Rice University

University 303
Class Report

May, 2000

UNIV 303 is a continuing course that focuses on environmental problems with respect to the Rice community. It basically uses Rice as a lab in which students can gain experience in devising and implementing solutions to these problems. Last year's class produced a report that detailed Rice's CO_2 output per year with an emphasis on information needed to comply with the standards set in the Kyoto Protocol.

This year our class began by focusing on potential solutions for reducing Rice's CO_2 output. It quickly became apparent that in order to propose ideas that realistically could be implemented, we would need to understand the management systems and procedures at Rice. The report that we have compiled contains descriptions of the organizational structures at Rice, as well as problems with those systems and possible changes. We also talk about potential ways to reduce the total CO_2 emissions per year of Rice.

Acknowledgments

Thanks to Arthur D. Little, Donald Ostdiek, John Posch, Kathy Collins, Leona Urbish, Noble Robinson, Ryan McMullan, and Scott Wise.

In Memory of Noble Robinson (Rice '55)

Executive Summary

This report develops proposals for Rice University that both foster an active commitment towards preserving the health of the natural environment and enhances Rice's position as a community and intellectual leader in this area. It specifically looks at bringing Rice in compliance with the Kyoto Protocol, which will require a decrease of 5,040 tons of carbon from the university's projected 2010 emission level, as estimated by last year's University 303 class. We argue that in order to increase the likelihood of successful action, proper procedures and channels in the university structure must be developed which are able to facilitate the passage of environmentally focused proposals.

We examine three central sections of the university. First, we develop basic descriptions of their current functions and the procedures that may cause problems for the proposal of environmental initiatives. We then look at possible steps the university can take to overcome these impediments. Our findings include:

Organizational Management

Problems

- Lack of a person with authority able to speak solely for environmental issues
- Conflicts of interest in departments during the appropriation process that work against pursuing environmental proposals

Solution

- Create a university position, reporting directly to the president, that has the authority to impact budget and policy decisions in a pro-environmental direction

Budget

Problems

- Lack of a direct way to initiate a budget proposal solely based upon its environmental merit
- Lack of budget criteria that consider the environmental impact of proposals

Solutions

- Create a specific budget criterion which considers proposals in terms of their environmental impact
- Create space in the operating budget to pay the salary for the position mentioned above

Formal Environmental Policy

Problem

- Not actively working towards the ten key pro-environmental commitments Rice made 1996 with its signing of the Talloires Declaration

Solutions

- Develop and implement an explicit campus-wide environmental policy
- Adopt an Environmental Management System to improve the administration's ability to reach environmental goals and commitments.

Once the internal structure of the university is more open to environmentally based proposals, Rice can consider larger solutions that address specific problems. To most efficiently reduce Rice's composite CO_2 emissions we propose two mitigatory solutions.

Mitigation Solutions

- Purchase and develop tree farms able to offset Rice's CO_2 emissions by the amount specified in the Kyoto Protocol
- Research emerging mitigation technologies including the permanent sequestering of CO_2 in abandoned mines, aquifers, or oceans.

RICE'S MANAGEMENT STRUCTURE AND BUDGET PROCESS

In order to develop practical CO_2 emission reduction strategies for Rice University, we found it crucial to have a working picture of the University's management structure, budget, and policy-making process. As our knowledge about these aspects of the University increased, two stumbling blocks for all proposals with primarily environmental elements became apparent.

The first is that proposals to make Rice environmentally sound often do not make it through the preliminary request stage because they do not fall directly under the jurisdictions of the deans and vice presidents who typically make the budget requests. To counter this trend we propose the University create the position of an Environmental Enhancement Officer who, in addition to facilitating already existing programs, would have the ability to propose and prioritize requests for funding in the same way that deans and vice presidents do.

The second hindrance is the tendency of institutions to look at proposals in purely economic terms. Realistically, most environmental pursuits are not profit making ventures. That is, they often cannot compete with other proposals in terms of payback time (though they usually still provide a positive payback). Rather, they need to be considered as a means through which Rice can take an initiative to help improve the greater community and establish itself as a leader in this field. Currently, reductions in energy consumption, emissions, and waste will be seen as positive steps taken by a forward-thinking institution. However, with the impending acceptance of the Kyoto Protocol and Houston's air quality non-attainment status these reductions may be made mandatory in the near future. In order to take a proactive approach and to prevent being caught off-guard by such regulations, we suggest that the University adopt an explicit environmental policy now that includes a criterion for weighing the environmental impacts of any proposals or capital projects.

The following sections describe the University's budget process and management system as well as highlight the aspects of both which hinder Rice's development as an environmental leader. The report offers various solutions that we consider appropriate for the Rice campus. The solutions include the adoption of a campus-wide environmental policy, the creation of a position authorized to advocate environmental pursuits, the adoption of a formal Environmental Management System, and a proposal for active CO_2 mitigation.

ORGANIZATIONAL MANAGEMENT

Rice University has a hierarchical management structure, the highest level of which is occupied by the Board of Trustees. The President is directly below the Board of Trustees, however in general, decisions are made by the president and then subject to review by the Board. The vice-presidents and the provost report to the President, who has authority over both the business and the academic sides of the university. (See Appendix 1)

Board of Trustees

Currently the Board is comprised of twenty members, each of whom have equal voting rights. The Board can have a maximum of twenty-five members at any time. A simple majority of the trustees must reside in Texas, with at least four residing in the greater Houston Area. The trustees meet for Board meetings a minimum of four times a year. Members serve without compensation.

The Board of Trustees is divided into six committees whose members and chairs are decided by the Chairman of the Board. The committees are:

- Building and Grounds*
  - Manages affairs related to the construction on campus
- Finance*
  - Manages financial affairs of the University
- Development*
  - Manages the future plans for the University
- Academic Affairs*
  - Manages the Academic issues at Rice
- Nominating
  - Proposes qualified people to serve as Board members
- Audit
  - Oversees the University's financial practices and procedures, financial reporting, internal controls, financial management, and conflicts of interest policy
  - Functions with the University's independent auditors to review scope, results, and costs of audit examinations

* Indicates that this committee generally reports at every Board meeting due to its active nature

- Monitors relationships between the management and independent auditors
- Reviews other matters as appropriate

While these committees generally meet around the time of each of the four Board meetings, they also can meet outside of these four times if necessary.

Committee chairs work closely with their Vice President counterparts. For example, the Vice President for Finance and Administration, and the Vice President for Investments and Treasurer work closely with the chair of the Finance committee. Similarly, the Provost directly interacts with the chair of the Academic Affairs committee. At the Board meetings, reports are made by the Board committees and also, on occasion, by various Vice Presidents of the University. Although less common, faculty and students are also able to make reports.

The Board of Trustees has the final legal authority for the governing of the university. It is responsible for appointing, outside of its membership, a President and a treasurer for the university, both whom are non-voting, ex officio members of the Board of Trustees. Trustees Emeriti and Trustee Advisors are mainly honorary positions. Members of either group are welcome to give their advice at Board meetings, but do not have a vote.

President

Presidential appointments are made by the Board of Trustees with the assistance of recommendations from a search committee that includes representatives from the faculty, students, and board. All seven vice presidents, the provost, and several other officials report directly to the President who, in turn, reports to the Board. While the President makes decisions for the university, his decisions are subject to a final review by the Board.

The President is advised on university policy matters by his own administrative staff and by a broadly representative University Council.[1] With the aid of an ad hoc selections committee, the President is responsible for filling any open administrative positions.

[1] This Council is made up of the president as chair, the provost, 2 individuals from the faculty or administration who are appointed by the President, 8 members of the Faculty Council who are elected by the faculty, one staff member appointed by the president, one graduate student selected by the Graduate Student Association, and two undergraduate student representatives selected by the Student Association.

Business

Vice Presidents

The Vice Presidents are the Vice President for Investments/Treasurer, the Vice President for Enrollment, the Vice President for Finance and Administration, the Vice President for Information Technology, the Vice President for Public Affairs, the Vice President for Resource Development, the Vice President for Graduate Studies, Research, and Information Systems, the Vice President for University Advancement and the Vice President for Student Affairs. Their duties include:

- **Vice President for Investments/Treasurer**
    - Responsible for overseeing the University endowment,
    - Works closely with the President on long-term financial planning,
    - Serves as a link between the internal auditor, risk manager, real estate manager, and mineral investment manager, and the Board and President
- **Vice President of Student Affairs**:
    - Responsible for all aspects of student life including student advising, student activities, residential college life, academic regulation, student discipline, the student center, and career placement.
    - In the absence of the president and the provost, he will act on their behalf for all matters relating to student life and student activities.
- **Vice President of Finance and Administration**:
    - Responsible for human resources, the controller, property management, physical plant, college operations, the campus store, campus security, traffic control, and campus services.
    - One of the primary advisors to the President on matters of financial planning and the administration of university finances.
    - In the absence of the provost and the president, he will act on their behalf for all matters relating to non-academic operations of the university.
- **Vice President for Graduate Studies, Research and Information Systems**:

        - Responsible for graduate studies administration, research stimulation and administration, technology transfer, computer services, library services, and telecommunications.
- **Vice President for University Advancement**:
    - Responsible for institutional development, alumni affairs, community and governmental relations, new offices, and university publications.

Academics

The Provost is the general administrative officer of the University who is in charge of all academic matters. All academic deans report to the Provost on policy, personnel, and budgetary matters.

Management Structure Problems

During the course of our research, we noticed several parts of the management structure that could be readjusted to facilitate the passage of environmental proposals. Under the current structure, it is not possible to represent an issue solely for its environmental value. University departments do not have the responsibility to recognize environmental problems, propose solutions, and then attain funding for the solutions.

Departments often experience a conflict of interests regarding environmental issues. For example, Food and Housing has a limited budget each year from which they must supply the entire campus. From an economic point of view, it is financially advantageous for them to purchase products that are less environmentally friendly, but monetarily cheaper.

Management Structure Solutions

Because Rice currently lacks an efficient pathway through which environmental proposals and concerns can be passed, we propose the creation of a staff position whose purpose is to facilitate the consideration of an environmental agenda. So that the officer would have influence and authority in both the business and the academic sections of the university, he/she would report directly to the President.

BUDGET PROCESS

Capital Budget vs. Operating Budget

There are two budget tracks at Rice University. The capital budget deals with expenditures that will have a long-term effect upon the University and/or will take more than one fiscal year to complete. Replacing roofs or constructing new buildings are examples of capital expenditures. The capital budget is zero based, meaning that it is constructed anew each year

The operating faculty and staff salaries, as well as routine maintenance and operating costs. Repairing the tiles on a particular section of roof or maintaining the grounds are examples of operating expenses.

Requests

Making Requests

Any budget request must be submitted via the office of a dean or a vice-president. These requests must be accompanied by a written paragraph of justification. Facilities and Engineering is in charge of making estimates for the capital budget process. Requests are turned in to F&E early in the academic year. F&E then estimates the cost for the project and returns the request to the dean or vice president from which it originated. Final requests are turned in to the budget officer at the end of November. Decisions on capital budget requests are made in January-February.

Because the capital budget is zero based, phased projects must reapply each fiscal year. It is recognized that such projects have already been started and they are generally—although not always—approved. For example, replacing roofs is an ongoing project, but the option to skip a year is always available. If a project is approved and it is not intended to be a phased project, the total amount of money needed to complete the project will be set aside in an account.

Operating budget requests are made in February and then reviewed with the Provost and the President. Decisions on the operating budget are made in April.

The Board of Trustees approves the overall budget in May. The fiscal year starts on July 1.

Important Dates Final capital request due—end of November
Decisions on capital budget—January-February
Operating budget requests due—February

Decisions on operating budget—April

Approval of overall budget—May

Start of the fiscal year—July 1

Evaluating Requests

The University prioritizes its spending with a main focus on teaching and research. The next priorities after these are for faculty and library support. One constraint on the budget is that revenues are set before expenditures.

There are several questions that are asked during the evaluation of a capitol request. At the school/division level, these are asked by the deans or by the vice presidents. At the university level, the budget is evaluated first by the budget committee (which includes the provost), then by the budget committee with the president, and finally by the Board of Trustees.

Sample Questions:

- What is the benefit to the school/division, and/or to Rice?
- What is the priority within the school/division?
- Is there an impact in other areas? (such as aesthetics, increased energy costs, etc.)
- Is it discretionary or non-discretionary?
- What are the timing needs? Can it be phased or delayed?
- Is it part of a multiyear plan?

Long Range Planning

Long range planning often uses the concept of a "payback period" to help make a decision. The payback time of a project is the amount of time that it takes to produce revenue exceeding the costs accrued by the project. The payback time can be crucially influential in getting a project approved. While there theoretically is no limit on the payback period, usually if it is longer than five years it is hard to compete with other proposed projects. Payback periods of less than two years will generally make a proposal seem attractive to the budget committee.

The Role of the Endowment

The endowment currently has a market value of around three billion dollars. Its purpose is to produce revenue and provide financial stability for the University.

Investments

Portfolio

The money from the endowment is invested in a diversified portfolio with a balance between longterm appreciation and a sustainable, predictable revenue stream. A small portion of the endowment (12%) is in fixed income bonds while the majority of the endowment (88%) is placed in equity investments.

Equity Investments Include:

- Market securities
- Common stocks
- Venture capital funds
- Real estate
- Oil and gas investments
- Timber plantations

These investments have varying levels of liquidity ranging from common stocks (which are more liquid) to venture capital/partnerships and real estate (which are less liquid). Campus land and buildings are not part of the endowment assets.

Restricted and Unrestricted Investments

There are many investments in the endowment that have been restricted to a particular purpose by the donor (For example, financial aid or chaired professorships). Restricted investments make up 40% of the endowment and unrestricted investments are the remaining 60% of the endowment. There are many checks to ensure that the money from a restricted portion of the endowment goes to the required area. The money from the unrestricted portion of the endowment goes through a similar revenue stream as tuition dollars and ends up in a general revenue account.

Budget

General

Rice's reliance upon income from the endowment for university running costs is one of the highest in the country. At this time, 42% of the budget for each fiscal year flows from the endowment.

Calculating Amount

To calculate the amount of money that goes into the budget per year, Rice takes the value of the amount of money in the previous year's budget and increases this amount by a certain percentage (typically 5%) of the growth rate above inflation.

Payout

The payout is the amount of money that the university takes from the endowment per year to put into the budget. The rest of the money in the budget comes from tuition dollars and other sources. The typical payout for the University is 5% of the market value of the endowment calculated over a three-year period.

Property

Purchasing

It is rare for Rice to purchase property outright. Land in the Village was purchased and is owned by several subsidiary corporations of Rice[2]. In the event that the university decides to invest in property, it is conducted through resources already in the endowment.

Donation

It is also rare for Rice to receive donations of property from a private individual or group. If a property donation were proposed, there is a process for determining if the university will accept or reject the donation. Rice is only interested in acquiring assets—not liabilities.

Budget Process Problems

Two central problems exist under the current budgetary structure: First, there is no process to initiate a proposal based upon its environmental merit. Budget requests must originate from within a department. Because each department requests money for its own activities, it is not possible for a single department to propose a university-wide policy. Another negative aspect of the current budgetary structure is that competition for funding results in many cheap, but less environmentally sound proposals.

A second problem is that, at this time, approval of a proposal because of its environmental value is not feasible. There is little consideration given to sustainability in the evaluation of requests. Questions about the environmental value of an initiative are not included in the current evaluation process.

Budget Process Solutions

In order to propose an environmental initiative, the parties involved must have a channel to go through that is separate from that of the individual departments. The creation of a position with the authority to make budget proposals of an environmental nature would allow this circumvention. Additionally, there needs to be a change in the decision criteria to include an emphasis on sustainability and environmental value of the proposal.

UNIVERSITY ENVIRONMENTAL POLICY

Rice University lacks an active policy that comprehensively addresses issues of environmental importance. As a signatory of the Talloires Declaration, an international initiative based on the belief that institutions of higher learning must exercise leadership to promote environmental responsibility, it has expresses its commitment to the environment on paper. However, this commitment has not yet been organized into a recognizable part of campus life or decision making.

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[2] Wise, Scott. e-mail

Talloires Declaration

With the signing of the Talloires Declaration in 1995, Rice administrators formally recognized the University's environmental responsibilities and expressed their commitment to fulfill them. Along with 269 other universities, Rice agreed that "University leaders must initiate and support mobilization of internal and external resources so that their institutions respond to this urgent challenge." Rice committed to undertake ten key pro-environmental actions as a means to accomplish this. These include:

- Establishing programs to produce environmental expertise and ensure that all graduates are environmentally literate
- Setting an example of environmental responsibility by establishing institutional ecology policies and prioritizing resource conservation
- Convening faculty and administrators with environmental practitioners to develop curricula and research initiatives that support an environmentally sustainable future and
- Establishing a Secretariat and a Steering Committee to support efforts in carrying out this declaration.[3]

Current Impediments to Achieving Talloires Commitments

For Rice University feasibly to achieve the commitments it made in the Talloires Declaration and to take a pro-active approach towards environmental concerns, it needs to reevaluate the current features of the budget and management process that impede this progress. The main impediments are:

- The lack of a channel for the formal submission of proposals that are primarily environmental
- The lack of an environmental budget criteria that treats sustainability as a value in itself and considers environmentally-based proposals that reach this stage for more than their economic return
- The lack of a campus position that has the formal standing needed to impact budget and policy decisions in an environmental direction.

An explicit campus environmental policy is the first step necessary to remedy these problems.

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[3] www.center1.com/ulsf

Necessary Criteria in Our Environmental Policy

Rice can build off of established environmental policies like those in place at Brown University and Tufts University to place itself in the forefront of the movement working towards environmental awareness and global health. To accomplish this an explicit, written environmental policy or set of policies necessary for the Rice campus. With support from the top administration, it could be effectively implemented throughout the University and become a criterion in the decision-making process.

Although economic factors are a real consideration, the campus environmental policy needs to be normative and, within reason, advocate making decisions that improve Rice's sustainability and enhance its compatibility with the natural world. A policy that would both fulfill the Talloires Declaration and demonstrate an active environmental concern includes the commitments to:

- Consider all forms University actions in terms of their environmental impact
- Ensure that all decision-makers are aware of the environmental impact of their choices
- Support the sustainable use of natural resources by promoting strategies to improve efficiency and reduce their consumption
- Promote and support education and research programs that address environmental issues and
- Incorporate the explanation of environmental responsibilities and resource efficiency into student and employee orientation.

The effectiveness of an environmental policy should be evaluated based on its environmental stewardship, economic viability and social equity. The acceptance of an explicit, comprehensive campus-wide policy supported by administrators would facilitate the fulfillment of Rice's environmental responsibilities to the local and global communities.

ENVIRONMENTAL MANAGEMENT SYSTEM

The development of an Environmental Management System (EMS) at Rice could effectively remedy the above stated problems. An EMS is defined as "organization structure, responsibilities, practices, procedures, processes, and resources for implementing and maintaining environmental management."[4] Such a system would provide a management structure through which environmental policies could be initiated, evaluated, and maintained. To operate effectively, however, an EMS needs the support of the top management or administration in an institution. Components of an EMS include:

- Policy formation
- Issue/risk identification
- Goal-setting
- Allocation of resources
- Assignment of responsibilities
- Development of manuals and control procedures
- Documentation and record-keeping
- Auditing and corrective action

The ISO[5] (International Organization for Standardization[6]) 14001 Model is an example of such a system that has been adopted by many organizations around the world. The purpose of this model is to create an international standard by which businesses deal with environmental and safety issues. The ISO 14001 is comprised of a cycle with 5 parts: (1) Environmental Policy (2) Planning (3) Implementation and Operation (4) Checking and Corrective Action and (5) Management Review.

Environmental Policy

The first section of the EMS involves the development of common standards that promote environmentally beneficial behavior or maintain and/or reduce negative environmental impacts. At Rice, environmental policies can be used to regulate resource procurement, consumption, resource development, and conservation.

Planning

During the planning stages, the feasibility of an environmental policy is reviewed and preparations for its implementation are made. This includes analyzing the policy's:

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[4] Arthur D. Little

[5] ISO is a foundation that was founded in 1947 and is headquartered in Geneva, Switzerland. It is comprised of approximately 130 countries who are interested in creating global standards in order to facilitate international trade and communication.

- Environmental aspects
- Legal and other requirements
- Objectives and targets

In this phase, Rice would consult its own faculty and experts, as well as outside experts, about the specifics of the environmental policies. This is also when legal implications of the policies would be checked and administrative responsibilities would be delegated.

Implementation and Operation

In this stage, the environmental policy is implemented. This process involves:

- Defining structure and responsibility
- Training, awareness, and competence
- Communications
- Documentation
- Document control
- Operational control

Checking and Corrective Action

At this point, the policy is reviewed, and areas that do not conform to the set standards are corrected. This stage includes:

- Monitoring and measurement
- Nonconformance, corrective, and preventative action
- Records

At Rice, this phase could be used to track the progress of implemented actions and identify areas of non-compliance. Once again, both Rice faculty and staff, as well as outside expertise can be called upon to help monitor and assess Rice's progress and compliance.

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[6] ISO is not an acronym. It is derived from the Greek word *isos*, which means equal. The organization is known as ISO throughout the world in order to avoid differences in abbreviations due to translations from different languages.

Management Review

In this stage of the ISO model, the policy and its effects are analyzed. Amendments to the policy are suggested. If these additions are passed, they become part of the environmental policy, and the cycle starts all over again.

CO_2 MITIGATION

In addition to adopting budgetary and managerial solutions, the University can alleviate the effects of the CO_2 emissions through mitigation. Although mitigation does not affect the amount of CO_2 Rice produces, it counters the global effects of these productions through the creation of carbon sinks. Our study proposes two principal venues of mitigation: (1) tree farming and (2) alternative forms of sequestration.

Mitigation Through Tree Plantations

Mitigation is an option for Rice University to reach compliance with the Kyoto Protocol. The University could opt to offset its carbon dioxide emissions rather than directly reducing them. One potential way to accomplish this objective is through carbon sequestration in tree plantations.

The Kyoto Protocol requires that, by the year 2010, carbon emissions be reduced by 7% from the 1990 emission levels. From previous calculations, it has been determined that, with Rice's current emission levels and future estimated additional tons due to construction and increased activities, Rice needs to either reduce or offset 5,040 tons of carbon emissions to reach compliance. In order to offset these 5,040 tons of carbon, Rice would need to plant 2,100 hectares (ha) of trees. The positive uptake of carbon by these trees would exactly counter the negative, current and expected, emissions given off by the University. These tree farms could be located anywhere[7], and would be similar to the ones in Louisiana currently owned by the University.

[7] "anywhere" refers to any available location with the proper soil condition and climate. Choosing the actual location is eventually a management decision.

Carbon Budgets

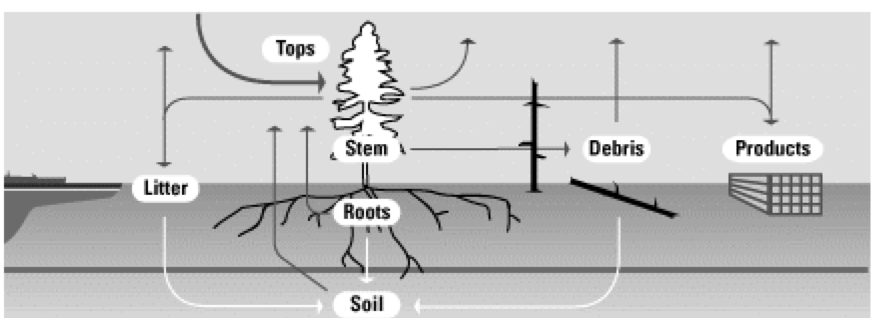
A carbon budget is often used to show the inventory of carbon in carbon pools and the balance of exchange between these pools. The carbon pool is represented as:

$$V_t = T_t + WD_t + L_t + U_t + S_t,$$

where V_t = total carbon in the forest, T_t = the amount of carbon in trees, aboveground and belowground, WD_t = carbon in wood detritus, L_t = the amount of carbon in the leaf litter layer, U_t = the amount of carbon in the understory, and S_t = the amount of soil carbon in the forest, all at time *t*. The carbon components of the leaf litter differ markedly in their rates of decomposition, with sugars decomposing most rapidly and phenols least rapidly.[8] Carbon flux, the net flow of carbon over time, is calculated by:

$$F_p = V_t - V_{(t-1)}$$

with F_p = carbon flux for period *p.*[9] If the average annual carbon flux is a positive number, the forest is sequestering more carbon than it is emitting into the atmosphere.



8 Bowen, G.D, and E.K.S. Nambiar ed. *Nutrition of Plantation Forests*. London: Academic, 1984.
9 *Northern Global Change Research Program*. USDA Forest Service. <http://www.fs.fed.us/ne/global/research/carbon/qanda.html>

Carbon Sequestration

Carbon sequestration in plants is the complex resultant of photosynthesis, respiration, growth, litter production, root exudation, decomposition and many other processes.[10] The respiration side of carbon flux is due mainly to carbon dioxide released into the atmosphere by soil bacteria and fungi. Trees are remarkably important absorbers of atmospheric carbon dioxide. It has been calculated that a cubic meter of wood contains about 250 kg of carbon.[11] The fact that trees are able to photosynthesize and lay down secondary growth makes it a powerful concentrator of carbon from the atmosphere into a fixed form.

Research done by Dr. Jiquan Chen, associate professor of the School of Forestry and Wood Products at Michigan Tech, showed that younger forests have a much higher carbon assimilation budget than older forests under similar climatic conditions.[12] At Harvard Forest, the majority of the forest stand is 60 yr old, dominated by oaks and maples. During the 1990's researchers in the Forest measured a mean carbon uptake of 2 Mg C/ha/yr for the entire forest. A mean of 2.4 Mg C/ha/yr was determined for a forest with similar species in Indiana.[13] After taking an average of these two, 2.2 Mg C/ha/yr, and dividing it into 5040 tons (the amount of Carbon Rice needs to eliminate), the resulting number becomes 2099.62 hectares. This number is a conservative estimate. As previously noted, the Harvard Forest is about sixty years old. According to Dr. Chen, a newly planted tree farm would sequester a slightly larger amount of carbon. Therefore the maximum amount of land Rice University would need to purchase and operate as a tree farm on in order to successfully offset its carbon dioxide emissions is 2099.62 hectares.

Photosynthesis and Respiration

In photosynthesis, a CO_2 concentration gradient develops from the atmosphere to the site of consumption in the chloroplast. The stomata provide the principal means of entry of CO_2 into the leaves of higher plants and therefore, their degree of opening can have a great degree of

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[10] *Carbon Sequestration Project*. Lancaster University Institute of Environmental and Natural Scienced. 4 March 2000.
[11] Moore, Patrick. *Greenspirit*. <http://www.greenspirit.com/carbon.htm>.
[12] Chen, Jiquan. *Forests Monitored for Roles in Carbon Budget*. Environmental News Network. <http:www.enn.com/enn-news-archive/1998/12/121798/carbon.asp>.
[13] Barford, Carol. Email. 6 April 2000.

influence on photosynthesis.[14] Photosynthesis can be measured in nine different ways. Some of these methods include measuring the change in energy content, the rate of formation of energy-rich intermediates or level of certain photosynthates.[15] Under optimal water conditions and normal CO_2 concentration, photosynthesis increases proportionally with photon flux density at low densities but levels off at higher densities.[16] The classic formula for photosynthesis is:

$$CO_2 + 2H_2O \text{ -> } [CH_20] + H_2O + O_2.$$

It is, however, the following biochemical mechanism that converts CO_2 into sugar using ATP and NADPH:

$$CO_2 + 3ATP + 2NADPH + 2H(+) \text{ -> } [CH_2O] + H_2O + 3ADP + 3P + 2NADP(+)$$ [17]

The process of respiration is unavoidable as the trees grow. It is a natural process, and can be described by the equation:

$$R = R_m W + R_c dW/dT,$$

Where R = total respiration, R_m = maintenance respiration, R_c = constructive respiration, W = biomass, dW/dT = growth rate.[18] It is during respiration that the trees release some of the carbon dioxide back into the atmosphere. However, as was stated earlier, the majority of the carbon dioxide returned to the air is due to the work of soil bacteria and fungi.

Maximizing Investment

A forest plantation is a dynamic system aimed at maximizing wood production. In order that the long-term nutrient supply of the soil is not impaired, it is important to identify the soil characteristics, which determine the supply of nutrients to trees.[19] The maximum productivity

[14] Leopold, Carl A. *Plant Growth and Development*. New York: McGraw-Hill, 1964.
[15] Sethuraj, M.R., and A.S. Paghavendra ed. *Tree Crop Physiology*. Amsterdam: Elsevier, 1987.
[16] Leopold, *Plant Growth and Development*
[17] Mohr, Hans, and Peter Schopfer. *Plant Physiology.* Berlin: Springer-Verlag, 1995.
[18] Thornley, J.H.M., and Hesketh, J.D. (1972) Journal Applied Ecology. 9, 315-317.
[19] Bowen, et. al., *Nutrition of Plantation Forests*

attained by tree crops are often due to a canopy branching structure that gradually builds up to support a continuous foliage cover. Therefore it may prove profitable to apply fertilizer to plantations to correct severe deficiencies in order to obtain a satisfactory crop of to increase productivity. This requires a detailed analysis of the nutrient status of the land and of the trees to be used. In order to maximize growth, nutrients should be added as efficiently as possible, and supply factors should be regulated through careful management of the soils and trees.[20] This would further increase the amount of carbon assimilated into the trees.

When the plantation of forests is viewed as a financial investment, there is often economic pressure to shorten the rotation length. The largest cost of plantation forestry is its establishment and the sooner a yield can be obtained, the sooner the cost and interest payments accounted to it may be balanced.[21] This does not appear to be a problem for Rice University. When property is purchased, resources in the endowment are used.[22] When considering the potential profits from tree sales, the plantation should more than pay for itself.

Additional Benefits

Although this endeavor may at first appear to be a large investment, it is in fact much easier to accomplish than the planned reductions of carbon dioxide emissions. In addition to reaching compliance with the Kyoto Protocol, Rice University may also be eligible for some extra benefits. Incentives to plant trees for the purpose of carbon sequestering include Federal cost-shares, forest management assistance programs, and tax credits.[23] Therefore, in addition to achieving its environmental goals, Rice University will benefit economically from investing in tree plantations.

In addition to allowing Rice University to reach compliance with the Kyoto Protocol, tree plantations could prove very educational to the Rice community. Students in many disciplines would find a trip to the plantations highly informative. Business majors might desire to view the management side of the tree farming, while biology majors might want to do studies regarding carbon uptake and plant physiology. Those students with a more environmental background could study the policies and procedures needed to start additional tree plantations. The civil

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[20] Ibid.
[21] Ibid.
[22] Wise, Scott. "Investments and the Treasury." City of Houston. Rice University. 19 April 2000.
[23] *Northern Global Change Research Program*, USDA Forest Service

engineering students might find the drainage systems and overall planning for the plantation in their area of interest. Therefore, the tree farms could be a valuable educational asset to the University in addition to being a good investment.

ALTERNATIVE FORMS OF CO_2 SEQUESTRATION

CO_2 sequestration is a second option that would allow Rice to mitigate CO_2 output. CO_2 sequestration is an emerging technology where CO_2 is stored underground or underwater permanently, or at least for a long time. Since CO_2 sequestration is such a young technology, many different options to sequester CO_2 are currently being studied.

CO_2 sequestration is essentially a four-step process. The first step is to separate the CO_2 from all other gases. The second step is to capture the CO_2 for storage. The third step involves transporting the stored CO_2 to the site where it is to be sequestered. Finally, the CO_2 is transferred into the sequestration site. Six different types of storage types have been researched.

Mined Salt Domes or Rock Caverns

While both options provide a large potential storage capacity and have previously been used to store petroleum, compressed gas, and natural gas, both have shortfalls. Rock caverns are expensive to excavate and difficult to seal off to sequester the CO_2. Solution mining (dissolving salt underground with a solvent, then removing the mixture) allows salt domes to be excavated much cheaper than rock caverns, but both still have the problem of waste disposal.[24] Due to high costs and disposal problems, this option is not viewed as a particularly promising sequestration method.

Deep Aquifers

This technique involves injecting CO_2 either as a gas or liquid into deep aquifers. Statoil of Norway began using this technique in September 1996 to avoid paying Norway's carbon tax. Statoil now injects 20,000 tonnes[25]/week of CO_2 into an aquifer 1000 meters below the North

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[24] Herzog, Drake, and Adams. *CO_2 Capture, Reuse, and Storage Technologies for Mitigating Global Climate Change*. MIT Energy Lab, January 1997. From www.co2experiment.org/papers.htm accessed 4/5/00.

[25] A tonne is a metric ton, which is 1,000 kilograms or approximately 2,205 pounds.

Sea. Early tests indicate that the CO_2 is sequestered in three different ways: it has reacted to form solid calcite, dissolved into water, or remained as a separate gas. Exxon and Pertamina have also made plans to begin injecting CO_2 into an aquifer 1000 meters below the China Sea floor.[26]

Since CO_2 injected into deep aquifers will remain there indefinitely, it is considered the best long-term solution (estimated 5-500 billion tonnes of potential storage). However, some technical uncertainty remains. For one, the long-term affects of injecting CO_2 into aquifers remain unknown. Also, aquifers chosen for injection must fit two characteristics. They must be located under an impermeable cap, and the aquifer must be highly permeable with high porosity to allow the CO_2 to disperse throughout the aquifer. There are over 400 deep aquifer wells in the U.S. used for injecting industrial waste, indicating that CO_2 injection into deep aquifers is definitely feasible.[27]

Depleted Oil and Gas Reservoirs

CO_2 sequestration in depleted oil and gas reservoirs is considered the best current option for CO_2 storage. Since these reservoirs previously held pressurized fluids for prolonged times, they are expected to have high storage integrity. Estimates indicate that current depleted reservoirs can hold 2.9 billion tonnes CO_2 (compared to 1.7 billion tonnes in annual CO_2 emissions from U.S. power plants). The main problems with this method are the high cost of transporting CO_2 to the reservoirs and the environmental impacts of doing so. Only in Texas are depleted reservoirs and power plants close enough geographically to consider building pipelines for CO_2 transport.[28]

Coal Beds

This third method for CO_2 sequestration is the first option to provide an economic incentive. Injecting CO_2 into underground coal seams displaces one molecule of methane for every two molecules CO_2 stored. The methane can then be captured for use. In 1996,

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[26] Herzog et. al., *CO_2 Capture, Reuse, and Storage Technologies for Mitigating Global Climate Change*
[27] Ibid.
[28] Ibid.

Burlington Resources began using this method of CO_2 sequestration in the northern San Juan basin, New Mexico (Allison Unit). This facility makes a profit of $15 per tonne CO_2 sequestered[29]. However, the Allison Unit is nearly ideal for this process, and most sites will not make a profit with current technology. It is estimated that worldwide, 5-15 billion tonnes CO_2 can be sequestered at a profit of $15/tonne. Additionally, 60 billion tonnes CO_2 can be sequestered at a cost of less than $50/tonne and 150 billion tonnes CO_2 can be sequestered at a cost of $100-120/tonne.

Coal seams must be relatively permeable for this process to work and can only absorb so much CO_2 before "breakthrough" occurs. This happens when the coal begins to release CO_2 back into the atmosphere. However, "breakthrough" is not as big a problem for coal bed injection as it is for oil and gas reservoir injection. Another limitation to this process is the high cost of gathering and transporting CO_2 to the injection site. In the San Juan basin, natural and anthropocentric sources of CO_2 are close enough to the injection sites to make injection profitable.[30]

Active Oil Reservoirs

Like the injection of CO_2 into coal seams, injecting CO_2 into active oil reservoirs enhances oil production and lengthens the oil field's lifetime. CO_2 has been used in the U.S. for enhanced oil recovery (EOR) for years. There are currently 67 commercial EOR projects (mostly in west Texas) running. Typically, 50% of injected CO_2 remains underground while 50% is removed with the oil.[31] Like injection into coal seams, the main concern with EOR is CO_2 "breakthrough". It is also 33% cheaper to use CO_2 from natural source rather than capturing it from industrial sources and transporting it to the injection sites.[32]

[29] Hanisch, Carola. *Exploring Options for CO_2 Capture and Management*. American Chemical Society web page: pubs.acs.org/hotartcl/est/99/feb/explor.html accessed 3/1/00.
[30] Stevens, Kuuskvaa, Spector, and Riemer. *CO_2 Sequestration in Deep Coal Seams: Pilot Results and Worldwide Potential*. From www.ieagreen.org.uk/pwrghgt4.htm accessed 4/3/00.
[31] Hanisch, Carola. *Exploring Options for Co_2 Capture and Management*
[32] Herzog, et. el., *CO_2 Capture, Reuse, and Storage Technologies for Mitigating Global Climate Change*

Ocean Storage

Oceans are by far the largest potential CO_2 sinks. They already hold 140 trillion tonnes of dissolved CO_2 (compared with 22 billion tonnes per year produced by global anthropogenic sources).[33] Anthropogenic emissions are low compared to the amount of CO_2 exchanged between the atmosphere and oceans every year. A small increase in oceanic absorption could have a big impact on atmospheric CO_2 concentrations.[34] Dissolved CO_2 is found in all surface water on Earth (lakes, rivers, oceans, etc) because it naturally dissolves into water from the atmosphere. Given thousands of years, oceanic CO_2 and atmospheric CO_2 will reach a state of equilibrium (no CO_2 transfer between atmosphere and ocean). Five methods of CO_2 injection into the ocean are being studied[35]:

- Dry ice can be released into the ocean from a ship.
- Liquid CO_2 can be injected through a pipeline to depths of around 1000 meters from a moving ship. From there, the less dense CO_2 will rise in a plume and dissolve.
- Liquid CO_2 can be injected from a stationary pipeline on the ocean floor at depths of 1000 meters. Again, the less dense CO_2 will rise in a plume and dissolve.
- A dense CO_2-seawater mixture can be injected through a pipeline to depths from 500-1000 meters. This mixture is denser than the surrounding seawater and would sink.
- Liquid CO_2 can be injected to depths of around 4000 meters on the ocean floor. The liquid CO_2 will form fairly stable "lakes" and remain in place for some time.

The deep ocean is viewed as an especially large potential CO_2 sink. Masutani and Masuda estimate that the deep ocean can potentially hold 100 times the 36 trillion tonnes CO_2 it currently holds. Surface waters act as a "bottleneck" between atmospheric CO_2 and the deep ocean due to the slow transfer of CO_2 from atmosphere to surface water.

A multi-national experiment (Japan, U.S., Norway, and Canada) will be conducted off the Kona coast in Hawaii sometime between the summer 2000 and summer 2001. For two weeks, liquid CO_2 will be pumped down to around 3000 feet and released. Instruments at the

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[33] Ibid.
[34] "Carbon Sequestration: expanding global options". Department of Energy web page: www.fe.doe.gov/coal_power/sequestration accessed 4/15/00.
[35] Herzog, et. al., *CO_2 Capture, Reuse, and Storage Technologies for Mitigating Global Climate Change*

ocean floor will measure and track the CO_2 as it disperses.[36] This method is the only option feasible with current technology and can be accomplished at $5-15 per tonne CO_2 injected.

Studies indicate that the deeper CO_2 is injected into the ocean, the longer it will take to equilibrate with the atmosphere. Thus it is removed from the atmosphere for a longer period of time[37]. The main setback to oceanic CO_2 injection is its potential impact on the environment. However, environmental impacts to the ocean from CO_2 injection are currently less of a concern than environmental impacts from atmospheric CO_2 (global warming).

The main environmental concern involving oceanic CO_2 injection is pH change. When CO_2 dissolves into water, it forms H_2CO_3, a weak acid. Thus dissolving mass quantities of CO_2 into the ocean will make the ocean more acidic (a drop in pH). The ambient pH of ocean water is 8, but it is estimated that very near to injection sites, pH could drop to as low as 4 (10,000 times more acidic). Of course, further away from the injection site the pH will be much closer to that of the ambient ocean. While these pH changes would have little impact on swimming species, it could impact bacteria and plankton. This, in turn, would impact other species higher up in the food chain. Making sure that injected CO_2 is dispersed over a large area can minimize local pH changes. Over the next few centuries, experts predict a .5 increase in pH due to anthropocentric CO_2 increases. Injection into oceans would create less than a .1 increase globally.[38]

Research Opportunities for Rice

According to Herzog, Drake, and Adams, the main obstacle CO_2 sequestration faces are the costs associated with separating and capturing CO_2 from point sources. Currently, CO_2 separation is done by using the solvent monoethanolamine (MEA)[39]. This method is expensive and inefficient. Emerging prospects to decrease CO_2 separation costs include new solvents, new membranes, and low-pressure formation of CO_2 hydrates.[40] We recommend that Rice invest in graduate and faculty research in these areas. Rice is ideally set up for this research with a cogeneration plant on-campus where new technologies can be tested. Rice could patent any

[36] Masutani and Masuda. "International Research on CO_2 Ocean Sequestration Proposed for Kona". From www.co2experiment.org/article.htm accessed 4/14/00.
[37] Hanisch, *Exploring Options for CO_2 Management*
[38] Herzog, et. al., *CO_2 Capture, Reuse, and Storage Technologies for Mitigating Global Climate Change*
[39] Ibid.
[40] Parson and Keith. "Climate Change: Fossil Fuels Without CO_2 Emissions". From *Science* online. 1998 November 6; 282: 1053-1054. www.sciencemag.org accessed 4/13/00.

breakthroughs in the field for profit. Without more cost-effective ways to separate and capture CO_2, the sequestration process will remain a financial liability.

Of course, for Rice to capture CO_2 from its cogeneration plant, the plant needs to be equipped with the hardware to perform the separation process. We recommend that Rice purchase the hardware needed to separate CO_2 so that technologies developed at Rice can be developed and tested. Rice will then have the ability to capture CO_2 in the upcoming years so that when sequestration becomes a common way of carbon mitigation, Rice can take advantage of it.

Thanks to the Evangeline aquifer, Rice has the opportunity to research CO_2 injection into deep aquifers. The Evangeline aquifer is a deep aquifer with a 300-foot thick, impermeable cap of marine clay. Rice has wells on-campus drilled down 2000 feet below the surface into the Evangeline aquifer.[41] This gives Rice a potential site to sequester CO_2 as well as a place to research the effects of CO_2 sequestration in deep aquifers. We recommend that Rice begin studying the dispersal and effects of deep aquifer CO_2 injection by injecting measured amounts of CO_2 through our wells into the Evangeline aquifer.

Finally, we recommend that Rice form a partnership with an oil/natural gas/coal company allowing Rice to research CO_2 injection into oil and gas reservoirs (active and inactive) as well as coal seam injection. In addition, access to offshore oil rigs would give Rice graduate students and faculty the opportunity to research deep ocean sequestration.

Other Potential Solutions

There are numerous other ways that Rice University can reduce its CO_2 emissions and lesson its strain on the environment in general. Unlike the proposals for the various forms of carbon sequestration we developed above, which are remidiational, these solutions address the source of the pollution. They focus on the practices of using clean energy and reducing energy consumption in general. They include:

- Purchasing "Clean," CO_2-Free Energy

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[41] Email from Dr. Philip Bedient, Professor of Environmental Science and Engineering at Rice University, 4/19/00.

    - Such a program is offered in Austin. Reliant Energy (the energy supplier for the City of Houston and Rice University) is currently working on a similar program for the Houston area.
    - This method involves purchasing energy that was produced using renewable power, creating no CO_2 in the process.
- Installing Solar Panels On the Roofs of Campus Buildings
    - This is another method that would allow Rice to use clean energy and thus lower the total CO_2 output indirectly produced by the university. One issue that needs to be taken into account with solar panels, however, is the amount of pollutants produced during the manufacture of the panels.
- Increasing Cogeneration
    - Rice has a cogeneration plant on campus that potentially is capable of powering the entire university. One negative aspect of this is the production of NOx during the cogeneration process.
- Reduce Energy Consumption in Student/Dorm Life
    - Install autolights which shutoff when the room is unoccupied
    - Bill rooms individually for energy use
    - Educate Students About their Role in the Energy Problem/Solution
- General University Life
    - encourage carpooling
    - limit faculty/athletic travel
    - require sleep mode for computers not in use
- Make Shuttles "Cleaner".
    - Possibilities include battery-powered shuttles or shuttles which are run on natural gas.

CONCLUSION

The initial goal of University 303 was to develop thoroughly options of available solutions able to reduce the amount of carbon dioxide the Rice campus releases to the amount specified by the Kyoto Protocol. In line with this objective, we developed methods of offsetting emissions through acquiring forested areas and constructing means for the permanent containment of the gas. To make the adoption of these and other primarily environmental suggestions a realistic possibility, some of our focus shifted towards cultivating an atmosphere at Rice where environmental concerns are integrated into decision making

The first steps in undertaking a policy change of this magnitude is to acquire a thorough understanding of the system in question and pinpoint its weak areas. The aspects of Rice that we determined cause the greatest obstacles to environmental pursuits could be sufficiently alleviated by the adoption of an explicit, university-wide environmental policy, a budget criteria valuing sustainability, and a university environmental position with the formal standing to be recognized by decision makers. As the system operates now, lacking these improvements, most proposals that are primarily environmental in nature do not have a realistic chance of being approved.

As a community leader and a respected institution of higher learning, Rice posses both the ability and obligation to take an active role in the advancement of social issues. The environment is one such area of concern where the University can have a definite positive impact on society through its own policies and its responsible education of future leaders. As Rice recognized in its signing of the Talloires Declaration, universities can and should be active in the progress towards sustainability.

The changes we are recommending for the university are not large and are within its immediate capabilities. There are likely few arguments against Rice fulfilling the commitments it made when it signed the Talloires Declaration. In addition to those, other valid goals include: reducing the consumption and waste of resources on campus, improving the current recycling and composting programs, and investing in means to mitigate what pollution we cannot eliminate. It is time for Rice to stop stating its commitments and start working towards them in a cohesive manner with the involvement of departments across campus. To do this effectively, support from the highest levels of administration is necessary. Most fundamentally, in times of decision-making, Rice needs to weigh equally economics with the best interests of the Rice community and the global ecosystem that we are a part of.

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