeting in developing this prospectus.

Objectives

We propose the following objectives for the consortium:

- Provide an objective source of assessment and information about carbon sequestration
- Establish a members’ information network to provide timely updates on relevant activities and new findings
- Explore the societal aspects of carbon sequestration as well as the technical ones
- Educate a wider audience on the possibilities of carbon sequestration
- Link industry to expanding governmental activities on these topics
- Stimulate and seed new research ideas
- Create an annual forum for strategic thinking and identification of new business opportunities

Consortium Components

To achieve our objectives, we will establish three main consortium components or tasks. We will reexamine these tasks in year three of the consortium and make modifications and additions as required. This section gives a broad description of the tasks. Ideas for specific topics can be found in Attachment B.

Task 1. Assessment and Outreach. This is an area in which the MIT Energy Laboratory has made a large contribution over the last ten years, primarily with funding from the U.S. DOE. We have written several highly regarded assessment reports on the topic of carbon sequestration, including our 1993 Research Needs Assessment and our 1997 White Paper. Our work with DOE will continue, but this consortium task will complement that effort by:

- Analyzing carbon sequestration strategies and technologies in an objective manner from an industrial perspective and feeding this general guidance back to DOE.
- Identifying areas for new business opportunities that arise as a result of carbon sequestration.
- Providing a credible and objective viewpoint on carbon management. This has always been one of our major strengths, but becomes more important as the carbon management field grows and many of the participants have vested interests and hidden agendas.
• Getting the message out to a wider audience about the potential for the carbon management strategy because public acceptance is crucial to any eventual implementation. Public outreach is needed because there are many groups whose agenda is helped by opposing fossil energy. Therefore, they will fight any technology that promotes the clean use of fossil. An axiom from politics applies to this case – if a candidate doesn’t define himself for voters, his opponent will, and not in flattering terms. As an example of an outreach activity, we have just co-authored a *Scientific American* article (with ABB and Statoil) explaining the basics of carbon management. The article will be in the February 2000 issue.

**Task 2. Information Exchange.** As the field of carbon management grows, it is becoming very hard to stay current with the latest developments. This task is set up to keep members informed not only on the breadth of this subject, but also to be able to explore important topics in depth. Specific activities include:

• Holding an annual forum. The forum will be modeled on those of MIT’s Joint Program on the Science and Policy of Climate Change. The forum sessions will focus on updates of major activities (e.g., results and implications of the seismic monitoring at Sleipner, DOE research interests and opportunities for partnerships, etc.) and frank discussions of key issues (e.g., how can we lower the cost of capture, can biotechnology play a role in carbon management, how can we effectively monitor CO$_2$ in the underground, etc.). The presenters will be a mix of experts from MIT, consortium members, and other governmental, academic, and industrial organizations. Ample time will be reserved in each session for general discussion so all attendees can actively participate.

• Establishing an e-mail list. Individuals in member companies will be able to subscribe to this list. Any subscriber can post an e-mail to the list and it will automatically be sent to all other subscribers. The primary purpose of the list will be to share news items. Subscribers needing help in answering a question or locating information concerning carbon sequestration can also use it.

• Creating a web site for the consortium. Our goal is for this to become a useful resource for members to quickly get information relating to carbon management. Examples of the information we will post are the latest news, a calendar of events, publications that can be downloaded, and links to other carbon sequestration sites.

**Task 3. Stimulate New Cutting Edge Research.** Technological advances are required for carbon sequestration to ultimately succeed. Therefore, it is important to persuade top researchers to become involved in developing this technology. Another goal is to interest leaders in other fields in applying their expertise to carbon sequestration problems. For example, the best way to see if biotechnology can advance carbon management technologies is to work with an expert in biotechnology. Specific activities for this task include:

• Seed new ideas by issuing one-time seed grants in the range of $50,000 to $100,000. A grant would be used to assess feasibility and develop a longer-range research plan for a proposed new concept. The primary deliverable would be a proposal sent to a major
funding source (e.g., government, consortium members) to continue the research. Attachment C is an initial list of researchers at MIT that have indicated their interest in being involved with the consortium.

- Involve new people. In addition to seed grants, we can try to interest new researchers in the field through outreach efforts and inviting them to events like the annual forum.

**Membership Fees and Benefits**

We propose an initial three-year program for the consortium running through June 30, 2003. Memberships will start immediately upon execution of the consortium agreement, with the first year ending June 30, 2001. Therefore, the first year's membership could cover more than twelve months. The annual fee for membership will be $30,000 per year. Members will have the option to leave the consortium at the end of any year (i.e., June 30) by giving written notification 60 days prior to the year-end. In the third year, we expect to evaluate the achievements of the consortium and propose a revised work plan for its continuation.

Decisions may be made in the next decade by national governments and international treaties that can have profound effects on your business. The consortium proposed here is a cost-effective way for your company to get the objective information it needs to understand the potential role of carbon management technologies, which is critical in formulating your response to climate change concerns. Also, by producing credible research results and assessment studies, we can perhaps influence the context of the international debate on how to address climate change, focussing the problem on greenhouse gases, not fossil energy. Specific deliverables from the consortium include:

- Participation in the annual forum. We plan to hold the first forum in the fall of 2000.
- Unlimited number of subscriptions to the e-mail news list.
- Input on setting priorities for assessment studies and seed grants at an annual sponsors’ meeting to be held the day before the annual forum.
- Project reports from assessment studies and seed grants, with an opportunity to review draft reports.

The level of activity of the consortium will depend on the number of members. Approximately $100,000 is required to administer the program, put on the annual forum (including paying travel costs of invited speakers), set up the communications network, etc. The rest of the money will be split between assessment studies and seeding new research projects, with the sponsors helping to determine the relative weighting. The sponsors will also help identify the priority topics from

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1 If you already are a member of the MIT Energy Choices Program, you can request the membership fee to be deducted from your contribution to that consortium.
the list in Attachment B. In addition to soliciting your priorities at the annual sponsors' meeting, all new members will be able to give their input through a new members' questionnaire.

The Next Steps:
After you have reviewed this prospectus, we will be happy to answer any follow-up questions. Feel free to contact either Howard Herzog or Elisabeth Drake as follows:

<table>
<thead>
<tr>
<th>Howard Herzog</th>
<th>Elisabeth Drake</th>
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<tr>
<td>+1-617-253-0688</td>
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<td><a href="mailto:hjherzog@mit.edu">hjherzog@mit.edu</a></td>
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Our goal is to enlist at least six charter members to successfully launch the consortium. We then project to add 2-3 new members each year so we can grow the consortium’s research activities. To quickly assess the interest in this consortium, we ask that you return the enclosed reply form as soon as possible. Assuming that there is sufficient interest to proceed, we will then send out consortium agreements to execute and officially launch the consortium.

We thank you for your consideration of this prospectus and look forward to hearing from you.
ATTACHMENT A

Research into Carbon Management at the MIT Energy Laboratory

The MIT Energy Laboratory has conducted research into technologies to capture, utilize, and sequester CO\textsubscript{2} from large stationary sources since 1989. We are recognized internationally as a leader in this field. The effort has had two major thrusts - (1) working closely with DOE on the analysis of these technologies and (2) performing research on specific capture and sequestration technologies. In this later area, our focus has been on ocean sequestration of CO\textsubscript{2}.

CURRENT PROJECTS


MAJOR ASSESSMENTS

Efforts we led:


Efforts we contributed to:


**Workshops and Conferences we hosted:**


**Completed Projects**


The Third International Conference on Carbon Dioxide Removal, DOE, EPRI, and others (1996).


ATTACHMENT B

Carbon Management Topics

Below is a list of specific topical areas we feel would be appropriate for the industrial consortium to address. A topic could be the subject of an assessment study, a session at the annual forum, and/or a seed grant. Within each topic, we list researchers at MIT with expertise in this area. Brief backgrounds and interests of the researchers are given in Attachment C.

- **Integrative Assessment of Carbon Management** (Elisabeth Drake, Denny Ellerman, Howard Herzog, John Heywood, Henry Jacoby, John Reilly, Peter Stone). This topic can be divided into two sub-topics, one being a top-down assessment, the other bottom-up. Top-down assessments help quantify the benefits of carbon management. This includes incorporating carbon management strategies in large economic models (i.e., general equilibrium models) to see the magnitude of their impact in the future under different scenarios. Bottom-up assessments integrate the different components of carbon sequestration (i.e., sources, transport, sinks) and analyze them as a system. This helps identify both barriers and opportunities.

- **Reducing the Cost of CO\(_2\) Capture** (Janos Beer, Alan Hatton, Howard Herzog, Jack Howard, Jeff Tester). This is a critical issue to any future deployment of these technologies. What are achievable targets with current technology? What types of new technology (e.g., membranes) are worth pursuing? What work needs to be done today versus waiting until there are market incentives?

- **Injecting CO\(_2\) into Underground Reservoirs** (Jeff Tester, Nafi Toksoz, Roger Turpening). Major reservoirs under consideration are oil and gas reservoirs, unmineable coal seams, and deep saline aquifers. Questions include: What are the capacities of these reservoirs and how much of that capacity can be practically utilized? What happens to the CO\(_2\) in these reservoirs over different timescales (from years to centuries)? What are the costs associated with each option? How can we convince the public and policy makers that underground sequestration is both safe and effective?

- **Monitoring CO\(_2\) in Underground Reservoirs** (Jeff Steinfeld, Jeff Tester, Roger Turpening). One key component for understanding injection of CO\(_2\) in the underground and eventually gaining public acceptance will be monitoring. The Earth Resources Laboratory at MIT is a leader in developing seismic monitoring for underground reservoirs. How can these technologies be applied to CO\(_2\) sequestration? What will be the costs associated with monitoring?

- **Direct Injection of CO\(_2\) into the Ocean** (Eric Adams, John Edmond, Mick Follows/Prof. John Marshall, Howard Herzog). Besides underground, the ocean is the other major sink for captured CO\(_2\). Developing as many useable sinks as possible will lead to lower costs. Note that location will play an important role in determining the best sink for any given source. We have on-going projects in ocean carbon sequestration under DOE support.
• **Role of Gas Hydrates in Sequestering CO₂** (Ken Smith, Jeff Tester, Bernhardt Trout). Under proper conditions of temperature, pressure, and composition, CO₂ will form a hydrate (i.e., a solid, snow-like compound). Can we use this property to our advantage for long-term sequestration of CO₂? Are there any synergies between storing CO₂ as hydrates and producing methane from methane hydrates?

• **Applying Biotechnology to Carbon Management** (Charles Cooney, Anthony Sinskey, Gregory Stephanopoulos). Biotechnology is revolutionizing several of our industries (e.g., agriculture, pharmaceuticals). Can these technologies be applied in carbon management? A workshop on this subject was held at MIT in December 1998. Our conclusion was that while difficult, there are some opportunities worth pursuing.

• **Public Outreach and Acceptance of Carbon Management Technologies** (Larry Bacow, Nazli Choucri, Elisabeth Drake, Howard Herzog). While our work in carbon sequestration has been mainly technical, even at this early stage of the field, we have had to deal with social aspects of the problem. Our experience has led us to believe that it is critical to become pro-active. Developing protocols to get out the message in positive ways are critical. So is listening to the concerns of the public and addressing them in an open manner.

• **Increasing Sequestration via Natural Processes** (Penny Chisholm, John Reilly). The natural cycles of interest here are carbon exchange between the atmosphere and the terrestrial biosphere (soils and vegetation) and the atmosphere and the ocean. We are fortunate to have experts in each of these areas. Claims to how inexpensively this strategy can be implemented need to be critically assessed. Other issues include environmental impacts, measurement and verification, durability (i.e., how long will carbon remain sequestered?), and additionality (i.e., would this have happened anyway).
ATTACHMENT C

Expertise of MIT Faculty and Staff Affiliated with the Carbon Sequestration Initiative Research Agenda

Eric Adams is a Senior Research Engineer and Lecturer with MIT's Dept of Civil and Environmental Engineering. He also directs the department's Master of Engineering Program and is an Associate Director for Research with the MIT Sea Grant College Program. His research interests include environmental fluid mechanics, physical and mathematical modeling of pollutant transport and mixing, and hydrologic tracer studies. He has studied fluid mechanical aspects of ocean carbon sequestration for 9 years, supervising students in the environmental impact assessment of various CO$_2$ injection systems. He serves on the Technical Committee overseeing the international pilot scale field experiment planned for the summer of 2001 in Hawaii.

Lawrence S. Bacow is the Chancellor of the Massachusetts Institute of Technology, and the Lee and Geraldine Martin Professor of Environmental Studies. Prior to being named as Chancellor, he served as Chairman of the MIT Faculty. Professor Bacow's teaching and research span a number of fields including environmental economics and policy, regulation of the development process, bargaining and negotiation theory, and risk assessment.

János M. Beér is a Professor of Chemical and Fuel Engineering at MIT and was the Scientific Director the MIT Combustion Research Facility from 1976 to 1993. He was Professor and Head, Department of Chemical Engineering and Fuel Technology at the University of Sheffield England, 1965-76; Professor of Fuel Science, The Pennsylvania State University, 1963-65; and the Head, Research Station, International Flame Research Foundation, Ijmuiden, The Netherlands, 1960 –63. His research interests include the physics and chemistry of combustion, control of combustion-generated pollution in boilers and gas turbines; electric power generation in coal-fired combined cycles. He is a Fellow of The Royal Academy of Engineering (UK); a Foreign Member, The Finnish Academy of Engineering; and an Honorary member, The Hungarian Academy of Sciences.

Sallie W. Chisholm holds a joint appointment in the Department of Civil and Environmental Engineering and the Department of Biology at MIT, and is the McAfee Professor of Engineering. She is past Director of the MIT/Woods Hole Joint Program in Oceanography. Prof. Chisholm is a biological oceanographer who specializes in phytoplankton ecology. She was co-discoverer of Prochlorococcus, a group of phytoplankton which comprise a significant fraction of the photosynthetic biomass in the oligotrophic oceans. Recently, she has been involved in unenclosed ocean fertilization experiments designed to help us understand the role of the oceans in past and future climate change. The results of these experiments have implications for human intervention in ocean fertility, and the sustainable use of ocean resources. Prof. Chisholm is a Fellow in the American Academy of Microbiology, American Geophysical Union, American Academy of Arts and Sciences, and the International Ecology Institute. She is also the recipient of the Rosenstiel Award in Ocean Sciences, and a Guggenheim Fellowship.
**Nazli Choucri** is Professor of Political Science and Associate Director of the Technology and Development Program at MIT. She is an analyst of international political and economic change, focusing on potentials for conflict at national, regional, and global levels. She has worked on problems related to conflict minimization in the world oil market, energy and development, and technology exchanges. She is the author of several books in this area, serves as consultant in various policy contexts, nationally and internationally, and is currently serving as Senior Advisor to the directors of two international institutions.

**Charles Cooney** is Professor of Chemical and Biochemical Engineering and Executive Officer of the Chemical Engineering Department at MIT. After an undergraduate education at the University of Pennsylvania, he received his Ph.D. from MIT. His research interests include biochemical process control with emphasis on the application of expert systems, artificial neural networks, and data reconciliation to fermentation and cell culture. He also works on techniques for biochemical product recovery, including vortex flow filtration in conjunction with membrane separation processes, for applications ranging from protein purification to waste treatment processes. As Co-Director of the MIT Program on the Pharmaceutical Industry, he leads research to better understand the factors which drive and constrain the implementation of new manufacturing technology in the pharmaceutical industry.

**Elisabeth M. Drake** is Associate Director for New Technologies at the MIT Energy Laboratory, and received S.B. and Sc.D. degrees in Chemical Engineering from MIT. She spent most of her career at Arthur D. Little, Inc., starting a hazardous facilities risk management group and becoming Vice President and leader of their Environment, Health and Safety Practice. From 1982-1986, Dr. Drake was the Cabot Professor of Chemical Engineering at Northeastern University and Chairman of their Chemical Engineering Department. At the MIT Energy Laboratory, she conducts research on new technology development in awareness of the growing importance of environmental sustainability and resource conservation in internationally competitive markets. She is a Fellow of the American Institute of Chemical Engineers (AIChE) and a Member of the National Academy of Engineering (NAE), as well as a Registered Professional Engineer.

**John M. Edmond** is Professor of Marine Chemistry in the Department of Earth, Atmospheric, and Planetary Sciences at MIT. He holds a Ph.D. in Marine Chemistry from the University of California, San Diego (Scripps Institution of Oceanography). His research interests include processes and mechanisms controlling the composition of oceanic and continental waters and sediments in space and time. He serves on the editorial board of *Earth and Planetary Science Letters, Chemical Geology/Isotope Geochemistry, and Geochimica et Cosmochimica Acta*. His honors include: James B. Macelwane Award and Fellow, American Geophysical Union, 1978; Fellow, Royal Society of London, 1986; Honorary Research Fellow, Southampton Oceanography Center, 1996; Fellow of the Geochemical Society and the European Association for Geochemistry, 1996.

**A. Denny Ellerman** is senior lecturer of the Sloan School of Management and executive director of the Center for Energy and Environmental Policy Research, in which capacity he also functions as executive director of the Joint Program on the Science and Policy of Global Change. Ellerman's research interests focus on emissions trading, fuel choice economics, and the
integrated assessment of climate change policies. Ellerman is the author, with colleagues, of *Markets for Clean Air: the U.S. Acid Rain Program*, the most successful emissions trading program to date. He is also author of numerous other articles and a frequent speaker on energy and environmental economics.

**Michael Follows** is a Research Scientist in the Department of Earth, Atmospheric and Planetary Sciences at MIT. His research is aimed at increasing our understanding of biogeochemical cycles in the ocean and atmosphere, using numerical models and data analysis. His recent studies include studies of the feedbacks between carbon cycle and climate in simplified models, and the interpretation of interannual variability ocean biological productivity and its relation to climatic regimes in the atmosphere.

**T. Alan Hatton** is the Ralph Landau Professor and Director of the David H. Koch School of Chemical Engineering Practice at MIT. Research interests include exploitation of structured fluids in chemical processing operations. We have focused most recently on the use of tailored solvents, and of surface-modified magnetic fluid nanoparticles, to enhance reaction and separation processes to minimize pollution.

**Howard J. Herzog** is a Principal Research Engineer at the MIT Energy Laboratory. He received his undergraduate and graduate education in Chemical Engineering at MIT. He has industrial experience with Eastman Kodak, Stone & Webster, Spectra Physics, and Aspen Technology. Since 1989, he has been on the Energy Laboratory staff, where he has led the research program on CO$_2$ sequestration from large stationary sources. Some specific activities in this area include: primary author of a *DOE Research Needs Assessment on the Capture, Utilization, and Disposal of CO$_2$* (1993), chairman of the Organizing Committee for the Third International Conference on CO$_2$ Removal (1996), and primary author of a *DOE White Paper on CO$_2$ Capture, Reuse, and Storage Technologies* (1997).

**John Heywood** is the Sun Jae professor of Mechanical Engineering at MIT and Director of the MIT Sloan Automotive Research Laboratory, which is a leading center in research on automotive engines and fuels, as well as on critical issues of lubrication system design. He has made several specific research contributions that improved the ability to modify combustion processes to improve efficiency and reduce emissions. He has been recognized by a number of professional society awards and is a member of the National Academy of Engineering. He is currently involved in research relating to future road transportation options in a GHG-constrained world.

**Jack Howard** is Hoyt C. Hottel Professor of Chemical Engineering. His research interests include high temperature chemistry, especially mechanisms and kinetics of reactions in combustion, environmental/emissions control, fuel processing, synthesis of carbon materials, and waste destruction, including: formation and oxidation of polycyclic aromatic hydrocarbons, fullerenes and soot formation in flames; and pyrolysis, gasification and combustion of coal, biomass and solid wastes.

**Henry D. Jacoby** is the William F. Pounds Professor of Management in the MIT Sloan School of Management. He is an applied economist who studies issues of policy and planning in the
areas of energy, natural resources, and environment. He has served as the Director of the MIT Center for Energy Policy Research, and as Associate Director of the MIT Energy Laboratory. At present, he co-directs the MIT Joint Program on the Science and Policy of Global Change. He has written widely on energy and environmental topics, including five books.

**John Marshall** is a Professor of Atmospheric and Oceanic Sciences in the Department of Earth, Atmospheric and Planetary Sciences. His research has been directed at understanding key components of the general circulation of the atmosphere and ocean and the development of models to study them. He is interested in a variety of problems in geophysical fluid dynamics and their role in climate, ranging from rotating convection to the global circulation of the ocean. I also carry out research into the dynamics of anomalous circulation patterns in the atmosphere and climate variability.

**John Reilly** is the Associate Director for Research in the Joint Program on the Science and Policy of Global Change at MIT. Much of his research has focused on the economics of climate change, including modeling of energy use and carbon emissions and on the economic impacts of climate change on agriculture as well as consideration of agriculture and forestry sinks. He has published numerous articles, books, and reports on the economics of climate change and on other issues related to natural resources, technology, and energy use and supply. He was a principal author for the IPCC Second Assessment Report and has served on many Federal government and international committees. Prior to joining MIT in 1998, he spent 12 years with the Economic Research Service of USDA, most recently as the Acting Director and Deputy Director for Research of the Resource Economics Division. He has been a scientist with Battelle's Pacific Northwest National Laboratory and with the Institute for Energy Analysis, Oak Ridge Associated Universities. He received his Ph.D. in economics from the University of Pennsylvania in 1983 and holds a B.S. in economics and political science from the University of Wisconsin.

**Anthony J. Sinskey** is Professor of Microbiology at MIT, where he received his Sc.D. in Food Science. He joined the MIT faculty after doing a Post Doctoral Fellowship at the Harvard School of Public Health. His major research interests encompass Microbiology, Biotechnology, Metabolic and Biopolymer Engineering, and Mammalian Cell Culture. His laboratory has specific goals of establishing an interdisciplinary approach to metabolic engineering, focusing on the fundamental physiology, biochemistry and molecular genetics of important organisms. In particular, they are studying key factors that regulate the synthesis of different biomolecules and apply metabolic engineering in several different project areas. Among prokaryotic systems, they study amino acid metabolism in *Corynebacterium glutamicum*, bioremediation and bioconversion processes in *Rhodococcus*, and biopolymer synthesis among Gram-negative bacteria. Among eukaryotic systems, they are studying apoptosis in mammalian cells, lipid biosynthesis in oil palm, and the accumulation of secondary metabolites in tropical plants.

**Kenneth A. Smith** is a Professor of Chemical Engineering at MIT who has, for over 30 years, devoted his research efforts to problems in fluid mechanics and in heat and mass transfer. He holds an Sc.D in Chemical Engineering from MIT; he has done postdoctoral and sabbatical research at Cambridge University; and he is a member of the National Academy of Engineering.
Previous research foci include turbulence, drag reduction, hydrodynamic stability, facilitated transport, transport in living systems, and crystal growth.

**Gregory Stephanopoulos** Professor of Chemical Engineering at MIT, received his Ph.D. from the University of Minnesota. His research includes applications of genetic engineering to strain improvement through metabolic engineering, to development of methods for the measurement and control of metabolic fluxes, and to study of cellular responses to genetic and environmental perturbations. He presently is conducting research on CO$_2$ fixation by cyanobacteria in collaboration with Prof. Sinskey’s work on directed evolution of PHA synthases.

**Jeffrey Steinfeld** is Professor of Chemistry, Massachusetts Institute of Technology, Cambridge, MA. B.S. Chemistry at M.I.T. (1962), Ph.D. in physical chemistry at Harvard (1965). N.S.F. Postdoctoral Fellow with Sir George Porter at the University of Sheffield (U.K.). Joined M.I.T. Chemistry Department in 1966. Research interests include molecular spectroscopy, molecular energy transfer, and laser applications to chemistry, including optical methods for remote sensing and atmospheric monitoring. Co-Director, Program on Environmental Education Research at M.I.T.; Chair, American Chemical Society's Committee on Environmental Improvement. Received 1999 ACS Director's Award for Advancing ACS Public Policy in Environment, for work to encourage the use of sound science in global climate change policy.

**Peter Stone** is Professor of Climate Dynamics, Department of Earth, Atmospheric, and Planetary Sciences, MIT. Professor Stone is an expert in atmospheric dynamics who has made important contributions to the development of climate models of all kinds, ranging from the simplest one-dimensional process models to full-scale three-dimensional general circulation models. He is a member of the team that developed the NASA/Goddard Institute for Space Studies general circulation climate model and has been applying it to climate change problems. Professor Stone is also a participant in the interdisciplinary part of NASA's Earth Observing System (EOS) program, which is making key observations of climate processes. Currently he is the Director of MIT's Climate Modelling Initiative, a new effort to construct improved coupled atmosphere-ocean general circulation models, and use them in studies of the predictability of climate.

**Jefferson W. Tester** is the H.P. Meissner Professor of Chemical Engineering and Director of MIT’s Energy Laboratory. For three decades, he has been involved in various aspects of chemical engineering process research as it relates to energy extraction and conversion and environmental control technologies. He has co-authored more than 100 papers and 8 books on various topics related to energy and environmental issues. Topics have ranged from geothermal energy and drilling technology to power conversion system design and economics, to assessing regional and global environmental effects of energy supply and use, including the possibilities of carbon sequestration.

**M. Nafi Toksöz** is Professor of Geophysics and Founder of the Earth Resources Laboratory at MIT. His research specialties include seismic tomography, rock physics, and reservoir characterization, with an extensive list of publications in these areas.
Bernhardt Trout is the Joseph R. Mares Assistant Professor of Chemical Engineering at MIT. He received an S.B. and an M.S. in Chemical Engineering Practice from the MIT, Department of Chemical Engineering, and a Ph.D. from the UC Berkeley, Department of Chemical Engineering. He spent a year in post-doctoral studies at the Max-Planck Institute, Stuttgart, Germany. His research interests involve developing and applying molecular computational methods to gain insights leading to the design of chemical materials and processes. Applications include heterogeneous catalysis on zeolites for the synthesis of cleaner-burning fuels and olefins, high conversion, next generation automotive catalysts, heterogeneous stratospheric chemistry to understand the consequences of releasing chemicals into the atmosphere, natural gas hydrates as an abundant, clean, future fuel source, CO$_2$ hydrates involved in the sequestration and storage of CO$_2$, and therapeutic protein stabilization. There is an overall emphasis on environmental research and the development of more environmentally benign technologies.

Roger Turpening is a Research Associate in the Earth Resources Laboratory (ERL) a unit of the Department of Earth, Atmospheric, and Planetary Sciences. He is a seismologist specializing in the hydrocarbon exploration segment of that science. In particular he enjoys the data acquisition problems associated with hydrocarbon exploration and in that capacity has been at the leading, innovative, edge of the vertical seismic profiling (VSP) methods, shear wave generation and recording techniques, cross well reflection and tomographic methods. Currently he leads a major data acquisition program at ERL sponsored by twelve oil companies and contractors that will, for the first time, deploy the receivers and the sources in a completely random manner. At the same time, this program will deploy a seismic vibrator in a deep borehole and record the seismic wave field with the same random spread of geophones. This technique is called reverse vertical seismic profiling (RVSP) and holds out the promise of much higher resolution 3-D images of the subsurface especially when the receivers are buried beneath the weathered zone.
TO: MARY GALLAGHER  
FAX: +1-617-253-8013

CARBON SEQUESTRATION INITIATIVES PROSPECTUS

REPLY FORM

Name: 

Company: 

Please indicate your interest in MIT’s Carbon Sequestration Initiative by checking one of the 3 boxes below.

☐ High
We are interested in becoming a charter member in MIT’s Carbon Sequestration Initiative. Please send us a consortium agreement to review. This expression of interest is non-binding, as there may be several steps required (e.g., further evaluation, management review, budget considerations) before obtaining a final approval.

☐ Moderate
We are interested in MIT’s Carbon Sequestration Initiative, but will not be able to join this calendar year. Please keep us informed of your activities, so we can evaluate joining at a later time.

☐ Low
We do not project joining MIT’s Carbon Sequestration Initiative in the foreseeable future.

Please use the following section for any comments or suggestions.

Comments: _______________________________