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Greenhouse Gas Abatement Through Non-Forest Biomass Production:

Allocating Costs to Global and Domestic Objectives

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ABSTRACT

Some projects have both global and domestic environmental benefits. The authors examine the feasibility of applying alternative cost allocation formulas to divide the incremental costs of such projects between domestic and international sources of funding.

This issue is an important one for the Global Environment Facility, and indeed for any international fund that finances the incremental costs of projects designed to further global environmental objectives, because the financing rule affects both project selection and financial resource mobilization.

The paper illustrates the application of alternative interpretations of the incremental cost financing rule to one of many possible types of global environment project: non-forest biomass production to abate greenhouse gas emission. For this initial exercise, greenhouse gas abatement was chosen because it illustrates very clearly the cost allocation issue inherent in "jointly products"--that is, "dual purpose" projects. These are projects that produce benefits at both the domestic level and the global level. (The incremental cost of projects that have **only** global benefits, such as some projects that substitute ozone-depleting substances, can only be associated with global benefits and do not pose such a difficult cost allocation issue.) Within the class of greenhouse gas abatement projects, non-forest biomass projects were selected as the examples because they constitute an interesting but relatively unexplored area, compared with (say) fossil fuel conservation and carbon sequestration in forests upon which much more has been written. Nevertheless, the cost allocation issue is a general one; it would also be worthwhile to examine the problems of applying cost allocation principles in other project types and in other global environment issues.

Principles of cost allocation are being reviewed by a number of interested parties. This report does not propose or recommend any particular principle or interpretation, but rather describes some of the operational implications of applying alternative principles that have been suggested elsewhere. Underlying cost allocation is the technical question of separating and quantifying the global and domestic environmental benefits; the authors describe the limitations of existing methodologies to do these but make suggestions for the preparation of non-forestry biomass projects which take these limitations, and other practical constraints, into account.

ABBREVIATION/ACRONYMS

BOD	Biological Oxygen Demand
Btu	British Thermal Unit
CFC	Chlorofluorocarbon
CIS	Confederation of Independent States
CO_2	Carbon Dioxide
C/N	Carbon/Nitrogen Ratio
ERT	Emissions Reduction Technology
FAO	Food and Agriculture Organization
GEF	Global Environment Facility
GET	Global Environment Trust
GHG	Greenhouse Gas
Gt	Gigatons (10^9)
Joule	Unit of energy = 0.239 calorie
MdT	Metric Dry Ton
MW	Megawatt
NaCl	Sodium Chloride
OECD	Organization for Economic Cooperation and Development
PCB	Polychloronated Biphenyls

GLOSSARY

Abatement	Lessening or reducing an amount of gas emitted.
Anthropogenic	Human produced.
Eutrophication	Process whereby increased nutrients cause excessive growth of aquatic plants, the resulting bacteria consuming nearly all the oxygen killing all the fish.
Halophyte	Salt-tolerant terrestrial plant (e.g. *Atriplex, Saliconia, Indica*).
Mitigation	Activity to restore environmental dammage or reduce negative environmental impacts.
Phycoculture	Culture of algae.
Seaweeds	Macroalgae, Brown (e.g. *Laminaria, Gracilaria, Gelidium, Sargassum muticum, Undaria*).
	Macroalgae, Red (e.g. *Palmaria, Eucheuma, Macrocyctis, Sagassum, Cystoseria*).
	Microalgae (e.g. *Spirulina*).
Sequestration	The conversion, through photosynthesis, of atmospheric carbon dioxide into organic form in plants.
Sub-bituminous	Any of several hard or semisolid materials obtained as a tarlike residue in the distillation of petroleum, coal, etc.

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CHAPTER I

INTRODUCTION

1.1 Environmental issues have become increasingly important within the World Bank in both its economic sector work and lending programs. As noted in the recent World Development Report (World Bank 1992a), environmental quality and protection are key to the living standards of much of the population of the developing world. In addition, environmental problems, unless addressed, may undermine development activities and economic growth. Because of the potential impacts of environmental degradation on economic growth, the Bank has an undeniable direct interest in assessing possible interventions to reduce its negative environmental impacts and to promote sustainable development.

1.2 This report focuses on how projects which promote the production of specific types of non-forest biomass (i.e. terrestrial and aquatic plants) can address domestic as well as global environmental issues. This report evaluates the potential of two types of plants: seaweeds and halophytes (salt-tolerant plants). The term "joint products" or "dual-purpose" projects is used in this paper to denote operations which positive environmental impacts at both the domestic and global levels. The specific project interventions considered in this report concern the use of such biomass to provide local economic and environmental benefits through land reclamation, energy production, food production, industrial chemical production, and the protection of waters from industrial and organic pollution. This paper focuses on the reduction of ambient levels of atmospheric carbon dioxide as the primary global environmental benefit of these projects. Because plant biomass captures, or sequesters, carbon in the atmosphere, they can help reduce the increases in ambient CO2 concentrations, a key factor linked to global climate change.

1.3 This paper analyzes the use of non-forest biomass, as opposed to forest biomass, for several reasons. The management of forest resources has been extensively discussed within the Bank, and is the subject of a Forest Policy Paper produced in 1992. Outside the Bank, the use of forests to sequester carbon as well as provide local domestic benefits has been well explored. Several demonstration projects using forests for global and local benefits have been completed, for example in Guatemala (Trexler et. al. 1989). The use of non-forest biomass, on the other hand, is a relatively new development and has not been extensively or comprehensively explored. Non-forest biomass can be produced on non-arable land or offshore sites. As a result, such production does not compete with agriculture for arable land which is under increasing demand. In addition, the existing data suggest that in some cases non-forest biomass could be effective in addressing both local and global environmental issues (Glenn et al. 1991).

1.4 The feasibility, technical, financial, and economic issues of these joint products are presented in detail in this report. The analysis of these issues is important because:

- Projects with joint products represent a more comprehensive approach to development because they consider both the global and domestic environmental impacts. As such they can address the environmental sustainability of projects, a major goal at the Bank.

- The techniques used in joint products often represent a combination of well proven and new technological approaches to project design and implementation, and need to be fully evaluated before they can be integrated into projects out on a wider scale.

- New financial mechanisms are being implemented which address global issues, and which can enhance the cost-effectiveness of normal Bank lending through support of the global cost components of projects.

- With economic and project costs and benefits dispersed between global and domestic products, an understanding of the cost and benefit allocation is necessary for proper cost allocation between regular Bank financing, and support from globally oriented funding sources.

1.5 As an outgrowth of its interest in addressing domestic and global environmental issues, the Bank has become a major funding source through the Global Environment Facility (GEF). The GEF is a program established by the Bank, the United Nations Development Program, and the United Nations Environment Program to focus on four major global environmental issues: biodiversity, ozone depletion, global climate change, and pollution of international waters. Since it was established in 1990, the GEF has provided $548 million for investment projects, technical assistance and, to a lesser extent, research. The project selection criteria for the GEF include projects which benefit the global environment in one of the four areas of activity, are innovative and demonstrate the effectiveness of a particular technology or approach. The techniques assessed in this report may meet this selection criteria.

Scope of Report

1.6 This report is written primarily for technical and operational staff within the Bank. While much of the focus of the report is on financial and economic considerations of joint products, environmental specialists, task managers, energy specialists, agricultural engineers and others may find sections of this paper useful. Chapter II considers the economic analysis of joint products, and should be of interest primarily to economists and those concerned with the allocation of economic and project costs between regular and global financing sources. Chapters III - VII consider domestic environmental issues for non-forest biomass projects including: land reclamation and habitat restoration, energy production, food production, industrial chemical production and pollution prevention. Chapter VIII considers the global benefits of joint products, and examines the issues of global climate change resulting from increases in ambient carbon dioxide levels. Chapter IX considers operational and implementation considerations for Bank interventions through projects with joint products. Chapter X compares the various joint products, and puts forward recommendations on those which appear to have the greatest potential for implementation by the Bank.

CHAPTER II

ECONOMIC ANALYSIS OF JOINT BIOMASS PROJECTS

2.1 This chapter focuses on the methodology for selecting dual-purpose projects that address global environmental issues, and simultaneously have significant domestic economic and environmental benefits. The specific global objective of these interventions center on reducing the emission of greenhouse gases (GHGs) through the cost-effective production of non-forest biomass. Biomass, in the greenhouse context, is a sink for atmospheric CO_2 -- which accounts for half of the GHGs -- as well as a source of renewable energy and a factor in pollution control. It is also considered as a valuable resource for improving the productivity of salinized land, increasing the availability of food and fodder, and as a source of chemicals. The conceptual approach adopted takes into account studies undertaken within the World Bank on *Greenhouse Gas Abatement* (King and Munasinghe 1991, 1992) and *Cost Sharing of Projects with Global and Domestic Environmental Benefits* (King 1992). This Chapter specifically addresses cost-benefit issues related to specific non-forest biomass crops -- halophytes and seaweeds. Cost allocation is a particularly important issue in the context of the World Bank funding mechanisms, that is, traditional lending program versus globally-oriented funding sources (e.g. GEF).

Global Funding Mechanism for Joint Projects

2.2 The Global Environment Facility (GEF) provides grants or concessional loans for joint projects that are consistent with global environmental conventions and country-specific environmental strategies or programs that use appropriate technology, and are both cost-effective and of high priority from the global perspective (IMF and World Bank 1991). From the financing perspective, a project can qualify for GEF support by meeting one of the following criteria:

(a) The project is justified on economic grounds and has an acceptable rate of return, but the country would not proceed without GEF involvement;

(b) The overall rate of return of a project is not attractive enough for the country to undertake it, but such a project would have substantial global environmental benefits;

(c) The investment is justified in domestic terms, but the country would need to incur extra costs to produce additional global benefits.

2.3 Wherever benefits for projects extend beyond national boundaries and the financial responsibilities for projects are divided, it is appropriate that a financial analysis be performed to evaluate which costs should be met nationally and which should be met internationally. A biomass project represents an incremental investment undertaken to reduce greenhouse gas emissions from what they otherwise would have been in the absence of the project. The incremental cost, rather than the total cost, is significant because of the funding criteria for the GEF. In addition, the total GHG emissions are less relevant than the amount of GHGs reduced by a project. This means that "with project" and "without project" scenarios need to be compared to evaluate the impact on GHG reduction. The issue of cost allocation for various economically justified biomass projects is part of the financial analysis, which will be dealt with later in this Chapter. The next section begins with the analysis of real resources of costs and benefits associated with biomass projects.

ECONOMIC ANALYSIS AND COST-BENEFIT CRITERIA

2.4 The economic analysis of biomass projects differs from financial analysis. The latter focuses on money profits accruing to the project entity, whereas the economic analysis measures the effect of a project on the efficiency objectives in relation to the whole economy. Cost-benefit analysis (CBA) is the key selection criterion for World Bank projects. The CBA assesses project costs and benefits using a common yardstick. Benefits are defined relative to their effect on the improvement in human well-being. Costs are defined in terms of their opportunity costs, which are benefits foregone by not using project resources in the best available alternative application.

2.5 Financial analysis focuses primarily on market prices and cash flows. Rather than financial prices, the economic analysis uses shadow prices to reflect opportunity costs. Wherever practical, economic analyses should include an assessment of the benefits and costs of the effects that biomass projects have on the environment, whether or not they are reflected in the market place. The environmental economic analysis improves the effectiveness of project design phase by paying more attention to the "externalities". In order to develop cost-effective means to reduce greenhouse gas emissions in developing countries through non-forest biomass production, it is essential that the project be evaluated both in terms of its domestic and global environmental impacts.

2.6 Table 2.1 describes the breakdown of domestic, and global costs and benefits for biomass projects following a three stage approach: (1) domestic economic impact, (2) domestic environmental impact, and (3) global environmental impact. While economic impacts are usually measured in monetary terms, environmental impacts are usually more difficult to measure and quantify. It is essential that double counting be avoided when translating environmental costs into economic costs.

2.7 Cost allocation is critical in determining whether or not a project will be eligible for global financing. The costs of production for biomass crops for domestic use may be different from the costs to produce the same crop for carbon sequestration alone. Costs for biomass projects may be allocated to the following categories: (1) domestic economic costs, i.e. project costs, including the valuation of externalities such as preventive capital expenses to reduce future environmental costs, and opportunity costs (alias, avoided future environmental cost of substituting renewable biomass for non-renewable fossil fuels), and loss of employment and labor as a result of environmental damage or disturbance; (2) domestic environmental costs, i.e. degradation of natural habitat, loss of biodiversity, and groundwater contamination; and (3) global environmental costs, i.e. additional project costs incurred, which are associated with long-term carbon storage. The latest two categories of costs are difficult to value and potential valuation techniques of biomass projects are further detailed in Table 2.2.

Table 2.1: Domestic and Global Costs and Benefits

Category	Costs	Benefits
Domestic Economic	1. Biomass Project Costs: a. Direct capital expenditures. b. Preventive capital expenditures to avoid future environmental costs. c. Operating costs. d. Opportunity costs of substituting renewable biomass for non-renewable fossil fuels. 2. Loss of Employment/Labor due to environmental degradation.	1. Increase in Present Value of earnings stemming from an increase in agricultural productivity. 2. Employment creation and labor income generation. 3. Increase in rental value of land. 4. Reduced travel cost.
Domestic Environmental	1. Destruction of natural habitat. 2. Loss of biodiversity. 3. Groundwater contamination.	1. Land restoration and reclamation. 2. Desalinization. 3. Reduction in industrial pollution. 4. Water purification capabilities.
Global Environmental	1. Additional project costs associated with long-term carbon storage.	1. Atmospheric carbon sequestration. 2. Reduction in pollution of international waters.

2.8 Similarly, benefits of biomass projects may be categorized as: (1) domestic economic benefits, i.e. the increase in Present Value (PV) of future earnings as a result of increased agricultural and fishing productivity1/, employment creation and labor income generation, production of rental value of land, and reduction of travel cost to collect fuel wood as biomass can be used as an alternative energy source; (2) domestic environmental benefits comprising from land reclamation via desalinization of agricultural soils, reduction in industrial pollution, and water purification capabilities; and (3) global environmental benefits, i.e. carbon sequestration, and reduction of pollution in international waters. Usually biomass projects take the "benefits" to be a given environmental standard which defines the socially desirable quality based on technical and political considerations. For example, the government may wish to increase tourism by intensifying seaweed cultivation to reduce industrial pollution and stabilize coastal shorelines.

2.9 The next section examines conventional economic analysis, which describes the *status quo* against which project alternatives needed to be measured, and then examines the costs of alternative projects and their effectiveness in reducing carbon emissions. What is important is to determine the incremental cost of a biomass project. Based on our analysis, it appears that while all project types incur incremental costs, the energy sector provides the largest incremental

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1/ It needs to be recognized that productivity changes are underlying in changes in real income.

costs as well as largest global benefit. The agricultural sector, on the other hand, provides relatively low incremental costs and high domestic benefits, but lowest global benefits. As a rule, the incremental benefits, rather than incremental costs will guide project selection.

COSTS CRITERIA AND FINANCING MECHANISMS

2.10 Figure 2.1 presents a schematic allocation of the economic project costs of a biomass investment. A biomass project comprises two types of costs at four different levels: (1) *Non-Separable Capital Costs* represent all start-up costs associated with the production of biomass, regardless of whether the project benefits are domestic and/or global; (2) *Non-Separable Operating Costs* include basic maintenance costs associated with the production of halophytes and seaweeds; (3) *Separable Domestic Operating Costs* reflect the costs related to the harvesting of biomass for domestic markets; and (4) *Separable Global Operating Costs* are related to the costs of carbon storage for the reduction of GHG emissions.

Non-Separable Capital Costs (Domestic and/or Global)

2.11 These costs can theoretically be separable or non-separable and are directly linked to the production of biomass.2/ However, for the purpose of this exercise the report assumes that all designed projects will pursue the dual objective of both domestic and global benefits, alias, a proportion of the biomass (carbon) will be used for local purposes and the remaining will be stored. Thus, capital costs would be assumed to be non-separable. For halophyte crops, these costs include land clearing, and planting. For seaweed plantations these costs entail preparing the sea bed, and planting.

Non-Separable Operating Costs (Domestic and/or Global)

2.12 These operating costs are inherent to the production of biomass projects, and are incurred regardless whether the project is designed for domestic or global purposes. For halophytes, these costs include watering, maintenance and plowing the biomass into the soil to improve soil quality and to store carbon. For seaweeds, the cost is limited to maintenance of sea beds. Once these biomass crops are under cultivation, they can be used for either strictly domestic benefits (habitat restoration, food -, energy -, industrial chemical production, and pollution control) or global benefits, i.e. carbon sequestration. The selected financing instrument will vary with the achieved benefits.

2.13 Biomass production costs for carbon sequestration vary with the type of crop used. Costs of seaweed farming are about twice as high as halophyte farming, and this difference in cost can be attributed to the relatively high cost of nearshore technological methods. Costs of halophyte cultivation appear to be somewhat more expensive than tree plantations, but the range of estimates overlap. Halophytes have one great advantage over trees in that they can be grown on land that

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2/ Costs would be considered global separable to the extent that the majority of the biomass (carbon) is stored. In this specific case, the cost of the project could entirely qualify for GEF funding. Costs could be classified as domestic separable when, for example, the majority of the biomass (carbon) is used for consumption. Global benefits would be low because of partial re-release of sequestered carbon in the atmosphere through respiration. Therefore, in this specific case, the costs would only be eligible for Bank's conventional financing mechanism.

has not been previously forested or farmed, whereas reforestation is largely restricted to arable land (see Chapter IV and VII).

Separable Operating Costs at the Domestic Level

2.14 The separable domestic operating costs in the five sub-sets of biomass projects are: (1) land reclamation: construction and operation of drainage systems, and harvesting; (2) food production: harvesting (net of storage), pre-treatment, processing and storage; (3) energy production: harvesting (net of storage), pre-treatment, methane conversion, waste water disposal, combustion emission, treatment and ash disposal; (4) industrial chemical production: harvesting (net of storage) and pre-treatment; and finally (5) pollution control: harvesting costs net of storage. Most of the operating costs of seaweed farms revolve around harvesting, whereas the main operating cost of halophyte farming is irrigation. Specific cost issues related to each of these five types of non-forest biomass projects will be addressed in the following chapters.

2.15 However, long-term carbon storage is an area which needs to be further explored in allocating operating costs for domestic or global benefits. For example, further research is needed to ascertain whether carbon can be stored effectively through the natural sloughing off of seaweed material in the ocean. If this technique is an effective long-term storage mechanism for carbon, the collection of biomass would only be required to prevent the toxics from accumulating in the higher levels of the food chain. As such, it would be categorized as a domestic cost. If this natural storage technique is ineffective, and, as a result the seaweed must be collected for carbon storage purposes, then the cost for collecting seaweeds should be allocated to global costs. Thus, seaweed may or may not be collected for pollution purposes, but would have to be collected for global purposes (Berger 1977). As a result, the associated cost could be allocated as either domestic or global.

Separable Operating Costs at the Global Level

2.16 These separable operating costs are strictly linked to the costs of long-term carbon storage, a global benefit. For halophytes, these costs would include plowing under of the biomass crop in the desert soils. If the carbon is stored in the arid saline fields in which the plants are grown, a portion of the halophyte material would eventually produce humus in the soil, and release a percentage as CO_2 back into the atmosphere. Thus, the costs would require adjustment based on the proportion of carbon re-released into the atmosphere.

2.17 No global costs are associated with the sloughing off of seaweed if that storage method for carbon is practical. If not, collection and deep-sea storage is necessary, which entails high costs. These costs are strictly global because they are solely related to achieving global benefits and would not be incurred for implementing projects with domestic benefits.

2.18 Given the limited available resources to finance joint biomass projects, it is critical that the environmental impact of a project be fully incorporated into the economic analysis. The next section attempts to allocate environmental costs and benefits to biomass projects.

ENVIRONMENTAL ECONOMIC ANALYSIS OF JOINT PROJECTS

2.19 It is generally acknowledged that environmental impacts are often difficult to measure in physical terms. Even when measured in physical terms, valuation in monetary terms is difficult. While economic cost-benefit analysis can be used to evaluate alternative projects in some sectors, quantitative cost-benefit analysis are not available in many instances. In order to evaluate whether a biomass project is economically justifiable and significantly contributes to greenhouse gas abatement, it is essential to: (a) determine the physical impacts and value these in monetary terms; (b) calculate the internal rate of return using the standard discount rate of 10 percent to offset long-term cost-benefit issues; and (c) make provision for risk and uncertainty issues.

Environmental Impacts and Measurement and Valuation Techniques

2.20 When evaluating the environmental impact of joint products, a distinction needs to be made between the domestic and global effects described above.

2.21 Table 2.2 presents a matrix of the possible domestic environmental costs and benefits of non-forest biomass production projects. The Table also provides the basic domestic measurement and valuation approaches, and the potential global environmental costs and benefits. Whenever possible, this report presents case studies to demonstrate how the cost/benefit analysis can be applied to each type of biomass project.

Domestic Costs and Benefits

Domestic Environmental Costs

2.22 The domestic environmental costs are similar for all five types of biomass projects. They encompass the potential reduction of biodiversity and pollution of water where biomass crops are either planted or harvested. A project may create changes in an ecosystem, which may in turn cause secondary effects and introduce an element of uncertainty, which needs to be accounted for in the cost-benefit analysis. These uncertainties exist because halophyte plantations may alter the level of soil salinization, reduce the biodiversity in planted areas, and accelerate eutrophication of adjacent bodies of water due to fertilizer run-off. In general, halophyte plantations may face similar problems to those that have plagued conventional irrigation projects, if the projects are not well planned.

Domestic Environmental Benefits

2.23 The domestic environmental benefits vary according to the economic use of the biomass. Biomass plantations can have multiple domestic environmental benefits resulting in increased economic activity and employment opportunities for the local population. For instance, **habitat restoration** projects using native halophytes can aid in revegetating bare coastlines. Halophytes can be used to reduce salinization (one of the biggest threats to agricultural land) and water-logging problems. One great advantage of growing halophytes and seaweeds over forest biomass is that non-arable land can be developed for food production, therefore reducing cultivation pressures on agricultural land. Halophytes cultivated as economic crops can also play a role in **land reclamation** through soil stabilization. Biomass can provide a potential source of non-fossil fuel **renewable energy** and thus reduce the demand on forest, oil and coal resources. In the

Table 2.2: Examples of Biomass Production Projects

Possible Environmental Impacts and Measurement and Valuation Techniques.

Type of Project	Domestic Environmental		Domestic Measurement and Valuation Techniques		Global Environmental	
	Costs	Benefits	Costs	Benefits	Costs	Benefits
Land Reclamation and Restoration Chapter III **CASE STUDIES** **CIS-Aral Sea** **Europe & East Eur.** **Western Australia**	Potential reduction of biodiversity and groundwater contamination where halophytes are planted. Potential disturbance of fish and invertebrate populations during seaweed harvesting.	1. Reduction of secondary salinization, waterlogging and overgrazed lands. 2. Increased land for agricultural production.	1. *Preventive expenditures* to reduce erosion and soil salinity. 2. *Reduced farming earnings* from fishing due to disturbance of seaweed harvesting or groundwater quality.	1. *Increased productivity* on marginal land. 2. *Enhanced value* of reclaimed land. 3. *Increased farming earnings* from improved land quality and value-added production.		1.Short/Medium/Long term reduction in ambient CO2 levels. 2. Reduced ambient particulate levels. 3. Reduction in sedimentation of international waters. 4. Protection of biodiversity through restoration of habitat.
Renewable Energy Chapter IV **CASE STUDIES** **Guatemala** **California, USA**	: : : : : :	Biomass project produces an alternative to fossil fuel energy, thus, reducing demand on forest, oil and coal resources through production and combustion of methane.	1. *Opportunity cost* of substitute biomass for fossil fuel energy source.	1. *Reduced travel cost* for wood collection.		1. Long term reduction of CO2 through offsets of fossil fuel emissions.
Food Production Chapter V **CASE STUDIES** **Pacific Rim** **Malaysia** **Indonesia**	: : : : : : : :	Sustainable <u>halophyte</u> plantation projects, while continuing to sequester carbon, can produce vegetable oil and animal feed. <u>Seaweeds</u> can grow in brackish water and produce microalgal mass rich in nutritional value.	1. *Preventive expenditures* to reduce erosion and soil salinity. 2. *Reduced farming earnings* from fishing due to disturbance of seaweed harvesting or groundwater quality	1. *Increase in productivity* of non-arable land because of salt water irrigation. 2. *Increased earnings* from new productive activities	Partial Re-release of carbon sequestered through respiration and methane production.	1. Short term reduction in ambient CO2 levels. 2. Reduced pressure for agricultural conversion.

context of using non-forest biomass for **food production**, halophytes can produce such products as animal feed and vegetable oil suitable for human consumption. Seaweeds may be eaten as salad (Philippines, Malaysia, Bali and Sri Lanka), used as an ingredient to make soups (e.g. *Durvillea antarctica* in Chile), and used as a nutritional value additive for weaning infant children (i.e. Chad) (FAO 1985). Biomass as a substitute input to **industrial chemical production** can reduce local pollution. Finally, seaweeds and halophytes, can play a role as biofilters in waste water management, or, serve a **pollution monitoring** function. While the above described domestic benefits are case specific, most projects have multiple environmental benefits. For example, recycling of village wastes (human, animal and vegetable) through a biofiltration system can improve sanitary conditions, and also be used as an energy source. (Fox 1987).

2.24 The production of halophytes and seaweeds also provides secondary environmental benefits. For example, revegetated desert areas may experience enhanced rainfall and lower temperatures. Thus, in the most optimistic scenario, halophytes could improve the local climate in arid regions and potentially reduce trends in desertification. These secondary uncertainties should be included in the project's economic analysis.

Domestic Measurement and Valuation Techniques (Munasinghe and Lutz, 1991)

2.25 The techniques used to value the domestic environmental costs and benefits in economic terms affect all five types of projects. These valuation techniques are presented in decreasing order of reliance upon market information, beginning with those that rely on actual market prices (change in capital increase associated with higher agricultural productivity and labor earnings, opportunity cost, cost-effectiveness and preventive expenditures), followed by those that use surrogate-market values (i.e. land values, travel costs), and ending with potential expenditures (contingent valuation, macroeconomic models). While markets are often distorted in developing countries, these valuation techniques might be only a partial measure, and shadow corrections may need to be applied.

2.26 Table 2.2 presents the various valuation techniques depending on the type of environmental impact, whether it is measurable in change in production or a change in environmental quality. The four key techniques used in describing the environmental impacts in quantifiable terms are presented below, along with two techniques which quantify the costs and qualify the benefits.

> *Change in Capital Increase Associated with Higher Agricultural Productivity*: Even if alternative projects are being considered, the "without-project" option should be retained. An assessment should be made of the effect on agricultural productivity of proceeding with the project and of not going ahead should be assessed. A land reclamation project involving planting halophytes can increase capital income as a result of higher agricultural productivity (benefit) of non-arable land through desalination, while simultaneously decreasing fisheries and future farming earnings (cost) as a result of groundwater contamination and run off from fertilizer and pesticide applications. In this particular case, assumptions need to be made on the time span over which the changes in productivity are measured, the market price used, and any future changes expected in relative prices.

Change in Labor Earnings: This technique is similar to that for changes in productivity, except in this case changes in human productivity are measured. For example, a seaweed pollution monitoring project could possibly improve the local water quality and reduce the adverse impact of toxics on individuals, thus improving their health and future earning potentials.

Opportunity Cost: This technique allows one to choose between the real value of alternative ways of meeting the same need, such as conventional energy sources versus renewable ones. With this technique it is possible to quantify the extra costs involved in choosing a more environmentally sustainable, but more expensive, alternative.

Travel Cost: This approach is used to value "travel time". The number of fuelwood collection trips could be reduced by substituting non-forest biomass products for wood, therefore giving the consumer a surplus in time. Users closer to the site of halophytes and seaweeds to be used for energy purposes, could incur lower travel costs.

2.27 The cost-effectiveness and preventive expenditures analysis rely on the use of market prices to evaluate costs that are really incurred. Neither approach attempts to estimate a monetary value for the benefits produced by the project. The project output is described in qualitative or physical terms (e.g. level of greenhouse gas abatement, or volume of water filtered).

Cost-Effectiveness Analysis: This method may be used to evaluate alternative projects sharing the same environmental objective of reducing pollution (e.g. air pollution or waste water management programs), and consists of analyzing the incremental cost of adopting one strategy over another (e.g. biomass versus conventional waste water treatment projects).

Preventive Expenditures: This technique examines the actual expenditures in order to determine the importance individuals attach to improving environmental conditions (e.g. quality of water).

2.28 Other potentially applicable techniques, which are less common, might use, for example, surrogate market values to determine the value of land. The production of halophytes can lead to land reclamation, whose ownership and rental value will need to be assessed. Finally, there are other methods available which use a group of survey-based methods to value the environmental impact of biomass projects in the absence of data on markets or surrogate-market prices (i.e. macro-economic modeling).

Global Costs and Benefits

2.29 Valuing the costs and benefits of greenhouse gas abatement is difficult, as no internationally agreed upon emission phase-out program has been established. It is, however, possible to physically quantify the environmental benefits in terms of short, medium and long term as they pertain to the release and reabsorption of CO_2 and reduction of pollution in international waters. The major global environmental costs associated with developing dual objective projects are related to long-term carbon storage. In the case of food production, the cost of releasing sequestered carbon through respiration and methane production will have to be qualified. It is not the purpose of the authors to value CO_2 reduction. The World Bank may wish to consider establishing a monetary value of unit abatement cost in order to determine the relative contribution of available financing mechanisms to dual purpose biomass projects. In the absence of such a monetary value, the environmental economic analysis for the project has been completed based on the physical CO_2 reduction level, the net economic cost (total cost of the project less domestic incremental benefits) will justify the country's access to global funding.

2.30 Carbon cycling and greenhouse gas simulation models can be an appropriate tool for examining such critical issues as costs/benefits of meeting various proposed emissions targets and integrating renewable and traditional energy supply technology with end-user efficiency needs. Research is currently being undertaken to investigate the economic impact of such proposals, as well as the most cost-effective strategies for achieving CO_2 emission benchmark, both domestically and globally (EPRI, 1991). Further work is also required on subjects including: the magnitude of future CO_2 emissions in the absence of emission abatement measures, the likely pattern of global energy use with population growth and economic development, the potential role of nuclear power, the potential expansion of renewable energy sources, end-use efficiency technology in reducing CO_2 emissions and the effect of various proposals to reduce international emissions on atmospheric concentrations of CO_2 (EPRI 1991).

B. Time and Discount Rate

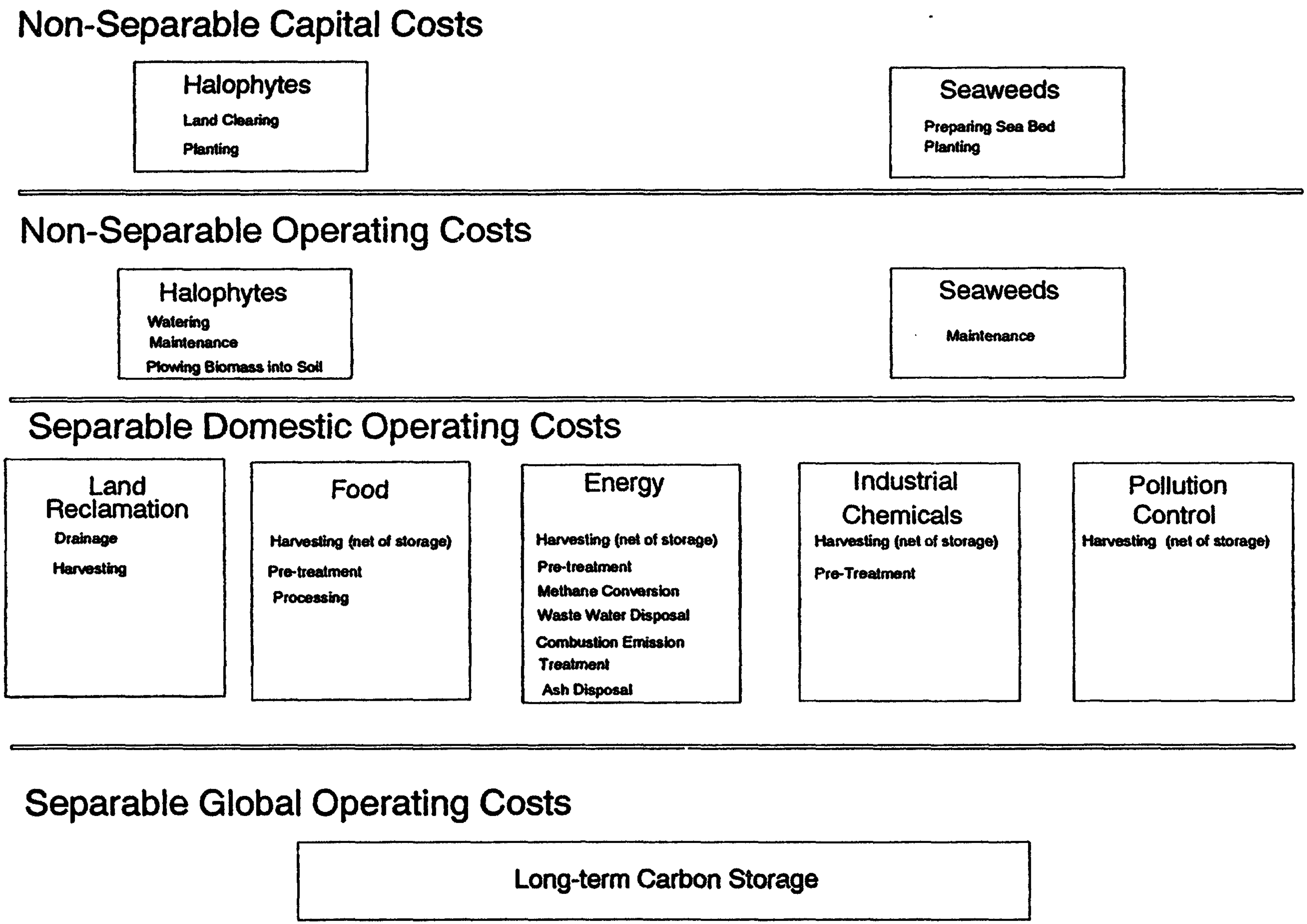
2.31 Following World Bank practices, the standard 10 percent discount rate is applied in this study. This rate may appear quite high for a project with long-term benefits (e.g. 10-years or more), and might discourage investments in halophyte or seaweed projects. The discount rate is retained for allocative decisions, and other policy instruments (i.e. natural resource taxes, carbon taxes, tariffs) and is used to maintain the appropriate scale of operations.

C. Risks and Uncertainties

2.32 A sound environmental economic analysis should make provision for risk factors (such as a loss of biomass crops due to unfavorable climate conditions), and uncertainty issues (such as introduction of new bio-technologies lowering the production cost of seaweed and halophyte crops to sequester carbon). Many secondary environmental impact issues discussed earlier, could be categorized as uncertainties.

2.33 The next five Chapters provide an operational approach for implementing the conceptual issues discussed above. The production of halophytes and seaweeds can address a broad spectrum of domestic issues: (1) land reclamation and habitat restoration, (2) renewable energy development, (3) food production, (4) industrial chemical production, and (5) pollution control and mitigation, and under certain circumstances may be compatible with their role as non-forest biomass crops for the reduction of global warming through carbon sequestration.

Figure 2.1 Cost Allocation of Biomass Projects



CHAPTER III

LAND RECLAMATION AND HABITAT RESTORATION

INTRODUCTION

3.1 It is estimated that up to 25% of the earth's surface is affected by salinity. As a result, millions of hectares of land throughout the world are too saline to produce economic crop yields, and more land becomes non-productive each year due to secondary salinization (Carter 1975). Unfortunately, the portions of the world now facing the greatest population pressures are the same areas that have the least amount of additional land available for agriculture and often include areas where waterlogging and salinization are a major problem (Skogerboe 1991). As the world's human population grows, competition for arable land has become a major issue in considerations of environmental projects, particularly the sequestration of atmospheric carbon through large-scale biomass production (Chapter VIII).

3.2 In contrast to reforestation, the use of seaweeds and halophytes as biomass crops to sequester carbon emissions does not compete for arable land. Halophytes can be grown in inland saline land which is already too salt-affected to produce agricultural crops (either naturally or due to secondary salinization from poor irrigation practices in the past), or in coastal saline deserts where seawater or brackish groundwater for irrigation is readily available (Glenn 1991, Chapter IX).

3.3 This chapter discusses projects which use of halophytes for land reclamation and seaweeds and halophytes for habitat restoration. In reviewing the literature, little information was available on seaweeds for these uses. Thus, although many of the ecological considerations pertain to both terrestrial and marine systems, the majority of the examples in the following discussion are restricted to halophytes.

3.4 **Secondary Salinization**. Sodium chloride (NaCl) is an alkali salt, and salinity problems with plant growth first appear when NaCl levels reach 0.5% in soil solution (Chapman 1975). Although some soils are intrinsically saline as a result of their parent material or proximity to the sea, secondary salinization (where previously non-saline soils become saline) is the result of poor water management practices related to irrigated agriculture. Soils affected by secondary salinization are found on all continents (Figure 3.1). Normally, salts formed during the weathering of soil minerals and soluble salts originally present in soils are leached through the upper soil horizons by rainfall, accumulating at depth in the groundwater, and may ultimately be transported to the ocean. This indicates a net percolation of water through the system (i.e. rainfall exceeds evapotranspiration). In areas of low rainfall, these salts are not fully leached, and increased evaporation rates further concentrate salts in both soils and surface waters. Irrigation with proper drainage may then restore net percolation to these arid systems. However, excessive irrigation in conjunction with inadequate provision of drainage leads to waterlogging, rising water tables, and contamination of soils and groundwater with salinity (Skogerboe 1991). Thus, disturbance of the water balance plays an important role in redistributing salts in the system.

3.5 **Reclamation versus Restoration**. Reclamation and habitat restoration may be viewed as the extreme points on a continuum for possible biomass projects (Armstrong 1993). Reclamation is used for the return of an extremely degraded (usually through human activities) ecosystem to some productive use. The plant community established on these reclaimed lands is not necessarily native or self-sustaining. For example, land reclamation may involve the construction of an agroecosystem which only persists with intensive management and external inputs (e.g., fertilizer, irrigation water). In contrast, habitat restoration implies the reconstruction of self-sustaining, ecologically functioning communities, ideally a return to the natural species assemblage that existed prior to disturbance (Bradshaw 1987).

3.6 This definition of reclamation differs from the use of the term in a broader economic context in that it does not consider *all* types of land conversion for human use to be examples of reclamation. Else, projects involving destruction of intact ecosystems (e.g. deforestation in the tropics and the conversion of coastal marshes to urban, agricultural and industrial uses) would be categorized as reclamation.

3.7 **Reclamation of Salt-affected Agricultural Lands.** Reclamation projects may have the objective of finding the technology to accomplish one or more specific goals: soil stabilization, pollution control, visual improvement, or a return to productivity. This report addresses land reclamation of salt-affected lands unsuitable for typical agricultural crops. There are several generic techniques for reclaiming salt-affected soils (Table 3.1) which may be integrated into a given reclamation project. These can be divided into three main types: (1) desalinating soils through modification of agricultural techniques, (2) planting cumulative halophytes which naturally remove salts from the soil (biological desalination), prior to cultivation of conventional crops, and (3) substituting halophytes for conventional crops without altering the salt levels in the soil. The techniques used depend on site conditions as well as economic considerations. Types (2) and (3) involve the use of halophytes to reclaim salt-affected soils and thus encompass potential biomass projects. The next three Chapters will discuss in greater detail the cultivation of halophytes and seaweeds as economic crops where their biomass is harvested for energy (Chapter IV), food (Chapter V), and industrial and chemical products (Chapter VI). Alternatively, when halophytes are grown to reduce salt levels in the soil native ecosystems could be subsequently established instead of economic crops (i.e. habitat restoration). Growing halophytes as biomass crops in plantations for the sole purpose of carbon sequestration is a special case of type (3).

Table 3.1[1]

Methods of Reclamation for Inland Saline Soils

Conditions	Reclamation Technique	Possible Environmental Impacts	Example	Comments
Salinity in surface soil prevents growth of crops	Deep plowing; scrape off highly saline surface soil layers	Soil erosion, nutrient loss	Canada	
Soil without sufficient gypsum	Addition of gypsum (CaSO4)	May inhibit native soil microbes, and impact nutrient cycling		Gypsum amendments reduce sodium absorption ratios in saline soils
Soil with sufficient gypsum	Extensive irrigation, flooding and leaching out of salts	Contamination of groundwater with salinized drainage water	Iran Iraq	Availability and quality of irrigation water; tiles or open drains assist in salt leaching, soil must be permeable to adequately drain excess water
	Prolonged leaching followed by crops of rice		India	
Highly saline soils	Plant very salt-tolerant plants, e.g. *Acacia arabica, Atriplex*	Species invasions	California Australia	Use native species if possible

[1] From Chapman (1975) and Kieft (1991).

3.8 Habitat restoration projects with seaweeds and halophytes can then include a special case of reclamation, and resemble carbon sequestration projects with several important differences. First, growing seaweeds and halophytes as biomass crops to sequester carbon emissions necessarily involves the use of large-scale, often monospecific, stands. The plants are not necessarily native, the emphasis is on productivity, and external inputs (fertilizer, irrigation water) are used to achieve this goal. Biomass may be harvested for long-term storage on or off-site. For habitat restoration, external inputs may be necessary to re-establish a functioning ecosystem, but the system is largely self-sustaining thereafter. The ecosystem's structure (e.g. density and pattern of planting), as well as the selection of predominantly native species, are designed to preserve biodiversity and maintain ecosystem functions. Carbon is stored in living biomass, which may be managed to some extent (e.g., through selective clipping and control of the age-structure of perennial species). As with reforestation projects, effective sequestration depends on the methods for long-term carbon storage (Chapter IX).

3.9 Integration of land reclamation and habitat restoration projects with global carbon sequestration projects requires that not all of the biomass (carbon) is harvested for subsequent consumption which returns the carbon to the atmosphere. Thus, the incremental cost of reclamation and restoration projects relative to carbon sequestration projects depends in large part on the ultimate fate of the biomass crop (the proportion designated for long-term carbon storage versus consumption).

ECONOMIC BENEFITS AND COSTS

3.10 GEF projects undergo environmental assessment according to the World Bank's operational directives in those cases where they are likely to have a significant impact (e.g., impacts on biodiversity, local food supply, etc.). In particular, for projects with the potential to affect ecosystem function, an objective assessment is required for the environmental services provided by the intact ecosystem, along with its ecological and economic value under various conditions (World Bank 1992b). Unfortunately, the valuation in monetary terms for environmental parameters such as clean air and water, nutrient and soil retention, and biodiversity is not well defined. This precludes a direct comparison of economic versus environmental costs and benefits, and thus we are left with abstract, philosophical or political discussions of the value of environmental costs traded off against monetary considerations of economic benefits.

3.11 In the lower Rio Grande Valley of Texas, highly saline soils are interspersed among non-saline soils, forcing farmers to plant and cultivate saline areas along with non-saline areas. As a result, they actually harvest only 75% of the land cultivated, adding to operational costs and making farming in the area less practical; (Carter 1975). With adequate resources, these salt-affected lands can be made productive through reclamation, increasing the amount of land available for economic crop production as well as the value of the land (see Chapter V).

3.12 Aside from the value of repairing damaged ecosystems (including agroecosystems), and mitigating environmental degradation, reclamation has potential economic benefits associated with the concurrent or subsequent production of economic crops on reclaimed soils. From an economic standpoint, it may be desirable to choose a halophyte species which can play a role in biological desalination as well as producing biomass of economic value (Singh 1970a, see Box 3.1).

3.13 Less obvious economic benefits of land reclamation and habitat restoration involve the preservation or restoration of ecosystem services. Restoration of native ecosystems may or may not be associated with additional economic benefits (e.g. increased habitat for economically important, harvested native wildlife, ecotourism, etc.). Thus, it may be necessary to have an economic appraisal of the total value of saline areas under wild conditions before and after reclamation, so that some firm recommendations can be made as to the total economic impacts and how much can be reclaimed without causing damage to the overall environment (Chapman 1975). For example, restoration of coastal areas may be evaluated as an alternative to conversion for agriculture or urban development. An attempt has been made to estimate the potential annual value of an acre of *Spartina alterniflora* salt marsh in coastal Georgia (Table 3.2), with multiple use values including aquaculture, grazing by cattle, microbial conversion to protein concentrate and water quality improvement. The estimated worth for one acre of salt marsh equated over 20 years was $100,000 (Reimold 1974). In many cases, it may not be economically beneficial to convert extremely productive natural ecosystems (e.g., coastal marshes and mangroves) to less productive, synthetic ecosystems. Finally, preventive expenses associated with reclamation and habitat restoration may reduce future monetary costs for mitigation of environmental damage (e.g, groundwater contamination).

3.14 Economic costs of land reclamation and habitat restoration vary along the continuum of possible biomass projects and are discussed in greater detail in the following chapters. Generally, the closer the project resembles habitat restoration (i.e. the more self-sustaining the ecosystem) the lower the economic cost and the lower the domestic benefits in traditional economic value. An economic benefit of using native plant species in reclamation and restoration projects lies in their adaptations to the local environment (McKell 1975). Native shrubs in arid ecosystems may be more efficient in their use of water and nitrogen, reducing the irrigation and fertilization costs associated with large-scale agriculture. Field trials with halophytes grown with seawater irrigation in Mexico demonstrated that native species were generally more productive than exotic species (Glenn and O'Leary 1985). In contrast, agro-ecosystems may have higher construction and maintenance costs (e.g., harvesting, irrigation, fertilization), but yield greater domestic economic benefits via subsequent consumption of harvested biomass.

ENVIRONMENTAL COSTS AND BENEFITS

3.15 The technology to implement these projects may affect both the physical and biological components of natural ecosystems. As opposed to the no-project alternative, reclamation of salt-affected, abandoned agricultural land may mitigate environmental degradation caused by human disturbance. Degradation of agricultural lands is measured not only in the loss of agricultural productivity, but also in associated environmental effects such as aesthetic values, effects on regional groundwater quality and negative impacts on biodiversity (see Box 3.2). Such derelict lands, unsuited for cultivation of conventional crops, may also experience accelerated environmental degradation. Benefits of these projects can therefore include both increased productivity and long-term environmental improvements to properties (Ahmad 1981), including protection of biodiversity through restoration of wildlife habitat.

3.16 In contrast, conversion of non-disturbed areas to agriculture often produces simplified ecosystems relative to the natural systems which they replace as measured by diversity, species composition, and ecosystem function (Bradshaw 1987) and thus incurs domestic and global environmental costs. Reclamation of potential agricultural areas may also incur environmental costs since remnants of natural vegetation are often restricted to lands not previously suited for agriculture (e.g. salt-affected soils). In this case, the demand for increased agricultural land is in direct conflict with the preservation of the remaining natural vegetation and its associated biodiversity.

3.17 There are two types of potentially significant ecological effects: (1) physical disturbance associated with agriculture (particularly large-scale irrigation with seawater) leading to a change in ecosystem functions such as hydrological cycling, nutrient cycling and other soil processes and (2) introduction of alien species which may escape from cultivation and impact existing native communities.

3.18 **Changes in Ecosystem Functions**. The environmental impacts of seaweed cultivation (most of which involve additions of chemicals to the water, but not a fundamental change in use) are discussed in Chapter V. However, large-scale seawater irrigation of arid ecosystems can be expected to have significant impacts at many levels. Water availability is a major factor in determining the vegetation of arid ecosystems. Even human populations in these areas are largely constrained by the availability of freshwater. The dominant vegetation type in these ecosystems reflects the climate and soils, and ranges from bushy plants and shrubs in arid regions to grasses in semi-arid regions (McKell 1975; Peterson et al. 1991). In addition, these systems are usually in equilibrium with respect to the cycling of water, nutrients and soil organic matter through the plants and soils. For example, nitrogen is added then consumed and/or lost by the soil-plant system at a given rate, with minimized leaching potential in all but the wettest years) and evapotranspiration does not exceed water availability. Cultivation of halophytes in these areas may be economically feasible using saline irrigation water, including salinized drainage water from adjacent irrigation systems (Watson 1990), and thus not compete for limited freshwater resources.

3.19 **Hydrology**. Although halophyte crops may be irrigated with saline water unfit for other crops, the disposal of this water is still an issue in determining the environmental impacts of large-scale cultivation. The long-term effects of continuous irrigation of halophyte crops with saline water are not well understood (Watson 1990). The most efficient irrigation systems would require enough water to equal the evapotranspiration rate (net percolation = 0), plus a leaching fraction sufficient to remove accumulated salts from the soil surface, to prevent inhibition of plant growth. Feasibility of seawater irrigation over the long term may require development of high frequency, low-volume irrigation systems (Glenn and O'Leary 1985).

3.20 As water evaporates from the soil surface or is transpired through the vegetation, the salt contents are left behind. To maintain the salt concentration of the root zone of plants, the volume of irrigation water times its salt concentration must equal the volume of water draining out of the soil times the salt concentration of the drainage water. As the salinity of the irrigation water increases, so does the leaching requirement. Thus a higher percentage of irrigation water would need to be drained out in order to prevent an increase in soil salinity (Shainberg 1975). When growing a salt-tolerant crop (e.g., halophytes or salt-tolerant strains of crops), it is not necessary to leach out all the salt from the soil profile. Also, as the water table into which salts are leached rises, it raises the salinity level of soil in the rooting zone of the plants, impairing productivity. Additional irrigation can only leach out the toxic salinity if it is allowed to drain. If not, it simply exacerbates the process.

3.21 The amount of salt added to the soil by irrigation is determined by the quality and the amount of irrigation water used (Shainberg 1975). Irrigation water may contain from 100 to 1000 g of salt/m3 water, which, with an annual application rate of 10,000 m3/ha, adds between 1 to 10 tons/ha of salt to the soil. Most irrigation systems have been designed to maximize the supply of water to farms without considering the balance of water supply and the capacity of the ecosystem to cycle water.

3.22 **Nitrogen Cycling**. Nitrogen is the only nutrient that changes significantly with ecosystem development and is also continually limiting to plant growth (Bradshaw 1987). Nitrogen is unusual in that it is required for plant growth but does not occur as a soil mineral. Instead it is supplied via the decomposition of organic matter contained in the soil, deposition and/or fixation of atmospheric nitrogen. Although nitrogen deficiencies are typical of irrigated agriculture in dry areas (Peterson et al. 1991), desert halophytes are adapted to low nitrogen availability of the soil. Cultivation of plants in these areas introduces disturbance of the soil surface, which may increase rates of soil erosion and nutrient loss. In addition, increasing water availability via irrigation, which is closely related to required levels of nitrogen and phosphorus fertilization, may increase rates of nutrient leaching from the upper soil layers to layers below the rooting zone of most crops. Furthermore, the removal of crops after harvesting leads to a loss of nitrogen from the system (Peterson et al. 1991).

3.23 Incorporation of biomass back into the desert soils has been discussed in the context of carbon sequestration (Chapter VIII). However, the creation of agriculture and self-sustaining ecosystems must also deal with the issue of nitrogen availability. Regardless of the purpose of cultivation of halophytes in these arid and semi-arid soils, some crop residue must remain to maintain the C/N ratio of the soil. If high C/N matter (e.g., straw) is returned to the soil without additional nitrogen amendment, the carbon is lost to the atmosphere as $CO2$. Thus, the economic feasibility of a project must take into account the long-term cost in fertilization and/or reduction in tillage necessary to maintain a sufficient level of soil organic matter for crop production. To the extent that nitrogen fertilization can be decreased by plowing crop residue back into the soil, the separable storage costs for carbon sequestration can be decreased.

3.24 **Soil stabilization with Halophytes**. The barren nature of saline soils, particularly abandoned agricultural areas, can lead to increased soil erosion and therefore a loss in soil productivity and deposition of salt in adjacent areas (see Box 3.1). Halophytes which may be used to stabilize soils include *Atriplex* spp. (Kelley et al. 1982), *Haloxylon aphullum* in the Aral Sea (Micklin 1988).

3.25 **Biological Desalination**. Several species of halophytes actually absorb salt from the soil solution and concentrate it in their above-ground biomass. Two perennial halophytes (*Juncus rigidus* and *J. acutus*) were studied at El Manzala in Egypt (Zahran and Wahid 1982). Soil samples were collected before and two years after transplanting Juncus rhizomes, then analyzed for total soluble salts. Results indicated that *Juncus* plants may significantly decrease the salt content of soil, and that the effect was greater for *J. rigidus*. In general, biological desalination with halophytes should be more cost-effective than increased irrigation or extensive modification of an existing irrigation system, which requires a large capital investment (singh 1970a; Glenn, pers. comm.).

3.26 The genus *Atriplex*, with over 200 species worldwide, has multiple uses as a halophyte adapted to stressful environments, including salt-affected arid areas. Aside from their use for biomass energy (Chapter IV) and forage for wild and domestic animals (Chapter V), these species may also prove useful in reclamation of salt-affected soils. *Atriplex* species extrude salts accumulated from the soil solution onto their leaf surfaces via hair-like structures (trichomes). These salts end up on the leaf surface when the hairs burst, and then are incorporated back into the soil through leaf litter or leaching from the leaves by rainfall. If cultivated and harvested on a large scale, these plants could also be used to decrease soil salinity (Kelley et al. 1982).

3.27 **Introduction of Alien Species**. For large-scale cultivation of both seaweeds and halophytes, the use of native species is recommended to discourage species introductions which may have potentially devastating effects on the community dynamics of native species. Not all species introductions are intentional. For example, accidental introductions of large brown algal species (*Sargassum muticum,* *Undaria pinnatifida and Laminaria japonica*) have accompanied importation of Japanese oysters in mariculture. The ecological consequences of these rapidly spreading species are difficult to predict, but may result in serious impacts to the ecosystem (Rueness 1989).

3.28 While rapidly spreading species may be economical in the sense that they reduce establishment costs, they may spread to areas where they are undesirable, and thus incur costly eradication efforts. For example, *Spartina townsendii* (salt marsh grass) can spread very rapidly under certain conditions. This halophyte species has proven very useful in stabilizing estuariane mudflats and trapping silt in coastal protection and reclamation efforts worldwide. However, it may also encroach on shallow channels, blocking access to boats, outcompete valuable grazing grass species, invade holiday beaches, and decrease the value of coastal nature reserves by replacing native vegetation which serves as food plants for wildfowl (Ranwell 1967).

3.29 Prevention of biological invasions requires detailed knowledge of the plant's biology. In the absence of this knowledge, potentially weedy species should be removed promptly when discovered. Managers should be advised to note (and possibly plow-under) non-native plants that are prolific seed producers. Close monitoring of all species introductions will also allow managers to implement control measures in a timely, and thus less costly, manner.

3.30 **Habitat Restoration with Halophytes**. Navigation channels are maintained by dredging material of infill, depositing the dredge spoil onto land several hundred feet away. The annual maintenance costs for 1,500 miles of channel in North Carolina in 1974 ranged from $2-3 million. When this spoil is not stabilized, much of it is redeposited into the channel due to wind and wave activity. At the same time, natural salt marsh habitat has been destroyed as these sites are converted to waste disposal and building sites. Restoration of *Spartina alterniflora* salt marsh on spoil deposits stabilizes the soil as well as increasing salt marsh habitat for wildlife and other ecological uses (Seneca 1974). The most time-consuming task in such restoration efforts involves digging up transplants from native stands. Nursery propagation has been developed as an alternative, and may serve to increase the economic feasibility of salt marsh restoration.

3.31 *Atriplex* has been proposed for use along desert highways due to its low-cost maintenance. Shrubs can also be important components of wildlife habitat (e.g. browse and cover for deer and small mammals, food for birds and rodents), and planting them may contribute to maintenance of local biodiversity (McKell 1975; Kelley et al. 1982). Halophytes have also been used in treatment of toxic saline drainage water in the San Joaquin Valley (Chapter VII). By reducing the volume of drainage water sent to evaporation ponds, the halophytes contribute to the protection of wildlife from selenium poisoning, thus restoring habitat (Riley, personal communication). Thus, pollution control, land reclamation, and habitat restoration may be integrated into one project (see Box 3.3).

3.32 **Habitat Restoration with Seaweeds**. Little information was found in the literature on this topic. The best example involved Giant kelp, *Macrocystis pyrifera*, along the California coast (Tarpley and Glantz 1992). These kelp forests provide essential habitat for a diverse species assemblage including marine fish, invertebrates and sea otters, as well as having commercial, recreational, and aesthetic value. Restoration efforts were carried out from 1967 to 1980 along the Palos Verdes Peninsula. By 1980, nearly 600 acres of kelp had been restored. Nine years later, it was estimated that the kelp forest had spread to over 1100 acres. Factors identified as contributing to the deterioration of kelp forests included storm damage (particularly El Niño), sea urchin grazing, intensive fishing for sea urchin predators, and pollution from domestic and industrial wastes. Unfortunately, no cost data were available for this project.

Box 3.1: Land Reclamation and Industrial Production Using Halophytes

Land Reclamation

Matricaria chamomilla L. is an annual halophyte in the Compositae (sunflower family) and is native to Europe. This species grows over a wide range of altitudes and soil types and can withstand temperatures as low as 2o C. It can be grown in both temperate and sub-tropical sites. In Hungary it is cultivated on clayey lime soils which are otherwise unsuited for other crops. Roughly 230,000 hectares of saline-soda soils are cultivated with Matricaria in Yugoslavia (Singh 1970a). The plant grows well even on highly saturated sodium soils and has a high tolerance to sodium ions. In fact, the crop has a high rate of salt uptake (27.97 Kg Na/hectare), and thus its cultivation helps to decrease the salinity of the topsoil.

Industrial Production

The drug known as false chamomile is derived from the flower heads of M. chamomilla and is recognized in a number of European pharmacopoeias. The air dried flowers are steam distilled to extract 0.3 to 1.00 per cent of a deep blue oil. This drug has antiseptic and antiphlogistic properties and serves as an antispasmodic expectorant, carminative, antihelmintic, sedative, diuretic as well as being used for children's ailments including: tooth aches, stomach disorders, earache, neuraligic pains and infantile convulsions (Singh 1970a). There is a great demand for the oil in Germany, France and other European countries.

Reported yields on saline soils were 1500 kg fresh flowers/acre. Five kg of fresh flowers yields one kg dried flowers. The cost of cultivation reported in 1970 was $135/acre. Processing costs to extract the oil were estimated at $50/100 kg flowers. This yields a return from the oil of roughly $1,000/acre.

Thus, *Matricaria* can be used both as an economic crop, and for reclamation of highly saline soils through biological desalination. Its wide temperature tolerance makes it a good candidate for use in World Bank projects.

Box 3.2: The Aral Sea

Economic and Environmental Impacts of Irrigated Agriculture

The Problem

The desiccation of the Aral Sea due to mismanagement of water and land resources in the Aral Sea Basin is a striking example of land degradation associated with irrigated agriculture (World Bank 1992; Micklin 1988). The problem involves inefficient irrigation systems, wasteful use of water and contamination of the groundwater through excessive application of fertilizers and pesticides. Environmental impacts of the expansion of irrigation in the 1950s and 1960s were grossly underestimated, emphasizing the tradeoff between economic gains from irrigated agriculture versus tangible economic benefits from the Aral Sea ecosystem, while ignoring impacts on ecosystem function as a whole. Thus, the Aral Sea provides a clear example of the dangers associated with ignoring long-term environmental costs for the sake of short-term economic benefits.

Economic and Environmental Costs

The resulting secondary salinization has had ramifications that include the impoverishment of biodiversity on a regional scale (a decrease from 173 animal species to 38 around the sea), increasing salinity of the soils (salts deposited on the soil with irrigation have increased from 6 to 8 ton/ha), a reduction in river flow, and groundwater contamination that has threatened the drinking water supply. The unanticipated environmental and economic costs have been staggering. A project involving the provision of safe drinking water for Nukus in the Amu Dar'ya Delta by constructing a 200-km pipeline is estimated to cost 200 million rubles (approximately $3.2 million). Employment associated with commercial fishing in the area (reported as 60,000 jobs in the 1950s) has disappeared.

Opportunities for Land Reclamation with Halophytes

As the sea shrinks, salts are deposited on the dry sea bed. An estimated 15 to 75 million tons of salt particles are carried via salt storms to contaminate adjacent areas, and salt is deposited as aerosols by rain and dew over 150,000 to 200,000 km2. Each hectare of the lower Aral basin is receiving 520 kg of salt deposition annually, affecting plant productivity. This situation is an ideal candidate for reclamation with halophytes. Small-scale trials with Haloxylon aphullum (black saksaul) have had some success. Other species should be tested as well, to increase survival of plants during the establishment phase. Soil stabilization and biological desalination on a large scale may be the most cost effective methods to combat further land degradation in the short-term while more costly and political long-term changes in both integrated ground water management and agricultural practices (e.g. no further reclamation of new lands for irrigated agriculture, removal of low productivity saline soils from present irrigation systems) can be implemented.

Box 3.3: Western Australia

Integration of Land Reclamation and Habitat Restoration

The Problem

The Shire of Tammin has the highest level of secondary salinity (>6% of the land) in the state of Western Australia. Although there are natural salt lakes in the area, secondary salinity has resulted from overclearing of the natural vegetation for agricultural purposes. Agriculture in the area rapidly expanded during the 1950s and 1960's. As the native vegetation was cleared, the water balance changed, leading to rising water tables. Salinization began to appear in the landscape between 20 and 30 yeats after this clearing. Prior to this period, the area was quite productive, comprising part of the Wheatbelt of Australia. Degraded bushland, resulting from a combination of soil erosion and salinization, is now very visible in this area and salinization is threatening the economic viability of the region.

Land Care Districts

Not only did good land become saline and useless, but the water supply was also threatened and required protection. A ban was imposed on further clearing. Tammin has been part of the Land Conservation District since 1985. Locally, Land Care Groups have been formed to confront the land degradation problems associated with salinity (e.g. planting halophytes, monitoring groundwater salinity with peizometers). Recognizing that ecosystem problems do not follow individual property lines, Tammin has initiated a project wherein farmers in Land Care Groups (delineated by water catchments or watersheds) develop and implement an integrated strategy to optimize agricultural production and profitability, and land and nature conservation. Each catchment plan coordinates the efforts of individual farmers for the benefit of the whole catchment. There are no existing examples of how this type of integration can be implemented on a farm basis.. It is hoped that the Tammin landcare model can be duplicated throughout the State.

Reclamation and Habitat Restoration

In the Shire of Tammin (108,700 hectares) only 7% of the land is occupied by remnants of natural vegetation, and local extinction of fauna is well documented. The conspicuous local land degradation has focused the farmers' attention on environmental concerns. Rising water tables indicate a need to use more water locally. Trees and other perennial plants can be used as pumps to control rising watertables; and thus prevent further land degradation. The farmers realized that the problem of secondary salinization could be confronted at the same time that remnant vegetation was protected and restored, at a landscape level. For example, by planting native species and re-establishing wildlife vegetation corridors in a coordinated way, an ecosystem favorable to fauna can be recreated. The projects in this area represent an integration of land reclamation and habitat restoration, and the success of these efforts will largely depend on the coordination of information and personnel from government agencies and individual farmers.

Table 3.2

Estimates of Potential Annual Value of an Acre of Marsh

		Annual Value Dollars	Pounds
Aquaculture -- moderate culture level			
Oyster meat production			1800 lb.
Dockside value @35 c		$430	
Value added during processing (70% dockside value)		$440	
	Total	$1070	
Assume 4 acres marsh per acre oyster raft	Net Value	$262 per acre marsh	
Aquaculture -- intensive raft culture of oysters			
Oyster meat production when stocked at 1/10 water surface			4500 lb.
Dockside value @35 c		$1575	
Value added during processing (70% dockside value)		$1100	
	Total	$2675	
Assume 4 acres marsh per acre oyster rafts	Net Value	$670 per acre marsh	
Grazing by beef cattle			
7500 lb. dry wt. grass * 10% conversion			1000 lb. animal tissue
Wholesale value @35 c		$350	
Value added in processing		$115	
	Total	$465	
Intensive microbial conversion to single-cell protein (50% protein)			
7500 lb. * 0.4 = raw high protein product			3000 lb.
Value @15 c		$450	
Water quality improvement (waste assimilation)			
19 lb. BOD removed per day @4 c per lb. for incremental secondary treatment		$247	
Economic contribution of allowing 1mg./m reduction in minimum level of dissolved oxygen from 4 mg./l to 3 mg./l (increasing BOD loadings by 4.3 lb./day)		$360	
"Life support" value			
Based on new primary production of 4 * 10^6 gm. dry wt.		$1600	
Based on gross production (assuming net production * 2)		$3200	
	Total	$4054 to $5654	

Source: Reimold (1974)

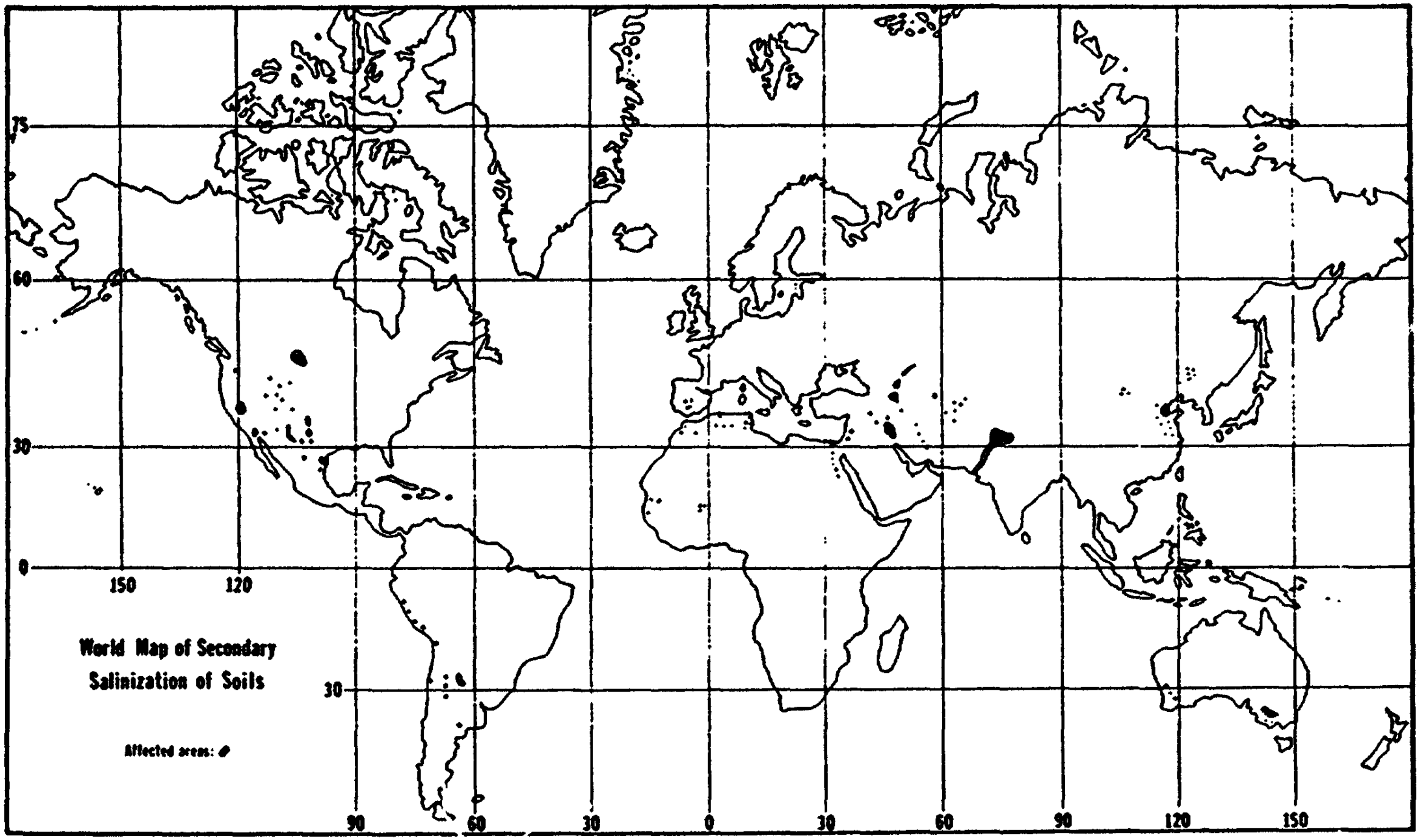


Figure 3.1 Global map of secondary salinization of irrigated and dryland soils. (Source: Dregne 1991).

CHAPTER IV

RENEWABLE ENERGY PRODUCTION

INTRODUCTION

4.1 Biomass fuels have been used extensively in centralized and dispersed energy production. The advantage of biomass fuels relates to their low technological requirements, ease of local production, adaptability to local conditions, and relatively low cost. Biomass-to-energy projects using halophytes and seaweeds present several theoretical advantages. In terms of domestic benefits, these projects do not involve the conversion of productive agricultural land (as do most tree plantations), can be developed in regions where other alternative fuels cannot be economically developed. Additionally, biomass-to-energy projects often utilize technology which has been extensively developed for other fuel types. The global benefits of using biomass fuels center on using them as substitutes for coal and other fossil fuels.

4.2 The use of halophytes and seaweeds in fossil-fueled power plants represents one potential solution to the long-term storage issues associated with any biomass crop used to sequester carbon. When biomass crops are used as substitutes for fossil fuels, the net effect is to "recycle" the atmospheric carbon via the carbon cycle. While biomass combustion does not reduce the level of carbon dioxide in the atmosphere, it does offset additional emissions from fossil fuel combustion. This contributes to a stabilization of ambient levels, and a decline in the levels of emissions from geological storage. It has been estimated that the use of carbon sequestering biomass crops as substitutes for coal doubles the beneficial effect on atmospheric carbon, compared to simply using the biomass to sequester carbon.

Assessing Energy Production Potential

4.3 The various components of a biomass-to-energy system must be considered in an integrated fashion. The size of any proposed system, in terms of required energy production, energy demands, availability of substitute fuels, and energy prices influences the type of conversion system to be developed. In addition, the amount of biomass required in such a system, ultimately determines the requisite harvesting and production systems. Similarly, limitations on the production and harvesting of biomass will influence power plant size, economics, design, and cost.

4.4 In view of these constraints, biomass-to-energy system are best evaluated as two separate subsystems: (1) *feedstock production subsystems* including cultivation, harvesting and transportation to a conversion facility; and (2) *conversion subsystems* which include storage, conversion to energy, and the recovery or purification of the end product such as methane.

4.5 Finally, the costs of producing energy from halophytes and seaweeds must be compared to the costs of alternative fuels, including natural gas, coal, and other biomass fuels, as well as renewable energy sources such as hydroelectricity and solar power.

ECONOMIC COSTS AND BENEFITS

Halophytes

4.6 As few pilot or full-scale conversion facilities have been developed or implemented for halophytes as a fuel source, the evaluation of this fuel source is at best tentative. Currently, the studies of halophyte fuels have focused on the heating content, and some of the technical questions posed by combustion of these fuels.

4.7 Halophytes compare favorably with the heating value of other biomass fuels, as well as to lignite, but are less effective than coal sources. However, some halophytes do have high ash contents, which is in part due to their high NaCl levels (Table 4.1). This ash content is significant because it places practical limits on the ratio of halophyte to coal in the fuel mix of existing coal-fired power plants.

Table 4.1

Heating Values and Ash Contents of Halophytes Compared to Other Fuels.

Fuel Type	Heating Value (K cal/g)	Ash Content (% of dry wt)
Halophytes:		
Sporoblus virginicus	4.29	6.9
Other species	2.63 - 4.29	6.9 - 46.1
Coal:		
Sub-bituminous A	6.11	6.9
Sub-bituminous B	5.56	-
Sub-bituminous C	5.00	-
Lignite A	4.01	7.1
Lignite B	3.50	23.0
Biomass:		
Wood	4.76	1.0
Garbage	4.71	16.0
Paper	4.21	6.0

Source: Perry et al. (1984)

4.8 A brief evaluation of halophytes as an energy source has been carried out in the United States (Glenn et al. 1991). This work suggests that, for example, a 500 MW coal-fired plant could substitute halophytes for 33% of the fuel mix. This ratio produces a fuel with a heating value of 5.17 kcal/g, or about 10% less than a fuel mix of 100% coal. The use of this halophyte production with coal fuel mix allows a fossil fuel plant to reduce its stack emissions by about 1.0%. However, because an additional

160 K tons of carbon emitted from the stack are sequestered by the halophyte production, the overall emissions released into the atmosphere are reduced by approximately 25%. These data are presented in Figure 4.1 and Table 4.2.

Table 4.2

Comparative Analysis of Two 500 MW Power Plants

	Plant A	Plant B
Fuel Mix		
% Coal	100	66.6
% Halophyte	0	33.3
Fuel Consumption (M Tons)	1.4	1.7
% Ash	6.9	11.6
Ash Produced (K ton/yr)	96.7	181.9
% Carbon in Fuel	47.4	42.0
Carbon Released (K ton/yr):		
Coal:	664.1	497.7
Biomass	0.0	160.3
Emitted from Stack	664.1	658.0
Carbon Re-absorbed	0.0	160.3
Net Carbon Released	664.1	497.7

Adapted from: Glenn, et al. (1991)

4.9 Significant technical and cost considerations require further quantification before the practicality of a halophyte-to-energy process can be fully assessed. These considerations include the salt and sulfur content of the materials, and their impact on air emissions and potential technical mitigation technologies required.

Seaweeds

4.10 Energy production using the brown kelp, *Macrocystis*, has progress further than for any other seaweed species, and has provided an important basis for the feasibility of using seaweed species in energy production through methane conversion. Offshore kelp harvesting in the United States has demonstrated that current methane production costs using kelp range from $12 - $80/G Joule, and are not competitive with natural gas prices in the U.S. ($6/G Joule), unless kelp yields are significantly improved (Bird 1987).

4.11 No full scale production facility for seaweed to energy conversion is currently operational. However, detailed economic and feasibility studies have been carried out in the United States. These studies use a baseline facility capable of producing 2.8 million scfd methane from 26.7 km^2 of artificially planted kelp beds. The costs for developing the kelp farm subsystem (site preparation, planting material, labor for planting and operating expense for planting) total $17.16 million, or 27% of total construction costs (Table 4.3). The technology required to convert the seaweed into methane gas accounts for the remainder of the capital costs. The estimated annual operating costs for the baseline system are $4.8 million, of which harvesting labor costs account for 43% of the annual costs. The financial analysis indicates that this baseline system would produce methane at a cost of $13.47/million Btu, or roughly twice the current price of gas at the wellhead.

Table 4.3.

Costs of Facility for Energy Production from Kelp

Capital Costs	$ (Millions)	% of Total
Site Preparation and Land Cost	2.52	4.0
Material to Plant	2.83	4.4
Assembly Plant	2.12	3.4
Process Plant and Work Site	3.76	6.0
Biodigester Plant Tanks	9.90	15.7
Facility Equipment	10.22	16.2
Labor for Planting	11.13	17.7
Operating Expenses for Planting	0.69	1.1
Gas Cleanup System	8.62	13.7
Energy Conservation System	11.17	17.7
Total Capital Costs	62.98	100.0
Operating Costs		
Material and Services	1.53	31.7
Labor	3.30	68.3
Total Operating Costs	4.83	100.0
Salable Product Output		
Gas - million Btu/yr HHV	928.7×10^9	

Source: Brehany (1983)

Impacts of Technology on Costs

4.12 Investment in newer production technologies can significantly reduce the costs of methane production from biomass fuels. Sensitivity analysis for the baseline system described above indicates that as capital costs decrease by $1 million, the levelized cost of gas decreases by only $0.10/million Btu. In contrast, the levelized cost of gas decreases by $1.25/million Btu when operating costs decrease by

$1 million/year. These data indicate that capital expenditures to reduced operating costs are rapidly returned. In addition, the analyses indicate that the use of newer, but existing technology, sharply reduces the gas costs, to the extent that the production cost of methane could be competitive with wellhead gas (Figure 4.2).

4.13 The implications of the sensitivity analysis are that the implementation of the newer technology substantially reduce production costs. These factors suggest that the transfer of technology to a suitable site in a developing country, combined with lower labor rates, could assist in making the economic costs of such a project competitive with other energy projects.

Algae to Energy Projects in Developing Countries.

4.14 Few seaweed to energy projects have been undertaken in developing countries. This lack of development can be partially attributed to the relatively high capital costs of building production conversion facilities, the lack of technology transfer from private corporations (which have carried out most of the development) in the developed world, as well as the focus of development institutions on using seaweeds as a food source (See Chapter V). For example, FAO has extensively explored and invested in the potential commercial uses of seaweeds and their products in the food sector, leaving the energy sector devoid of significant exploration or development funding (FAO 1985, 1987).

4.15 Private sector commercialization of seaweed has also focused on food and chemical production, because of the relative costs and benefits of the existing technology. The value of dry kelp for food production is approximately $0.05 US per pound, compared to $1.00 per pound for alginate production, which does not require the significant capital expenditure in harvesting, fermentation and energy conversion technology (U.S. Government 1980).

4.16 A small number of demonstrations projects utilizing algae-to-energy techniques have been undertaken in developing countries. One of these studies, carried out in Senegal, focused on the use of seaweed biomass which becomes naturally stranded each year along the West African shoreline (Leclerq et al. 1985). Such biomass, which was not used prior to this study, contributed to significant beach pollution. This study attempted to evaluate the potential for using the biomass to produce biogas and fertilizer through methanogenic fermentation processes. The demonstration project used continuous biodigesters to optimize biomass production. Unfortunately, the report focused on non-economic issues such as seaweed composition, batch fermentation processes, and did not carry out a cost benefit analysis.

4.17 While little international development funding has been made available for seaweed-to-energy production, considerable work has been carried out in the general area of biomass for renewable energy. For example, the Bank, through the Global Environment Facility (GEF), is currently involved in a pilot project to produce energy from sugar cane in Mauritius and biomass gasification in Brazil. These projects have been selected to serve as demonstration sites because of their high degree of replicability.

4.18 **Domestic Economic Benefits**. The economic benefits of using seaweeds and halophytes as fuel include employment opportunities, use of otherwise unproductive land (for halophytes), diversification of economic production and the potential for developing electric generation in new areas which do not have sufficient coal supplies. The maintenance and harvesting of both halophytes and seaweeds is fairly labor intensive, opening up opportunities for local employment. The development of new productive technologies can also provide needed economic development and investment in areas which otherwise might not receive such economic stimuli.

ECONOMIC COST COMPARISONS WITH OTHER FUEL TYPES

4.19 In addition to the value associated with the opportunity cost of substituting renewable biomass for fossil fuels (Chap II), it is possible to make an economic comparison of the alternative fuel types. From the conventional economic perspective, seaweeds have a much higher cost per unit of energy than other biomass or fossil fuels (Table 4.4). Halophytes, on the other hand, fall within the range of other biomass fuels, as well as other fossil fuels. These data, however, do not include additional costs which might be required for combustion, such as additional emissions control data, fuel preparation, and transportation of fuel to the combustion facility. Some other costs might also be required to mitigate the high salt and ash content of some halophyte species as well as seaweeds.

Table 4.4

Costs of Energy Production Using Renewable and Fossil Fuels

Fuel	Costs ($/MM Btu)
Seaweeds and Halophytes:	
Seaweeds:	
Current Technology	13.1
Advanced Technology	6.9
Halophytes:	
Brackish Water	3.4
Seawater	4.3
Other Biomass:	
Manures	0.1
Forest residues	1.3
Orchard pruning	2.6
Cassava	7.9
Eucalyptuys (alcohol)	12.4
Cereal Straw (methane)	4.0
Fossil Fuels:	
Coal	3.5
Residual fuel oil	4.7
Natural Gas	6.3
Distillate Fuel Oil	6.9

Adapted From: Tuvell (1985) and Slesser and Lewis (1987).

4.20 These data suggest that including halophyte biomass in the fuel mix of existing fossil fuel plants, could be economically feasible. The potential for fuel substitution would require the proper circumstances such as proximity between a fossil fuel plant and suitable land for a halophyte plantation.

ENVIRONMENTAL COSTS AND BENEFITS

4.21 **Domestic Environmental Costs.** The primary environmental costs of biomass-to-energy center on the introduction of exotic species into natural habitat, even if this land is considered "non-productive" in the case of halophytes. The costs could include the loss of biological diversity and ecosystem functioning and are discussed in detail in Chapter III.

4.22 The other environmental costs relate to the combustion of halophytes and seaweeds in fossil-fuel plants which are not equipped with adequate combustion technology or air emissions control equipment. Existing combustion technology in coal-fired power plants would probably be able to handle up to about 33% of halophytes in the fuel mix without the need to alter combustion equipment (EPRI pers. comm). However, little information is available concerning the emissions characteristics of these biomass fuels, and the potential for adverse human or environmental impacts from combustion. Potential emissions include increased sulphur dioxide, volatile organic compounds, nitrous oxides, and, in the case of seaweeds, heavy metals. Further work is required before these domestic costs can be adequately assessed.

4.23 **Domestic Environmental Benefits.** The domestic environmental benefits of using halophytes and seaweeds center on the potential reduction in deforestation rates resulting from fuelwood collection. In addition, the developing and sustainable harvesting of seaweed could have domestic benefits including reducing beach erosion and providing habitat for fish species and thus protecting biological diversity.

4.24 **Global Environmental Benefits.** The global environmental benefits of using biomass fuels are based on their substitution for fossil-fuel in coal-fired power plants. The combustion of biomass fuels as a substitute for fossil fuels prevents the release of carbon from geological storage, and essentially "recycles" the existing atmospheric carbon. A global scenario developed by the World Bank suggests that a shift away from fossil fuels to biomass fuels could lead to an increase of only 25% in ambient CO_2 levels over the next 60 years. Without such a shift in the global fuel mix, CO_2 levels would be expected to more than triple during that 60 year period (Figure 4.3).

4.25 The overall impact of halophyte fuel on the global carbon cycle could be significant. Given the availability of suitable habitat for halophyte plantations, the full production of halophytes on this land could essentially reduce overall fossil fuel emissions by upward of 24%, or the equivalent of 1 billion metric tons of carbon. While the planting of all the areas suitable for halophytes is neither practical or desirable, its does suggest that halophyte production for energy could be one method of reducing CO_2 emissions by upwards of 10%.

4.26 The use of seaweeds to produce methane for electricity production also has the global benefit of recycling atmospheric carbon, and lowering the requirements for burning fossil fuel. In addition, since the product of the digestion is methane, and methane is more efficient than coal in its heating value, the process is more effective in stabilizing GHG's than is directly burning the biomass. With the potential area available for seaweed production estimated at 1.17 million km^2, and a sequestration rate of 520 tons of carbon $km^{-1}yr^{-1}$, the overall potential of using seaweeds as fuels could produce emissions reductions by us much as 10%.

Figure 4.1
Comparative Analysis of Two 500 MW Power Plants

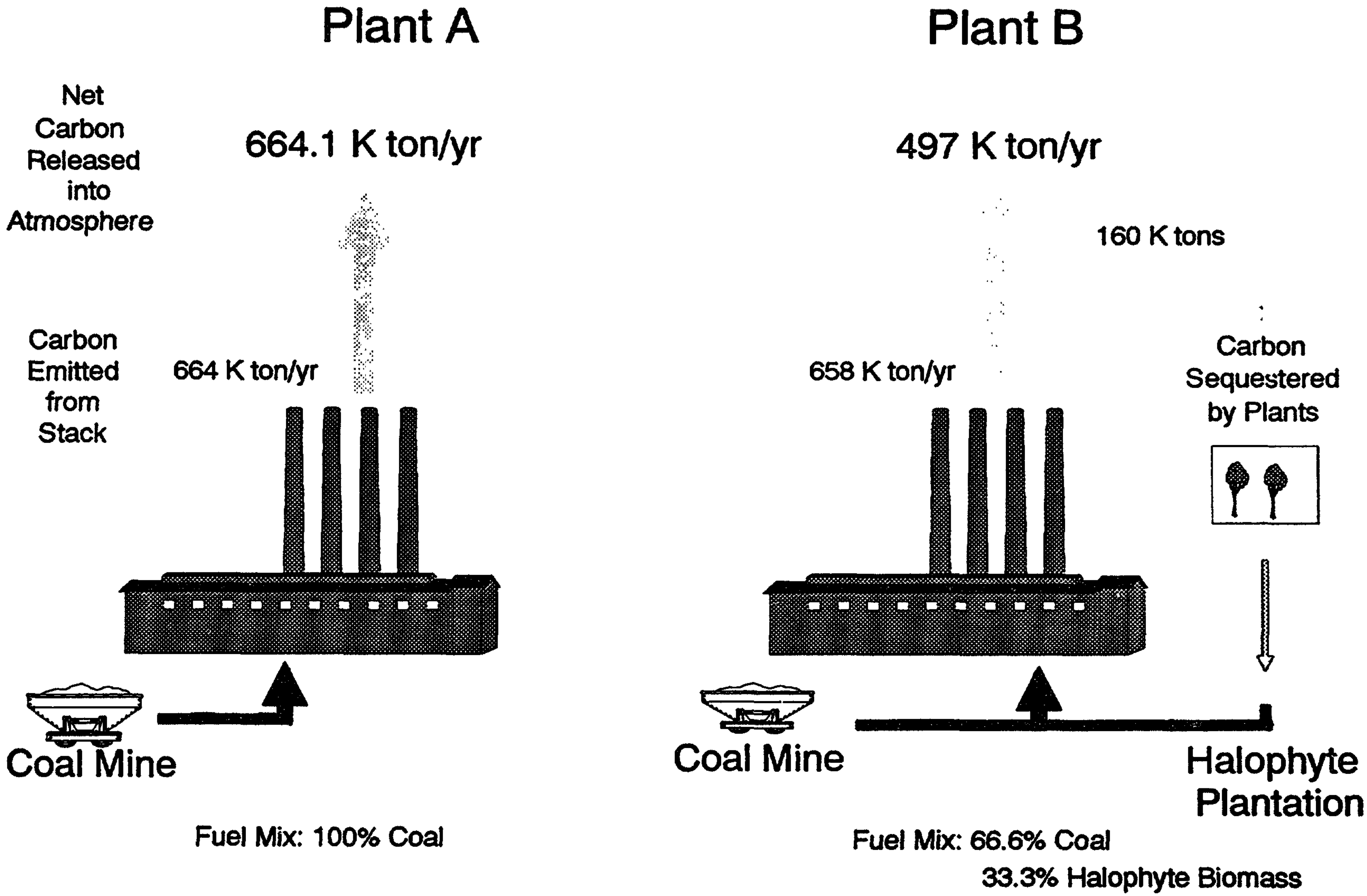


Figure 4.2
Comparison of Costs for Kelp-Energy Production Facilities

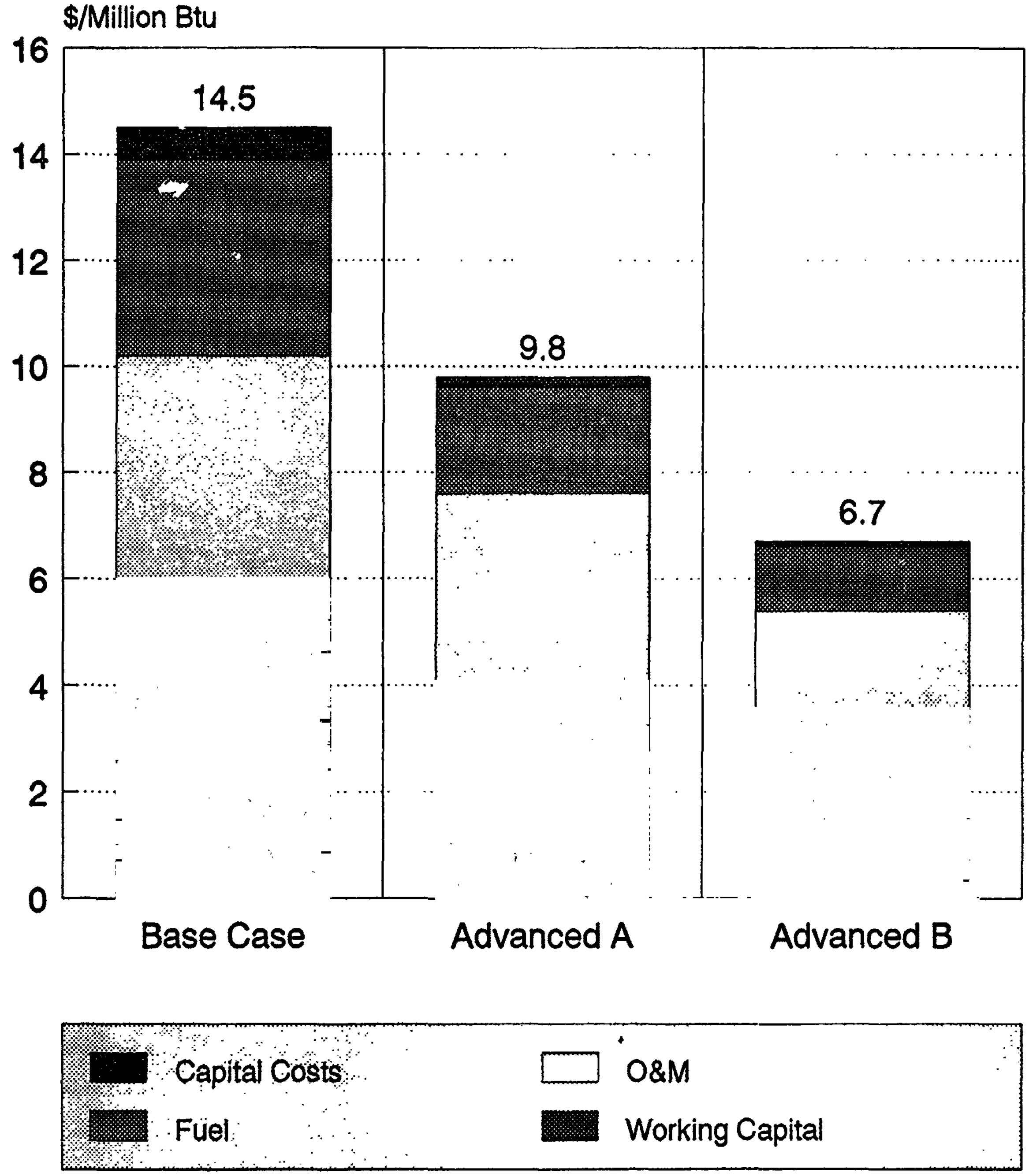
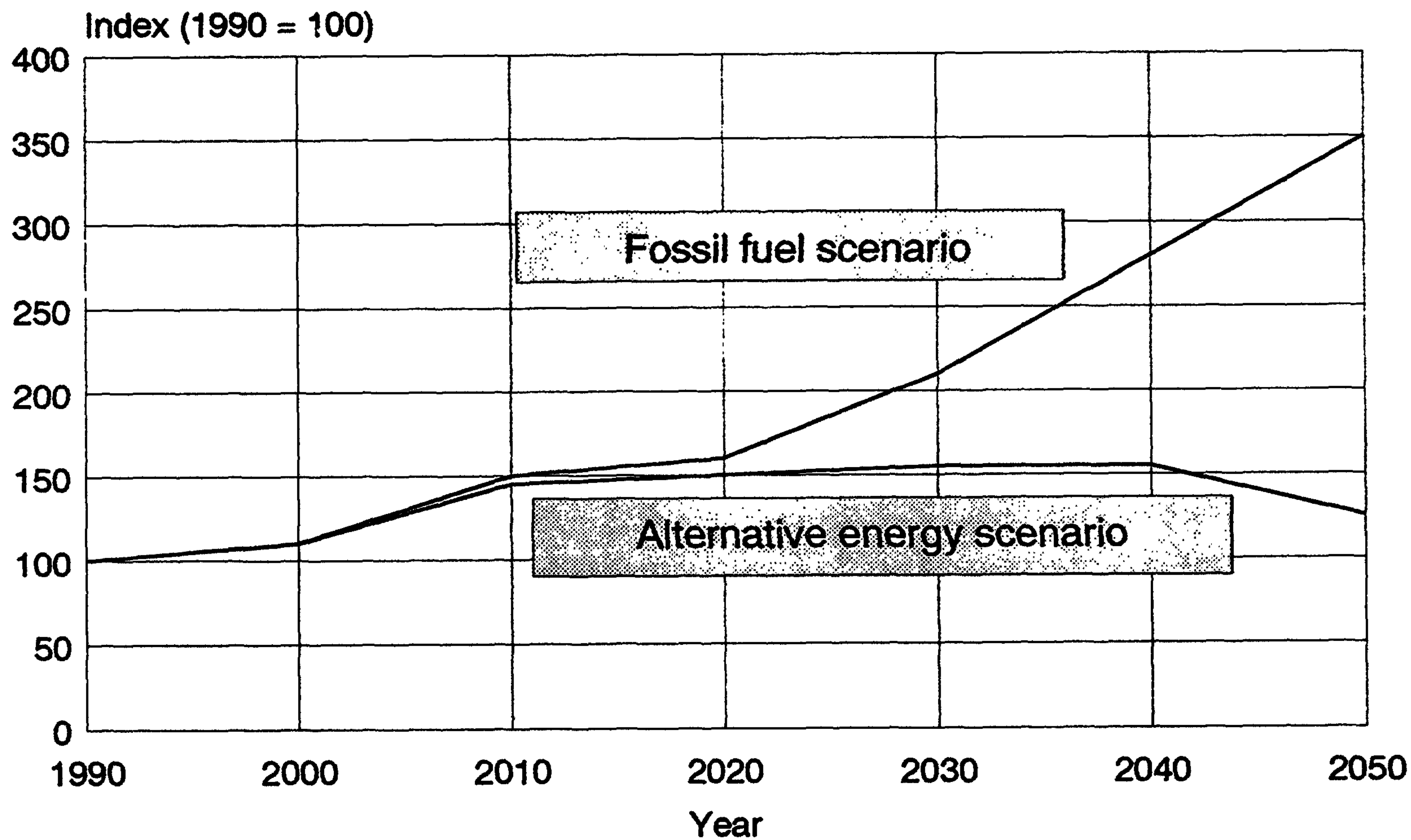


Figure 4.3
Annual Carbon Emissions - Impacts of Switching from Fossil Fuel



Source: World Bank 1992a

CHAPTER V

FOOD PRODUCTION

INTRODUCTION

5.1 The use of seawater to grow seaweeds or irrigate salt-tolerant terrestrial (halophytes) crops has been suggested as a way to increase agricultural production without competing for land, which is suitable for other food crops. Halophytes can be grown in areas where there is an insufficient supply of fresh water necessary to irrigate traditional food crops. Some halophyte species have high nutritional value as forage or fodder crops. Many species also have high digestibility. Halophytes can produce seed which resembles millet - a major staple in Africa - and vegetables similar to spinach. These seeds have high protein and oil contents and compare favorably with traditional oilseed crops for both animal and human consumption. Seaweed cultivation has long provided an important worldwide food and business in Asia --- seaweed production raised between $1 - $2 billion in the late sixties (Bird and Benson 1987). The success of seaweed cultivation in China, Japan, and the Philippines is intimately tied to the use of cultivated species for food. This food is consumed within those countries and also exported. As a result of the growing international demand for the seaweed *Gracilaria*, Chilean production tripled in price between 1972 and 1974. Growing biomass crops provides products other than food and fodder, their extracts are widely used in agro-business, cosmetics and pharmaceutical industries (Chapter VI).

Halophyte Crops: *Atriplex* (forage), *Salicornia* (food and fodder)

5.2 There are two approaches to developing crops which are tolerant to seawater concentrations of salinity. One is to develop salt-tolerance in food crops through selection and genetic engineering. A second alternative is to cultivate plant species which are naturally salt-tolerant (halophytes) as food crops. *Atriplex* species and *Salicornia bigelovii* are plants recognized for their productivity, overall nutritive values and tolerance of salinized soils. *Atriplex* is extensively used as a forage crop (e.g. in Mexico). *Salicornia* produces oilseeds with characteristics similar to soybean and safflower oil. After the seeds have been removed via threshing from the harvested product, the residual vegetative material (straw) can be used as a feed source for cattle, goats or sheep.1/ One of the key factors to successful halophyte production is adequate seawater or brackish irrigation water. There has been increased interest in the agronomic approach of irrigating *Atriplex*. Agronomic testing, feeding trials and development of the best agronomic practices for forage are taking place in saline deserts in Egypt (Sen and Rajpurohit 1982).

1/ From a 2000 hectare farm producing 30,000 mt of total biomass, about 18,000 mt of washed straw (15% salt) can be produced. This is an adequate yearly source of roughage for 10,000 cattle or 25,000 goats or sheep.

Seaweeds: macroalgae - *Eucheuma* (food) and *Laminaria* (food), *Palmaria* (fodder)
microalgae - *Spirulina* (food)

5.3 Similar to halophytes, seaweeds can serve both for human food and animal fodder. While seaweeds have long served as food to east and south Asia, most seaweeds used by western nations are not consumed directly. Instead, their extracts are widely processed in a variety of food and other industries. For example, the brown seaweed *Laminaria* has been used for confectionaries. As fodder, the red seaweeds (*Palmaria*) have been used to feed cattle, sheep, goats as well as fish in aquaculture ponds. These types of seaweeds contain carbohydrates, and small amounts of protein, fat, and ash, which are of particular nutritional value to the animals. The carbohydrates are not easily digested by humans. The red seaweed *Eucheuma* is often consumed as a fresh salad component or pickled. In the West, commercial seaweed cultivation is poised on the threshold of economic feasibility. The transition from dependence on natural seaweed populations to mariculture is concurrent with exploration of the use of algae for pollution control purposes and for biomass conversion to meet energy needs. However, due to the high demand for seaweed and seaweed products, combined with the increasing level of pollutant discharge into the oceans, many seaweed cultivation sites have been threatened.

5.4 Although the seaweeds considered in the context of greenhouse gas reduction are macroalgae, the microalgae *Spirulina* holds great promises to improve the diets of local populations, particularly pregnant and lactating women, and children, by virtue of its high available protein and vitamin content. In some societies, *Spirulina* can reach these groups through their traditional foods - in sauces or incorporated with cereals. In other societies, this microalgae is used as medicine. It has been observed that the geographic locations of malnutrition coincide with the climatic conditions favorable for the growth of *Spirulina* (Fox 1987). In addition, the recycling of village wastes along with a little salt, can provide the nutrients essential for mass culture of this algae. Projects in Togo, India and China have indicated that it is possible to produce medically acceptable food algae from the bacterial load from latrines through to the finished algal product (Fox 1987a).

ECONOMIC COSTS AND BENEFITS

5.5 With the increasing world population and the need for increased seaweed and halophyte crop production, non-productive lands, many of them salt-affected, may be used to produce non-conventional crops of economic value. In general there are few cost/benefit data available on using halophyte and seaweed biomass for food production despite the fact that crops (in particular seaweeds) are produced on tens of thousands of farms. At present, the linkage between biotechnological experimentation and commercialization is poorly documented. In this context, biotechnology is defined as a family of tools and techniques that can be used to generate a desired biological product and/or process. Currently, various projects are ongoing to implement new bio-techniques and to evaluate the socio-economic impact of this type of a biomass project on the beneficiaries. For instance, the seaweed culture of *Gracilaria* in Chile generated a return worth $15 million, and provided employment opportunities for an estimated 9,000 fishermen and their families in 1986 (Santelices and Ugarte 1987).

Halophytes

5.6 The costs of halophyte farms include: initial preparation of land, seeding, irrigating, harvesting and replanting. One major difference between planting halophytes as food crops and planting them as carbon-sequestering crops may be in the mode of harvest. For carbon-sequestering purposes, it may be sufficient (in theory) to merely clip the plants once a year and let the litter fall to the ground to form a mulch. This mulch will build up over the years and represent stored carbon. If perennial species of halophytes are used, they can be continuously clipped for five years or longer, at which time they will need to be harvested completely and replaced with new plants. If annual plants are used, they can be reseeded into the previous years' mulch soil. Whereas, for food or fodder production purposes, all or part of the biomass is removed and therefore it is not available as stored carbon.

5.7 Certain species of halophytes (e.g. *Indica* in Egypt) will increase the area of green forage and could increase the levels of meat production in these regions. Some micro-climate models predict that planting large areas in arid and semi-arid zones with specific patterns of vegetation can enhance convective rainfall (Glenn et al. 1991). Hence coastal deserts planted initially with halophytes could eventually be converted to rainfed agriculture. Agro-management strategies to provide optimum regrowth yields and quality forage from halophytes would need to consider cut heights, cutting and baling methods, and harvest times and frequency. Regardless of the cutting and harvest methods, the main operating cost is irrigation. Irrigation costs depend on the evapotranspiration rate, the local energy costs, the lift efficiency of the pump, the soil type, and the irrigation method. A seawater-irrigated farm in theory needs more water than a brackish-irrigated farm, because a 50% leaching fraction must be added to control soil salinity in the case of the seawater farm (see Chapter III). Brackish halophytes are expected to cost roughly $25 per ton of biomass, and seawater halophytes $40 per ton of biomass to produce. These costs include the initial startup costs over the first ten years of farm operation (EPRI, 1991).

5.8 Figure 5.1 compares costs in establishing and operating a halophyte farm on brackish water or seawater. The scenarios are for a perennial halophyte crop grown on brackish water (e.g. *Atriplex*) and an annual halophyte crop grown on seawater (e.g. *Salicornia bigelovii*). For the brackish perennial, it is assumed that the crop is to be established from seed, clipped once a year, and the clippings allowed to fall to the ground to build a mulch layer. On the sixth year the crop is cut down to ground level and the stand re-established. In the case of the annual crop, the farm must be replanted each year. The difference between the two types of irrigation is in the amount of water used. Halophytes grown in brackish water, for instance, have approximately the same irrigation requirements as have conventional crops grown in a similar climate. However, halophytes grown with seawater have a greater irrigation requirement because they need more water to control salt levels in the root zone. The figure clearly shows that the clipping and irrigating costs are almost twice as high for the annual crop irrigated with seawater. The costs specifically related to the domestic production of food are: harvesting, pretreatment, storage and processing. These costs are estimated to range between 25-35% of the total production cost for a halophyte crop (Singh, 1970b).

Seaweeds

5.9 In spite of the limited availability of cost figures, some comparative installation and production cost data for seaweeds do exist. The most important costs of seaweed farming revolve around harvesting. The installation costs vary considerably according to the type of harvesting technology used. The cost can be as low as $3,325 per hectare for installations in shallow water (e.g., Indonesia) and as high as $54,349 per hectare nearshore (Japan). Besides the higher costs of anchoring structures in deep water, it is also more difficult to harvest. Nearshore production costs in Chile are four times the cost of shallow water production costs in Indonesia. Production costs in a semi-natural environment are in the middle of this range. While farms set up for the exclusive purpose of carbon sequestration need not necessarily be harvested, the harvesting cost is inherent to seaweed farms set up for food production. The natural sloughing of excess seaweed from the farm could be sufficient to sequester carbon in the sediment, although this is open to substantial debate (Berger 1977).

Table 5.1

Installation and Production Costs for Seaweed Cultivation

Cost of Seaweed Cultivation	*Eucheuma* Shallow H_2O (Indonesia)	*Gracilaria* Pond Culture (Taiwan)	*Gracilaria* Nearshore (Chile)	*Macrocystis* Nearshore (USA)	*Laminaria* Nearshore (Japan)
Installation Cost/Ha	$3,325	N/A	$13,537	$7,862	$54,349
Production Cost/dt	$89	$138	$360	N/A	N/A

5.10 **Employment Generation.** Both halophyte and seaweed crops are important in terms of employment generation, and in many countries significantly contribute to increasing foreign earnings. Mariculture has generated 2.4 million tonnes of wet seaweeds worth hundreds of millions of dollars, and involved close to 1 million of people in east and south Asia. The cultivation of *Laminaria* in China alone employed 50% of the local farmers (Tseng and Fei, 1987).

ENVIRONMENTAL COSTS AND BENEFITS

5.11 It is impossible to predict the effects of massive plantings on the environment, aside from their intended roles of removing carbon. While there are some points of comparison with the forestation option, some domestic and global impacts specifically related to the two biomass crops under examination are presented below.

5.12 **Domestic Environmental Costs:** Even though halophytes are physiologically adaptable to a low amount of water in the soil, when soil salinity and/or climatic aridity becomes higher than the tolerance of the plants, their growth will be impaired and they may die. Massive saline water irrigation programs can create imbalances in the groundwater conditions, especially in undrained internal basins (Chapter III). Therefore, as with any irrigation scheme, it is important that drainage be considered as an integral part of project design.

Box 5.1: The economic costs and benefits of harvesting *Eucheuma* in the Pacific Rim

Introduction: Over 95% of the annual commercial *Eucheuma* crop is from farms in the tropical far western Pacific. In addition to foreign exchange earnings for those countries exporting seaweed and the final use values of its carrageenans, the labor-intensive farming of *Eucheuma* is of great socio-economic value to the often nearly indigent shore dwelling families who grow it.

Harvesting and Commercialization: Wild crops of *Eucheuma* were first harvested in Malaysia. As a result of over-harvesting, farmers and fishermen shifted from collecting wild species to farming *Eucheuma* to obtain desirable size, stability and quality of crop. In commercial farms drying is carried out immediately after harvesting. Buying stations among the farms are usually in charge of the drying and transportation to the local distribution centers. In small-scale family farming in Indonesia, the traditionally recognized village leader accumulates the seaweeds and sells to the entrepreneur, trader or exporter.

Costs: The estimated costs (in million 1980 US$) for capital investment per one acre monoline *Eucheuma* farm are US$3,070. The three main cost categories are material (US$1,418), labor (US$1,552) and equipment (US$100). Most farms are probably near one tenth of a hectare or less (1 hectare = 2.47 acres).

Employment and Income Generation: Both large and small scale farming are practiced. When the farm is small, the artisanal fisherman can often continue his traditional ways of obtaining a livelihood, as it is often his wife who farms the seaweed, thus contributing to increasing the family income. Experiences have pointed out that *Eucheuma* from an absent-owner state-managed farm costs $0.34 per kg, a resident-owner farm hiring workers costs $0.37 per kg, and only $0.20 per kg from a family farm without paid employees.

Constraints: From the farmers point of view, the constraints are of a legal and financial nature. Obtaining the right to farm often is a cumbersome administrative task, and essentially there are no sources of credit or insurance for seaweed crops. Most of the financing is provided by informal banking associations (i.e. local merchants). From the investors perspective, finding competent personnel for selecting a site, installing a farm and managing it are the greatest challenges.

Source: FAO 1987

5.13 Potential negative impacts of implementing seaweed farms are a reduction in nutrients available for plankton. If chemicals or fertilizers were used, the secondary effects could be important, as the entire aquatic ecosystem would be affected by increased nitrogen levels. There is also a possibility that massive seaweed planting might lead to eutrophication of the oceans, with potential detrimental consequences for the atmosphere. Eutrophication, most often occurs in confined bodies of water, is the process whereby increased nutrients cause excessive growth of aquatic plants, the resulting bacteria associated with increased decomposing plant biomass, deplete the oxygen levels in the water, and this can lead to large scale fish die-offs.

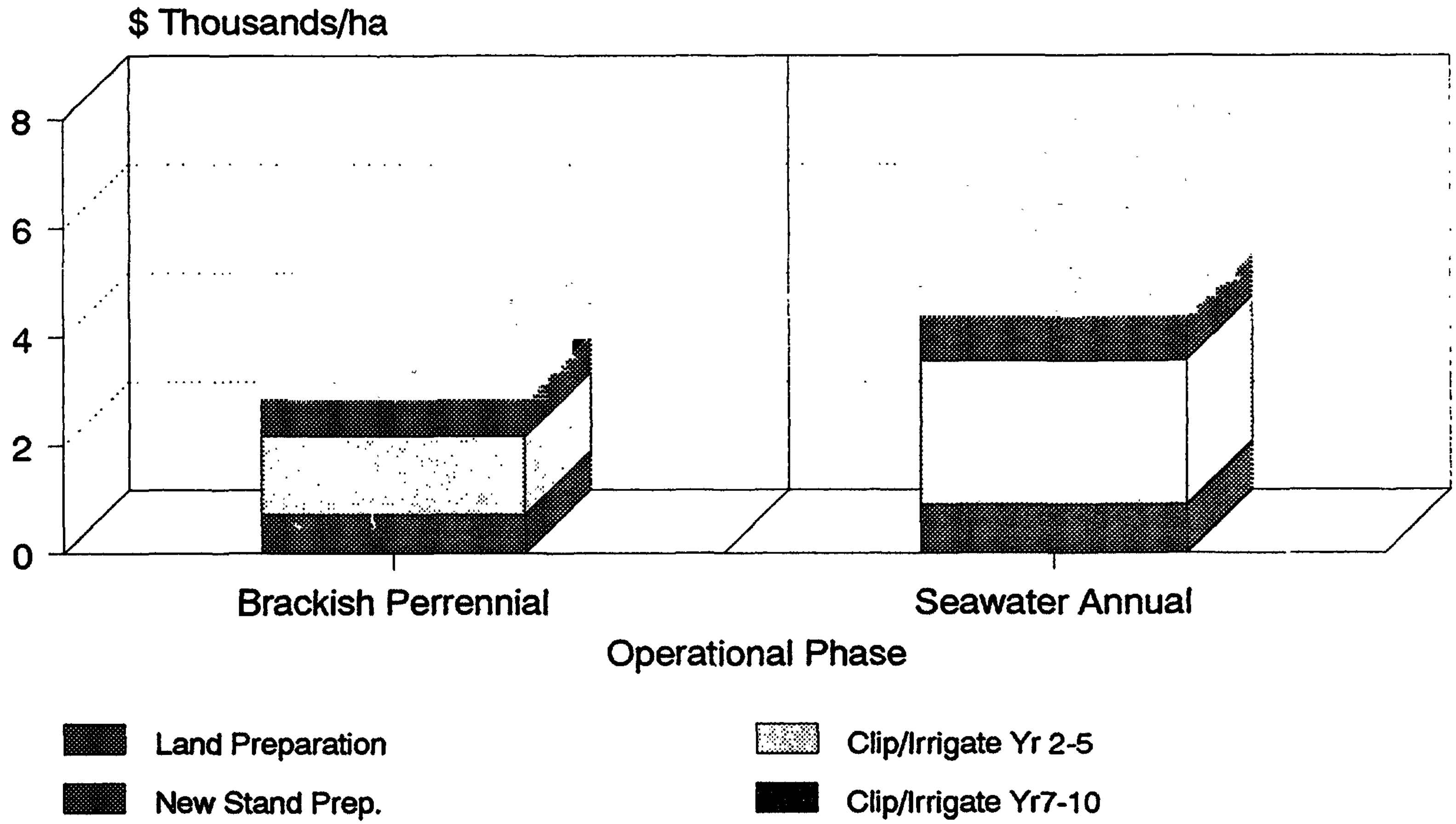
5.14 **Domestic Environmental Benefits**: The cultivation of saline lands with halophytic plants may be considered as a biological technique for soil desalination (i.e. biological desalination) and thus land reclamation (Chapter III). Potentially suitable areas for halophyte cultivation are discussed in Chapter IX. Some positive impacts of seaweeds, which provide cover and food, is that the fish and crustacean populations increase in presence of these maritime crops.

5.15 **Global Environmental Benefits**: There remains a question of what to do with the biomass once it is produced. Removing CO_2 from the atmosphere requires the use of biomass with a long carbon storage lifetime, such as wood, peat, or biomass deposited in deep-sea or wet sediments. The CO_2 incorporated into biomass for food and fodder has a residence time of only one to two years and is of no value for atmospheric CO_2 reduction. Therefore, halophyte as well as seaweed biomass must either be stabilized for long-term storage or used as a replacement for fossil fuels to make a direct contribution to removing CO_2 from the atmosphere.

5.16 However, growing halophytes and seaweeds for food and fodder could make an indirect contribution to atmospheric carbon mitigation by reducing the need for deforestation to create new cropland. Estimates of how much new cropland will be needed to support the world population that is expected to exist in 75 years are on the order of 200 million hectares, most of which must come from the remaining undisturbed tropical forests or from forest fallow if conventional crops are to be grown. But if the 1.3 million km^2 of coastal desert and inland saline land identified as suitable by the scientists were planted with halophytes, and a comparable area of continental shelf were planted with seaweeds to produce food and fodder, the existing forest land could be spared, thus, leaving the stored carbon in the standing crop of trees rather than releasing it into the atmosphere by land clearing. In addition, these estimated values could offset the need for new tree plantations to sequester carbon.

5.17 Lastly, mangrove plantations offer a special case for carbon storage in halophyte tissues. Because they are extremely long-lived, mangroves can be used as a more permanent form of carbon storage than other halophytes. Mangroves once thrived in many coastal desert environments but have been eliminated by shoreline modifications. Replanting mangroves in these areas and extending the mangrove habitats by irrigating new coastal land with seawater is one possibility for enhancing carbon storage, while simultaneously increasing food and crustacean and/or fish production. Experiments are also underway using mangroves for waste water treatment, similar to constructed wetlands, in developing countries with inadequate sanitation facilities (Hammer pers. comm).

Figure 5.1
Operational costs for Brackish and Seawater Halophyte Farms



Source: Glenn et al. 1991a

CHAPTER VI

INDUSTRIAL PRODUCTION

INTRODUCTION

6.1 Halophytes and seaweeds provide raw materials for many types of industries including agro-business, manufacturing, pharmaceutical, petroleum, and biotechnology. Seaweeds, for example, are used in the production of toothpaste, cosmetics, shampoo, pet foods, baby foods, milk and other food products. While industrial uses of halophytes seem much more limited, they can be used as a source of raw materials in paper, and in pharmaceutical industries. Because of the multiple uses of biomass products, demand has increased, and harvesting pressure has been particularly severe on the world's seaweed resources. Over time, the easily accessible seaweed beds have become overharvested, and polluted coastal waters have deteriorated seaweed habitat in several areas (Hansen et al. 1981).

6.2 However, as new and wider properties are developed, the range of applications will broaden over the years, increasing the linkage between seaweeds and biotechnology. The seaweed extract industry is growing in the United States. Other major suppliers are Denmark, France, and, on a smaller scale, Japan, Taiwan, Korea, China, the Philippines, Portugal, Brazil, Argentina and Canada. The extracts provided by marine algae are classified into three main groups: alginates, carrageenans' and agars. Alginates are obtained from a number of brown algae (e.g. *Laminaria)* and provide important compounds for the food industry, from dairy products to noncarbonated fruit beverages and processed food. Commercial ventures were set up to manufacture these products in Europe and the US in the late 1950s and early 1960s, but were unsuccesful. With the renewed interest in eliminating wastage, controlling pollution, and reducing the high cost of fruit and vegetable ingredients, there has been an upsurge in use of biomass by-products (Glicksman 1987). Carrageenans are polysaccharides extracted from a number of different red seaweeds (e.g. *Eucheuma)*, and are widely used in the food processing industry. Many instant foods that come in powdered form for mixing with liquids contain this extract. Finally, agars are mixtures of polysaccharides extracted from certain seaweeds, particularly *Gracilaria* and *Gelidium*, that have the ability to gel aqueous solutions at low concentration. Their most significant use is in non-food and pharmaceutical products.

6.3 Table 6.1 indicates various geographical locations which are particularly suitable for cultivating red seaweeds in the genus, *Gelidium*, and producing the agar extract. *Gelidium* seaweed cultivation is widely dispersed over the Asian continent, Chile, and some Mediterranean countries. The annual production and harvest method varies between countries, and the agar content of *Gelidium* varies with species, season, location, and environment. Japan, Portugal and Morocco are reaching annual production levels varying from 3,300 to 1,000 million dry tons. The most commonly used harvesting method seems to be the labor-intensive handpicking technique, followed by the drifting method practiced in the Mediterranean, and diving in Japan. Commercially, a yield of 17 to 25% is considered normal. Agar production offers considerable developmental opportunities in these regions, and can evolve into an important export commodity (e.g. in Chile, all the harvested crops are exported as raw material for agar production).

Table 6.1

Geographical Distribution of Seaweed (*Gelidium*) Production, Harvesting Method and Agar Production.

Gelidium Species	Location	Annual Production Metric Dry Tons	Harvesting Method Used	Amount of Agar
amansii	Japan	3,000-3,300	Hand Pick,Diving	20 to 30%
chilense	Chile	100 - 150	Hand Picking	25 to 31%
latifolium	Java	N/A	N/A	25 to 35%
lingulatum	Chile	100 - 150	Hand Picking	20 to 24%
licropterum	India	N/A	N/A	43%
pusillum	Philippines	N/A	N/A	41%
	India	N/A	N/A	50%
rex	Chile	100 -150	Hand Picking	27%
sesquipedale	Portugal	2,500 - 3,000	Drift, Hand Pick.	24%
spinolosum	Morocco	1,000 - 1,500	Hand Pick., Drift	33%
	Sri Lanka	N/A	N/A	21 to 40%

Source: FAO 1985

ECONOMIC COSTS AND BENEFITS

6.4 The available cost data on using halophytes and seaweeds for industrial purposes are poorly documented and outdated. The main costs associated with using biomass for industrial production generally relate to the pre-treatment phase. Both halophytes and seaweeds have been used for multiple purposes. For instance, halophytes have been used in the production of rose-oil in India and the paper industry in Egypt. Similarly, seaweed products have been used in a wide variety of industries, particularly food and pharmaceutical.

Halophytes

6.5 Table 6.2 details the non-separable and separable costs, over a period of ten years, involved in the production of rose-oil from the halophyte *Rosa damascena* for the cosmetic industry in India (Singh 1970b). It is estimated that the total cost from land preparation through final processing stage averages 76,000 Rupees per year. The non-separable costs comprise the various stages from land clearing to maintenance, and have to be incurred regardless whether the project is intended to sequester carbon or to develop local industrial production. The separable costs are specifically related to harvesting, pretreatment and processing activities of the halophyte, to produce an oil extract which can subsequently be used in the production of cosmetics. Table 6.2 clearly shows that manures and fertilizers represent the largest costs, 26,000 Rupees, of the non-separable cost category, or 35% of the total cost, whereas the harvesting, pre-treatment and processing stages represent about 30%. Hence, the domestic incremental costs are relatively modest and warrant the investment provided that either the domestic and/or global benefits are positive. However, caution needs to be given to the disposal of the chemicals used in extraction.

Table 6.2

India - The Costs of Rose-Oil Production (In Rupees)

Expenditure per hectare	1st year	2nd year	3rd to 10th year	Total for 10 years
Non-Separable Costs				
Land Clearing	500	nil	nil	500
Planting	5,000	nil	nil	5,000
Watering	500	500	4,000	5,000
Maintenance				
Manures + Fertilizer	4,000	2,000	20,000	26,000
Other	800	1,500	12,000	14,300
Rent of Land	100	100	800	1,000
Separable Costs				
Harvesting	nil	1,000	10,000	11,000
Pretreatment and Processing	nil	1,000	12,000	13,000
Total	10,900	6,100	58,800	75,800

Source: Singh (1970b)

6.6 Box 6.1 describes the multiple domestic economic benefits of using halophytes in Egypt to develop employment opportunities across a large variety of sectors, from the paper industry to the more artisanal activities, such as shoe, mat, and drug production. While specific costs figures were unavailable, experience indicates that growing halophytes, particulary for the paper industry, has proven to be successful, and has contributed to decreasing Egypt's dependence on foreign markets.

Seaweeds

6.7 The principal costs associated with extracting carrageenans from *Eucheuma* are in heat and separating the carrageenan from the extraction water. Three approaches are used for water removal after centrifugation, filtering and sometimes vacuum removal of water: (a) spray drying on steam-heated drums as in the making of powdered milk; (b) cold-water extraction of the seaweed; and (c) precipitation with alcohol. Each process has its merits, and some large companies use more than one method to obtain different qualities in their final products. Aside from the raw seaweed material, the principal costs of carrageenan are in inventory, warehousing, water, power, alcohol recovery (in alcohol precipitation plants), filtration, and chemicals.

6.8 The principal costs linked to extracting agar from *Gracilaria* are similar to normal pressing process costs with relatively minor adjustments allowing for defects of the raw material. The process requires flexibility of the operators to adjust constantly for yield variations and bleaching changes. The bleaching process is also quite intricate, but the end result remains an acceptably bleached agar with a sufficient gel strength, adequate for industrial usage. As Box 6.2 shows, the whole process is labor-intensive representing about 25% of the total costs.

6.9 In addition to the conventional economic benefits similar to the other types of biomass projects, such as job creation impacting particularly the agro-, manufacturing and pharmaceutical industries, reduction of foreign dependance on imported goods, etc., the cultivation of seaweeds has contributed to the development of biotechnology.

6.10 **Biotechnology Development**. The polysaccharides from seaweeds have enabled scientists to develop modern biotechnology tools and techniques. Potentially productive applications of biotechnology to seaweeds can be accomplished by genetically engineering the various species to better meet future needs. Without seaweeds, or at least the hydrocolloids they contain, the biotechnological advances, which may be extremely beneficial to mankind, would not have been possible (Renn 1990).

Box 6.1: Egypt - The Industrial Potentials of Halophytes

The halophyte *Juncus*, can be grown on saline non-productive soils in Egypt and other parts of the Mediterranean region, and is an important raw material to multiple industries:

Paper Industry: In Egypt, traditionally rice straw, bagasse and waste paper are the main local raw materials used for the production of paper. These materials are, however, technically difficult to process because of their heterogenous composition and structure, and financially costly to handle, collect and transport. Consequently, as an alternative for reducing Egypt's dependance on foreign markets, it was discovered that the salt-tolerant and fiber producing (i.e. high in cellulose) *Juncus* plants provided a higher quality pulp than the conventionally used local raw materials. However, large-scale economic production of paper entails large production of *Juncus* plants. Hence, it will be of importance to study the main factors affecting the productivity of such plants under agricultural practices on saline soils.

Other Industries: Other economic uses of the *Juncus* plant can be found in the mat, basket and shoe industries. Its seeds have been important ingredients to oriental medicine as a remedy for diarrhea, and studies suggest the possibility of using *Juncus* seeds as a potential source of oil. While these uses are of less importance in monetary terms, their contribution to improving local market products is not negligible.

Lesson: The cultivation of halophytes in arid and semi-arid soil offers a potential solution to producing local raw materials and extracts to be used in the agro-, manufacturing and pharmaceutical industries, while contributing to reducing the salinity of the soil (see Chapter III) which, in turn, translates into increased productivity of the land. The global benefits include carbon sequestration and potential mitigation of global climate change.

Source: Sen and Rajputohit (1982)

ENVIRONMENTAL COSTS AND BENEFITS

6.11 The domestic environmental issues that may emerge in using biomass for industrial production can be of the following nature:

6.12 **Domestic Environmental Costs**: Because of the increasing demand for biomass by-products, there is a risk of overharvesting the natural aquatic and terrestrial species. Such overharvesting could lead to a decrease in biological diversity and impairment of ecosystem functioning. For the production of biomass such as seaweeds in artificial or semi-natural environments, the use of fertilizers and agro-chemicals could lead to the pollution of local waters. One important issue to consider when developing a biomass project for agro-business, pharmaceutical or manufacturing purposes, will be the disposal of the waste after treatment of the algae to produce agar, carrageenans or alginates. If not disposed of properly, these projects could contaminate the surface water or groundwater. Similarly, special care needs to be given to the disposal of chemicals used to produce fibers from halophytes for the paper industry.

6.13 Another concern is the amount of fossil fuel that must be expended to process the seaweeds into compounds for industrial use. Fossil fuel is usually used in the production stage of seaweeds to power the pumps, tractors and other farm equipment, as well as the processing stage. Fuel costs at the production stage are usually higher than the processing stage, about 30% and 10% respectively (Glenn et al. 1991). If this fuel were supplied by diesel fuel containing 85% carbon, the carbon expenditures are 67 kg of fossil fuel per ton of carbon fixed in brackish halophyte biomass and 107 kg of carbon per ton of carbon in seawater halophyte biomass. Hence relatively little carbon is expended in production compared to the amount fixed by growing halophytes and seaweeds.

6.14 **Domestic Environmental Benefits**: One of the advantages of using biomass as an input to industrial production, is that they can be used in multiple sectors and satisfy other environmentally sound objectives, such as the production of renewable energy (Chapter IV) and waste water treatment (Chapter VII). The greatest results will of course be achieved when all these multiple uses are integrated in a single approach or project (Chapter III, Box 3.2).

6.15 **Global Environmental Benefits**: The global benefits are similar to those discussed in the preceding chapters and the impact of using halophytes and seaweeds could contribute to short and long term reduction of ambient CO_2 emissions.

Box 6.2: Learning from the Namibia Seaweed Farming Experience

Namibia has developed a process to transform cast, stranded, seaweed into: (a) marketable *Gracilaria*, (b) production of agar, and (c) development of polyculture combining algae and crustaceans. The high quality of the seaweeds has enabled Namibia to become the second largest *Gracilaria* supplier to Japan. The industry has created 250 jobs, and a plan has been developed to cultivate this seaweed in ponds on land to offset the seasonal character of the operation. Because of its success, efforts are being made to reduce high energy costs for pumping and allow for larger scale production. New ways for handling, treating and sorting the seaweed to meet market requirements involve all processing stages:

(a) **Production of dried seaweed**: Cast seaweed is loaded onto trucks, and transported to an isolated area in the desert. The algae is spread as a thin mat onto the desert sand, unwanted particles are removed, and the product is left to dry. The cleaning process can take up to six weeks, while the color of *Gracilaria* changes from maroon-brown to golden-yellow. The clean seaweed is stored and classified according to origin and color, length, moisture content and general appearance, packed and shipped overseas for food consumption.

(b) **Agar Production**: A process has been designed to use the waste material of the algae in a local agar plant, which will translate into production of up to 10 tons of agar per month.

(c) **Phycoculture to polyculture**: The phycoculture of *Gracilaria* has resulted in transferring seaweeds collected from the sea into ponds. It was observed that growth increased to ten times the original mass in three months. The costs per hectare involve largely labor and equipment. Net income before tax was 13% of the turnover, indicating a good return considering the small-scale operation. The operation is currently considering converting from monoculture to polyculture with Pacific oysters, mussels and prawns.

Lesson: Seaweed cultivation can have both a positive impact on the national economy affecting employment generation, trade, development of alternative sources of energy (e.g. wind), waste treatment, and on the global environment by sequestring carbon dioxide, in the context of an integrated project.

Source: Ragan and Bird (1987)

CHAPTER VII

POLLUTION CONTROL AND MONITORING

INTRODUCTION

7.1 Biomass has been used in both developed and developing countries to monitor and control pollution. For example, water hyacinths (*Eichornia crassipes*), have been used extensively to capture organic pollutants from organic waste streams, and heavy metals in lakes and ponds (e.g., Smith et al. 1984, Cullinane et al. 1987, Tsugawa et al. 1991).

7.2 The majority of activities with seaweeds have focused on using biomass as an indictor of marine pollution from heavy metals, organic pollution, and polychlorinated biphenyls (PCB's). Halophytes have been used less extensively in pollution control or monitoring, and techniques are in an earlier, more experimental, stage of development.

7.3 **Halophytes.** A study of the eelgrass (*Zostera marina* L), found that this species could contribute to the detoxification of tributylin in seawater (Francols et al. 1989). The plant absorbs the pollutant very rapidly in water, and later releases monobutylin, which is much less toxic. However, as eelgrass is at the base of the food chain in temperate estuaries, accumulation of toxic chemicals in the plant's tissue could result in later accumulation at higher trophic levels. Thus, the use of eelgrass as a form of pollution control would require regular harvesting and disposal. Such harvesting would be considered as a domestic cost and would offset carbon sequestration.

7.4 Only one field demonstration using halophytes for pollution control has been described in detail in the literature. This case, carried out in the central valley of California in the United States, used halophytes as one stage in a water purification system. Because of extensive irrigated agriculture in the region, water reservoirs had become polluted with high levels of selenium. This pollution was significantly impacting waterfowl populations by causing growth mutations.

7.5 In this case study, halophytes were used as a secondary water treatment and selenium removal system. First, the polluted water was used to irrigate eucalyptus trees. The drainage water, collected in a series of drainage ditches, was reduced in volume by approximately 50%, and approached the salinity of seawater. This water was then used to irrigate halophytes, particularly *Atriplex* species. The halophytes accumulated the selenium in the leaves. A 50% leaching fraction of un-contaminated water returned to the water table. The remaining 50% of water was collected via drainage from the halophyte crop and was deposited in evaporation ponds. The halophytes, which contained the selenium and other salts, were then collected and used as a nutrient additive for cattle (Figure 7.1).

7.6 This case study is applicable to developing countries, especially in regions where overuse of rivers leads to secondary salinization of irrigation sources, and consequently agricultural land. The use of halophytes, rather than drainage systems to reclaim the salt-affected agricultural land by removing salts and other pollutants could be much more cost effective (Glenn pers. comm).

7.7 **Seaweeds.** To date, the use of seaweeds as biological monitors of pollution has largely been carried out in laboratories and few pilot or demonstration projects have been developed. *Laminaria* gametophytes and early sporophytes show promise for toxicity monitoring. In addition, *Sargassum* and *Cystoseria* have been recently used to test the toxicity of the pollutant hydrazine (North and James 1987).

The embryos of these species demonstrate changes in cellular development with increasing concentrations of pollutants. The major problem with using these species as pollutant monitors in developing countries, however, is that the species are relatively slow growing and the analytical techniques require a moderate level of technical and laboratory sophistication to be carried out.

7.8 **Microalgae.** The greatest amount of work using algae to reduce pollution has involved microalgae, notably *Spirulina*, a blue-green alga, as opposed to seaweeds which are macroalgae. *Spirulina* has been used to treat swine wastes (Chung et al. 1978) as well as human organic waste in Taiwan, India and Togo (i.e. Soong 1980). The primary benefits of *Spirulina* are that it is relatively inexpensive to establish, has a relatively low technology requirement, and can be implemented on a local or regional scale (Fox 1987).

ECONOMIC COSTS AND BENEFITS

7.9 **Halophytes**. Although the system is still in the experimental stage, the available information on halophytes suggests that removal of pollutants from water can be cost effective under certain circumstances. These circumstances include:

- The primary pollutant is concentrated in the halophyte biomass.
- The halophyte biomass can be used as cattle fodder, a substitute for fossil fuel, or another economically valuable commodity.
- The primary water treatment biomass, such as eucalyptus, has commercial value.

7.10 If these conditions are present, it might be technically and economically feasible to use halophytes as part of a pollution control system. Based on **extremely** preliminary data, a system would use 24,000 m^3 per ha of contaminated water, release 12,000 m^3 of un-contaminated water, at a cost of $633.40/ha, or $0.0527 per m^3 of clean water. These cost estimates are presented in Table 8.1. It should be noted however, that these cost figures do not include the cost of the water lost in the system due to uptake by the *Eucalyptus* and halophytes, as well as a number of other factors which can not be estimated from the available data.

Seaweeds

7.11 Because of the lack of operational or demonstration sites where seaweeds have been used to monitor or control pollution, few economic data are available. In addition, further detailed trials need to be carried out before the feasibility and economic practicability of large scale seaweed plantations to control pollution can be adequately assessed. Therefore, at present no analysis can be made of the economic costs of a system using seaweed, except that production costs are estimated at $89 - $138 per dry ton of biomass and that production on seaweed farms is estimated at 16.7 dry tons ha^{-1} yr^{-1}.

Table 7.1

Preliminary Cost Estimates of Halophyte Control of Pollution

Costs:	$/ha
Halophyte Plantation	430.4
Eucalyptus Plantation	22.6
Energy	1.4
Drainage	8.6
Evaporation Pond	0.9
Contaminated Water Input (24,000 m^3 @ $0.0145/$m^3$)	350.0
Total Costs	813.9
Benefits:	
Sale of Biomass	180.50
Water Output:	12,000 m^3

Sources: Glenn (pers. com), EPRI (pers. comm).

ENVIRONMENTAL COSTS AND BENEFITS

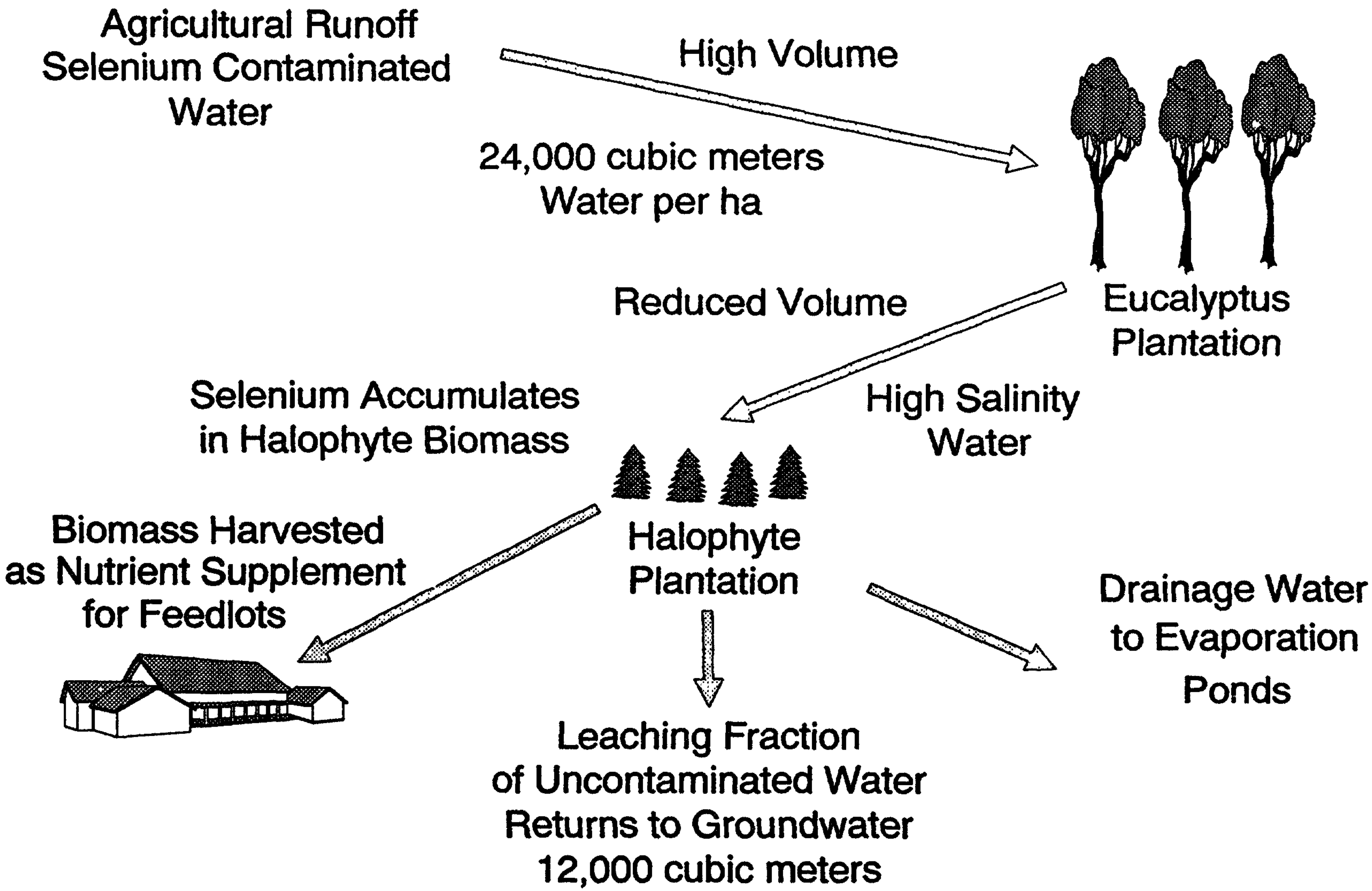
7.12 Because of the tentative nature of data on using seaweeds and halophytes to control and monitor pollution in the field, estimating the environmental costs and benefits is preliminary. However, despite this drawback, it is possible to draw some initial conclusions.

7.13 **Halophytes.** The primary environmental benefits of using such as system is to clean up water reservoirs and rivers which have become polluted with a contaminant that is accumulated in the halophyte. This reduction of contamination could have significant beneficial impacts on animals, plants and humans which use the water system. This de-contamination system would also prevent the concentration of the pollutant in the upper levels of the food chain.

7.14 The costs of such a system are in the amount of water lost during de-contamination. This loss, approximately 50% of water volume, could be significant in arid regions. In addition, the pollutant is not entirely removed from the region. Instead, it is transformed from a aqueous solution in the water table into halophyte biomass or as residue in the evaporation pond. Ultimately, the residue from the evaporation pond will require collection and storage to prevent subsequent contamination.

7.15 **Seaweeds.** The primary environmental benefits of using seaweed would be the removal of the pollutant from the marisphere, thus preventing the concentration of the pollutant in fish or other animals. However, further data are needed to make a realistic assessment of the environmental costs and benefits of this system.

Figure 7.1 Schematic Diagram of Pollution Reduction System Using Halophytes



CHAPTER VIII

GLOBAL COSTS AND BENEFITS THROUGH GREENHOUSE GAS ABATEMENT

8.1 The primary global benefit of biomass projects is the reduction in atmospheric levels of CO_2. The increase in CO_2 is considered as a major global environmental issue, because of the potential impacts on global climate and changes in sea level. This Chapter briefly reviews the issue of global warming and its relation to CO_2 build up, and considers the economic and practical issues relating to sequestration of CO_2 through biomass production.

THE GREENHOUSE EFFECT

8.2 The earth's temperature represents a balance between energy coming in from the sun and outgoing infrared (heat) radiated from the earth's surface. A portion of solar energy which strikes the earth is absorbed, raising the temperature of the planet's surface, and resulting in infrared radiation being transmitted upward through the atmosphere into space. Some gases, referred to as "greenhouse gases," in the lower atmosphere absorb the energy emitted by the earth's surface and heat up the atmosphere. These gases include carbon dioxide, methane, and water vapor (which occur naturally as well as being produced by human activity), and those gases solely produced from anthropogenic (human) activities such as chlorofluorocarbons, or CFCs.

8.3 Carbon dioxide, the largest single contributor to the greenhouse effect after water vapor, is produced by natural processes, such as volcanic activity, as well as by the combustion of fossil fuels. Worldwide emissions of carbon dioxide have more than tripled between 1950 and 1980, and at present, approximately 5.5 billion tons of carbon are released per year into the atmosphere. CFCs are the second major contributor to the greenhouse effect and, although emitted in small volumes, they have warming potentials up to 7,300 times as high as CO_2 per unit mass. The contribution of various gases to the greenhouse effect is presented in Figure 8.1.

8.4 Any predictions of how such emissions will affect the global climate are limited by the historic records available as well as uncertainty surrounding our understanding of the global carbon cycle. There is firm evidence that the concentration of carbon in the atmosphere before the industrial revolution remained at 280 parts per million (ppm) or less. Today's level is about 350 ppm, which is attributed to the combined factors of fossil fuel combustion and deforestation in tropical and mid-latitude areas.

8.5 Changes in the level of carbon dioxide are the result of differences in the amounts of CO_2 which are stored by natural processes, and the amounts emitted by both anthropogenic and natural processes. The three major terrestrial carbon pools are (1) carbon stored in rocks, coal and other geological formations (geological storage); (2) carbon stored in vegetation and soils (biological storage); and (3) the carbon dioxide stored in the atmosphere and ocean systems (Table 8.1).

8.6 Recent increases in atmospheric carbon are thought to be the result of releases from geological storage through the combustion of coal and weathering of rocks, and by the release from biological storage through deforestation and land use changes. Land use changes impact carbon dioxide levels because clearing land is carried out by burning of the vegetation which releases the stored carbon directly into the atmosphere. In addition, such land changes reduce the amount of carbon which can be stored by vegetation, especially when land clearing is carried out in tropical moist forests (Schlesinger 1984).

Table 8.1

Terrestrial Components of Global Carbon Cycle[a]

Terrestrial Pools (Pg)[b]	
Atmosphere	750
Vegetation	560
Organic carbon in soils	1450
Terrestrial Fluxes (Pg/yr)	
Uptake by plants	120 (approx)
Release by plants	60
Released from litter and soil	60
Release by fossil fuel combustion	5.5
Net release by deforestation	1.5 (approx)
Changes (Pg/yr)	
Accumulation in atmosphere	3
Net addition to the Ocean and Terrestrial Ecosystems	3

a. Source: Bolin (1983)
b. Pg is defined as 10^{15} g

8.7 A number of General Circulation Models have been developed to predict global climate change in response to rising CO_2 levels. While the results of these models differs, the most widely accepted models indicate that a doubling of CO_2 concentrations will result in increases of temperature of between 1.9°C and 5.2°C.

Current and Future Sources of Greenhouse Gases

8.8 Assessing the sources of total global emissions of CO_2 is a complex issue. At present, OECD countries contribute about 73% of the total anthropogenic CO_2 emissions from all sources. The largest individual producers of CO_2 are the United States, the Confederation of Independent States (CIS), Brazil, India and China (Figure 8.2 and 8.3). These data indicate that both industrialized and developing nations are among the largest emitters of greenhouse gases. They also indicate little relationship exists between the largest producers, and the ability of countries to contribute to potential mitigation measures, now or in the future. By the year 2060, it is expected that lesser developed countries will emit as much or more carbon than developed countries (Figure 8.4). Therefore, direct interventions in the developing world on CO_2 emissions will be critical in achieving a comprehensive global approach to the problem.

MITIGATING GREENHOUSE GASES

8.9 International efforts at mitigating the increasing levels of carbon has focused on three main strategies: (1) reduction of emissions of carbon at the source, (2) increasing the levels at which atmospheric carbon is sequestered by living plants (biomass production), and (3) using this biomass as a substitute for fossil fuels. A summary comparison of how various strategies compare in terms of costs and potential for reducing CO_2 levels in the U.S. is presented in Table 8.2.

Table 8.2

Comparison of Selected CO_2 Mitigation Options in U.S.
(Adapted from National Academy of Sciences 1991)

Mitigation Option	Net Implementation Costs[a]	Potential Reduction in Ambient Levels or Emissions (t CO_2/yr) 0x
Increased Efficiencies:		
Transportation	Net Benefit to Low cost	350 million
Energy Demand of Buildings	Net Benefit	900 million[c]
Power Plants	Net Benefit to Low Cost	50 million
Biomass Production	Low to Moderate Cost	550 million
Electrical Production[b]	Low to Moderate Cost	1700 million

a: Net benefit= cost less than or equal to zero.
Low Cost= Cost between \$1 and \$9 per ton of CO_2.
Moderate Cost= Cost between \$10 and \$99 per ton of CO_2.

b: Maximum feasible assumes 100% implementation.

c: Depends on implementation and is controversial. Figure represents middle of possible range.

Reducing Stack Emissions

8.10 One strategy for moderating the levels of ambient CO_2 is to reduce the level of emissions from most important point source, coal-fired power plants. Currently, coal is the second largest fuel source, supplying some 30% of total global energy use. The burning of coal by electric utilities contributes approximately 35% of total CO_2 emissions globally. Carbon combustion for energy consumption in the U.S. represents the single most important source of CO_2 and greenhouse gas emissions globally. Therefore, reductions in the levels of CO_2 in the atmosphere by reducing emissions from major point sources must be included in any comprehensive approach.

8.11 The short-term costs of reducing CO_2 emissions through controls depends on the degree of mitigation sought and the rate of achievement of the desired level. In the short-term, reducing stack emissions could be carried out by a combination of enhancing end-use efficiencies, improving efficiencies of existing fossil fuel generating units, and by substituting natural gas where feasible in coal-fired boilers. These short-term mitigation strategies could result in either a net savings, because of increased efficiencies, or a small to large cost, depending on the amount of CO_2 reduced. Current estimates on the overall costs of short-term CO_2 mitigation and the costs per ton of CO_2 not emitted are presented in Figure 8.5.

8.12 One study has suggested that between 1990 and 2050, a 35% reduction in primary energy consumption (equal to 1.7 billion metric tons of carbon) on a worldwide basis, might require a total incremental capital investment ranging between $1.1 and $ 3.6 trillion. This investment would focus on deploying more efficient end-use technologies in developed countries and improving generation efficiencies and emissions controls in developing countries across all energy sectors (Yu and Kinderman 1992). Depending on the assumptions about future fuel prices and costs of capital, the above capital investment could be paid back, assuming a 6% discount rate, in 4 to 26 years in energy costs savings.

8.13 In the longer term (from the years 2000 to 2100) many new options will be available to the utility industry in reducing CO_2 emissions. The estimated costs of these long-term reductions have ranged from $20 to $200 per ton of CO_2 abated. These figures represent values approximately half of the range of costs for short-term mitigation strategies. In addition, the long-term strategies have the capability of reducing long-term global emissions to a much greater extent.

SEQUESTERING CO_2 THROUGH BIOMASS PRODUCTION

8.14 In part because of the relatively high cost of abating large quantities of carbon dioxide from the stacks of coal-fired power plants in the near future, scientists have begun to consider stabilizing, and perhaps eventually reducing, ambient CO_2 levels by increasing carbon sequestration in plant biomass. Plants capture atmospheric CO_2 during photosynthesis and release oxygen as a by-product. The three types of plants considered to have the greatest potential for use in carbon sequestration are trees, salt-tolerant terrestrial plants (i.e. halophytes), and seaweeds.

8.15 **Tree Plantations.** The option of using tree plantations to sequester CO_2 has received considerable attention (e.g., Marland 1988, Sedjo 1989, and Vitousek 1990). These studies have evaluated the amount of carbon which could be stored through major tree planting programs. The amount of carbon stored in biomass is dependent on the amount of land available, the rate of potential carbon storage and the fate of carbon stored. A massive effort of reforesting about 800 million hectares of the land which could support forests would sequester up to 6 billion metric tons of carbon annually. This figure is close to the amount of carbon currently released from fossil fuel emissions and deforestation combined. Such an effort would rapidly accumulate carbon for approximately 20 years. After this period, the plantations would gradually lose their ability to serve as a carbon sink but would continue to store the carbon already accumulated. The carbon stored in such trees would also need to be stored in a manner to inhibit decay, in order to prevent the stored carbon from being released into the atmosphere.

Box 8.1: Guatemala - Tree Plantations to Offset Carbon Emissions from a Coal-Fired Power Plant

In 1988, Applied Energy Systems (AES), a U.S. based electric utility, developed a tree plantation program in Guatemala to attempt to mitigate the carbon emissions from a new 183 MW power plant being built in Connecticut. As part of this program AES explored ways of offsetting the 15.5 million tons of carbon which would be emitted as carbon dioxide over the 40 year life of the plant. Working with several non-governmental organizations, such as CARE and World Resources Institute, AES developed a project consisting of 12,000 ha of woodlots, and an additional 65,000 ha of less densely planted agroforestry sites.

An analysis of this project suggested that the net carbon storage in woodlots and agroforestry plots would total approximately 16 million tons of carbon, thereby completely offsetting the emissions from the Coal fired plant. The total costs of this project were estimated at $16.3 million, resulting in a carbon storage costs of only $1 per ton of carbon, and representing approximately 5.8% of the costs of the power plant. These costs, however, do not take into account the full storage costs, or the amount of carbon sequestration which would have naturally occurred on the woodlots if the project had not been carried out. They also do not include a risk factor for potential project failure.

Construction of Power Plant:	
Construction Costs	$275 million
Emissions (387,000 t carbon/yr)	15.48 million
Sequestration Project:	
Cost:	$16.3 million
Carbon Offset (millions of tons of carbon):	
Net storage in woodlots	0.6
Natural forest carbon saved from burning	3.6
Net storage in agroforestry	1.7
Natural forest carbon saved by agroforestry	9.5
Natural forest carbon saved by fire protection	0.6
Carbon added to soils	0.3
Total	16.3

Because the wood produced by the woodlots was not stored long-term, the estimated carbon offset is actually only a short-term benefit; the carbon would be returned to the atmosphere through combustion of the wood or decay. More accurately, the long-term benefits of the project resulted from the amount of wood combustion and deforestation which was foregone by the project activities. Thus, this type of project can only reduce the increase in atmospheric carbon accumulation in the short-term (Trexler et al. 1989, Vitousek 1991).

8.16 While the use of wood in construction could be an effective form of storage, the amount of wood produced in any widescale production scheme would likely result in significant oversupply of timber products, and have significant market impacts on a global basis.

8.17 The planting of trees and subsequent use of such trees as firewood in local rural areas would not have any long-term impact on atmospheric CO_2, because the carbon would be released during burning. If, on the other hand, the biomass was used as a substitute for coal in power plants, the effect would be to lower overall emissions into the atmosphere by recycling carbon already emitted (See Figure 8.6).

8.18 The overall costs of storing carbon vary widely. In the United States, the costs of sequestering carbon through tree plantations ranges between \$10.40 and \$45.00 per ton of carbon. In addition, harvesting and storage of the wood to prevent decay would add an additional \$60 - \$120 per ton of carbon. Thus the range of costs of sequestering carbon in temperate climates rages from a low of \$70.40 per ton of carbon to a high of \$165 per ton.

8.19 In tropical climates, the efficiencies of storing carbon in the first 20 years of the plantation's life are about 50% higher due to faster growth. However, though no studies have been carried out, the cost of storing such carbon would also be expected to be higher because increased temperatures would lead to higher decomposition rates.

8.20 The key constraint in developing large scale programs for tree plantations relates to the availability of suitable land. Much of the land available for tree plantations is presently used for agricultural and pastoral production, and could not realistically be made available. In addition, it has been suggested that over the next 75 years, upwards of 20 million ha of new agricultural land will need to be made available to support the food requirements of the population inhabiting the tropics. Thus the increased competition for land for agriculture realistically precludes the opportunity for halting the increase in atmospheric carbon solely through tree plantations.

8.21 **Halophytes**. More recently, salt-tolerant terrestrial plants, referred to as halophytes have been considered as potential resources for sequestering CO_2. Halophytes are generally defined as plants which can tolerate a soil solution containing 0.5% or more sodium chloride (NaCl). Unlike trees, halophytes can be grown in areas too saline for use by agriculture. These areas include coastal deserts, inland saline basins, and salinized agricultural land. In addition, halophytes can be irrigated with seawater or brackish water which is not suitable for agriculture or drinking.

8.22 The total available land suitable for halophyte cultivation is estimated at 720 x 10^6 ha (See Table 8.3). Much of this land is relatively unproductive and often devoid of natural vegetation, due to the extreme salinity of the surface soils. Given the constraints of elevation, existing land use, vegetation cover, available water for irrigation, and soil type and slope, it has been estimated that 17% of the coastal desert and 15% of inland salt desert is usable for halophytes. In addition, 6% of existing agricultural land is unproductive due to secondary salinization from overwatering and would also be available for halophyte production (Glenn et al. 1991). This yields a more realistic total of 126 x 10^6 ha of land potentially available for halophyte production.

8.23 Halophyte plantations can sequester up to 5.5 metric tons of carbon per hectare, suggesting that if all the 126 x 106 ha of realistically available land were fully planted, carbon sequestration with halophytes could range as high as 693 million tons of carbon annually, or about 12% of annual carbon emissions from fossil fuel combustion.

Table 8.3

Estimated Total and Usable Land for Halophyte Production Worldwide (10^6 ha)

Region	Coastal Desert	Inland Saline Soils	Irrigated Land
Europe	0	3	13
Asia	31	119	165
Africa	230	81	9
N & Central America	7	2	27
S. America	5	13	7
Australia	22	36	2
CIS	0	171	12
% Usable	17	15	6
Amount Available (ha)	50	63	13

Source: Glenn et al. (1992a)

8.24 The costs of sequestering carbon through halophyte plantations has been estimated from large scale pilot projects carried out in the United States. These studies have shown that, based on irrigation requirements and farm costs, sequestration of carbon is slightly more expensive for halophytes than for tree plantations, but much less expensive when costs of long-term storage are included. In general, costs of carbon sequestration and storage through halophyte production range from $100 to $160 per ton of carbon sequestered.

8.25 In addition, halophytes may offer several other advantages over tree plantations in terms of carbon storage, although further experimental work is needed before these advantages can be fully proven. Because desert soils often have low amounts of organic matter, the crop can be plowed into the soil to increase productivity. The high salinity of the soil inhibits microbes in the soil from breaking down the carbon and releasing it into the atmosphere. Alternatively, the halophyte crop can be harvested for subsequent use in food and chemical production, although these uses will not reduce atmospheric CO_2 (See Chapters V and VI).

8.26 **Seaweeds.** The potential for seaweeds as carbon sinks is the least explored biomass production technique. The uncertainty of this technique stems from the lack of sufficient information on potential areas for seaweed production and the variables surrounding carbon sequestration rates, storage costs and technological suitability for developing countries.

8.27 The total usable area available for seaweed production from natural beds is estimated at 149,400 km^2 (Menard and Smith 1966). This represents about 5% of the nearshore (less than 30m in depth) area. In addition, seaweed production could also be carried out on floating farms anchored in waters 30 - 200 m in depth, increasing the area available by 1.17 million km^2. While no open-ocean seaweed farms for biomass are in commercial operation, they are considered to be both technically feasible and practical by experts (Rhyther 1985).

8.28 The amount of carbon sequestered by seaweed has been estimated at 31% of dryweight, with a mean yield of 16.7 dry ton of biomass ha^{-1}. This suggests a potential sequestration rate from seaweed farms of 5.2 ton of carbon ha^{-1} $year^{-1}$. The costs of production from seaweed farms have ranged from \$89 per dry ton to \$138 per dry ton in Taiwan. These figures indicate a sequestration cost of \$17 to \$26 per ton of carbon sequestered.

8.29 The greatest unknown associated with using seaweeds and halophytes in carbon sequestration involves long-term storage. In theory, the natural sloughing off of seaweed could be sufficient to sequester carbon in the ocean sediments (Berger 1977), however, this is currently unknown. If this is not sufficient, deep sea disposal will be required, which would increase the costs, using current technology, to a level of \$300 per ton of carbon sequestered (Glenn et al. 1991).

PROJECT SELECTION ACCORDING ECONOMIC COSTS AND BENEFITS

8.30 Although uncertainties remain, there is sufficient knowledge to justify prompt action to slow the emission of GHGs in the atmosphere, and in particular carbon dioxide. While the domestic costs and benefits of biomass projects can be valued, global benefits of reducing GHG emissions can only be physically quantified. Therefore, it may be assumed that these combined benefits exceed the relatively modest domestic costs of the transition to alternatives. This assumption implies that the domestic and global projects should be designed to maximize benefits rather than minimize the costs. A benefit maximization approach would focus on maximizing the impact that a given amount of resources would achieve, for instance, by selecting a biomass project that had the lowest abatement costs.

8.31 Suppose, all costs and benefits of a biomass project are known, and that one can determine the present worth of the costs, the domestic benefits, and global benefits using the same appropriate discount rate and period of analysis. Based on these assumptions, and depending on the project selection criteria, a project manager is faced by several project alternatives. These alternatives are mutually exclusive projects, and divisible projects.

8.32 **Mutually exclusive projects**: When selecting mutually exclusive project alternatives, a biomass project will always be preferred in terms of incremental cost. The incremental cost is the cost difference between two alternatives, and the decision rule is that if incremental benefits exceed incremental costs, the higher cost alternative should be chosen. Assume two alternative biomass projects competing for the same parcel of semi-arid land - one oilseed halophyte and the other a biomass crop (e.g. trees) - and that one alternative plan costs more but releases less greenhouse gases. The oilseed halophyte straw would be used for carbon sequestration (global benefit) and the seeds for human consumption (domestic benefit) has an annual rate of carbon storage which varies between 3.2 and 6.2 tons per hectare. The annual rate for tree plantations and other biomass crops is 5 tons per hectare (Glenn et al. 1991).

8.33 The non-separable costs, which are both incurred at the global and domestic level, are estimated at \$53 per dry ton of biomass (\$160 per ton of carbon) for seawater irrigation. These costs include the initial startup costs spread over the first ten years of farm operation. By comparison, other high-productivity energy tree crops are estimated to cost between \$30 and \$45 per dry ton (between \$60 - 120 per ton of carbon) spread over thirty years.[1] Hence, the production costs of halophyte biomass would be somewhat higher than that of trees, but not prohibitively so. Furthermore, oilseed halophytes contain biomass rich in nutritional value and contribute to diversifying the diets of the local population, as well

[1] While the costs of sequestering carbon through biomass production may vary from one source to the other, the cost ranges are similar.

as other properties valuable to various economic sectors. The incremental domestic benefits are expected to exceed by far the domestic incremental costs.

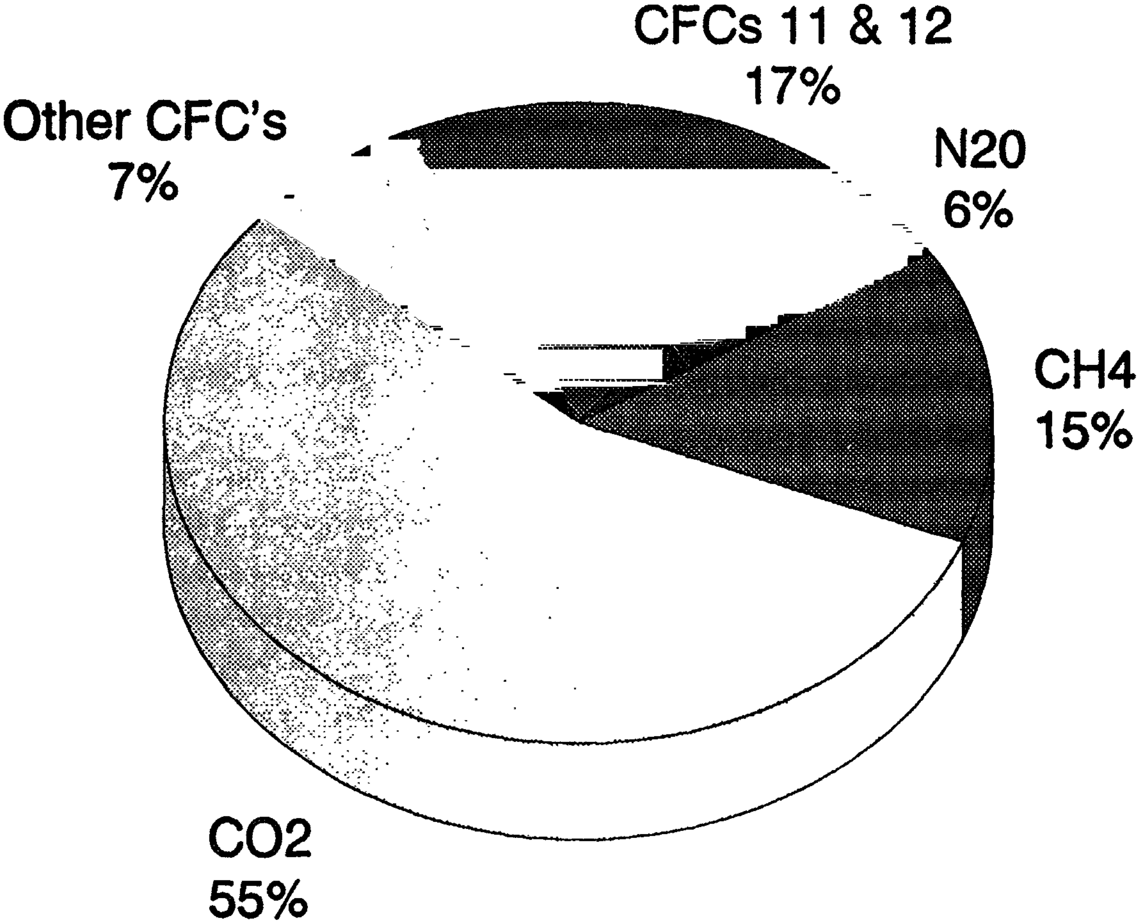
Table 8.4

Comparison of Costs between Halophytes and Trees

	Oil Halophytes (seawater)	Trees
Non-Separable Cost ($/tBiomass)	$53	$30-45
Cost ($/ha):		
Land Clearing	67.0	
Planting	1,296.0	data
Watering	5,251.4	breakdown
Maintenance	296.2	is not
		available
Separable Costs		
Harvesting (net of storage)	100.0	
Pretreatment		
Storage		
Processing		
Productivity (tC/ha/yr)	4.4	3-8
Carbon Storage (GtC/yr)	0.6	0.6-1.6
Cost ($/tC)	160	60-120

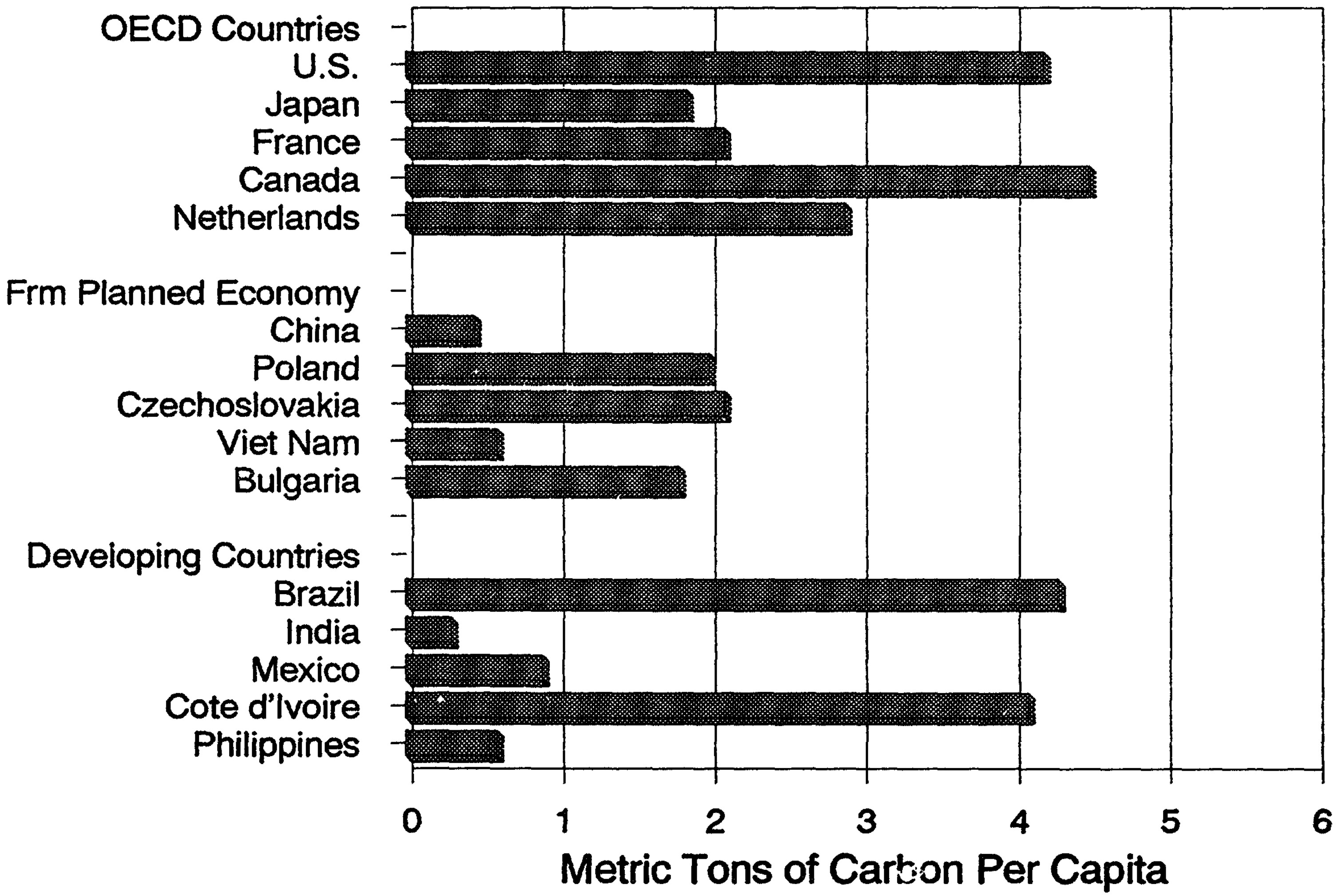
8.34 **Divisible Projects**: The case of divisible projects is a subset of mutually exclusive projects, where one is faced by selecting two mutually exclusive sub-components of a single project. For example, an energy production project could rehabilitate a fossil-fuel plant and as a sub-component develop local biomass fuels. These and other alternative project scenarios have been discussed earlier in Chapter IV.

Figure 8.1
Anthropogenic Global Contributions to the Greenhouse Effect



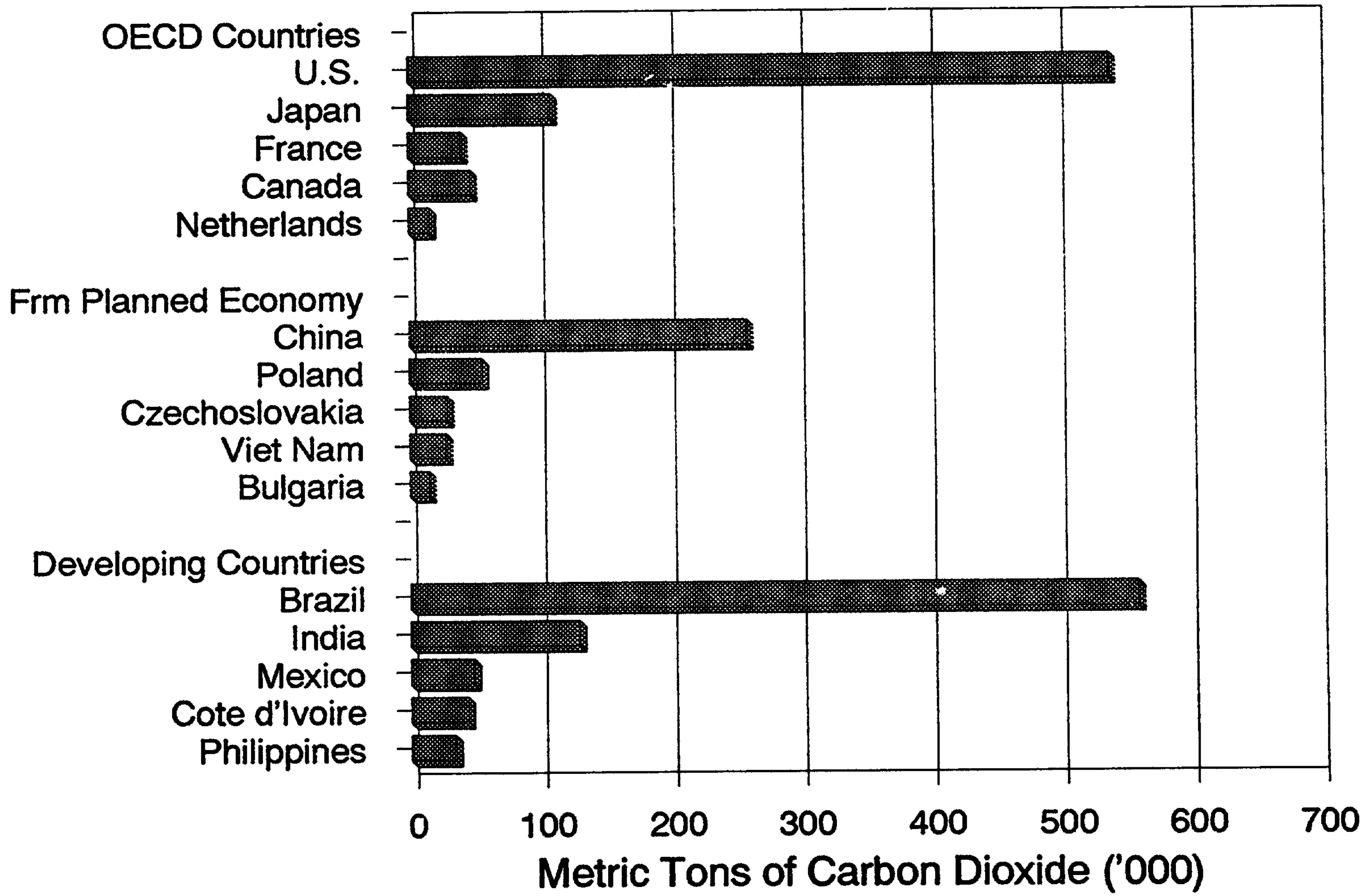
Source: IPCC. 1990.

Figure 8.2
Examples of Per Capita Net GHG Emissions



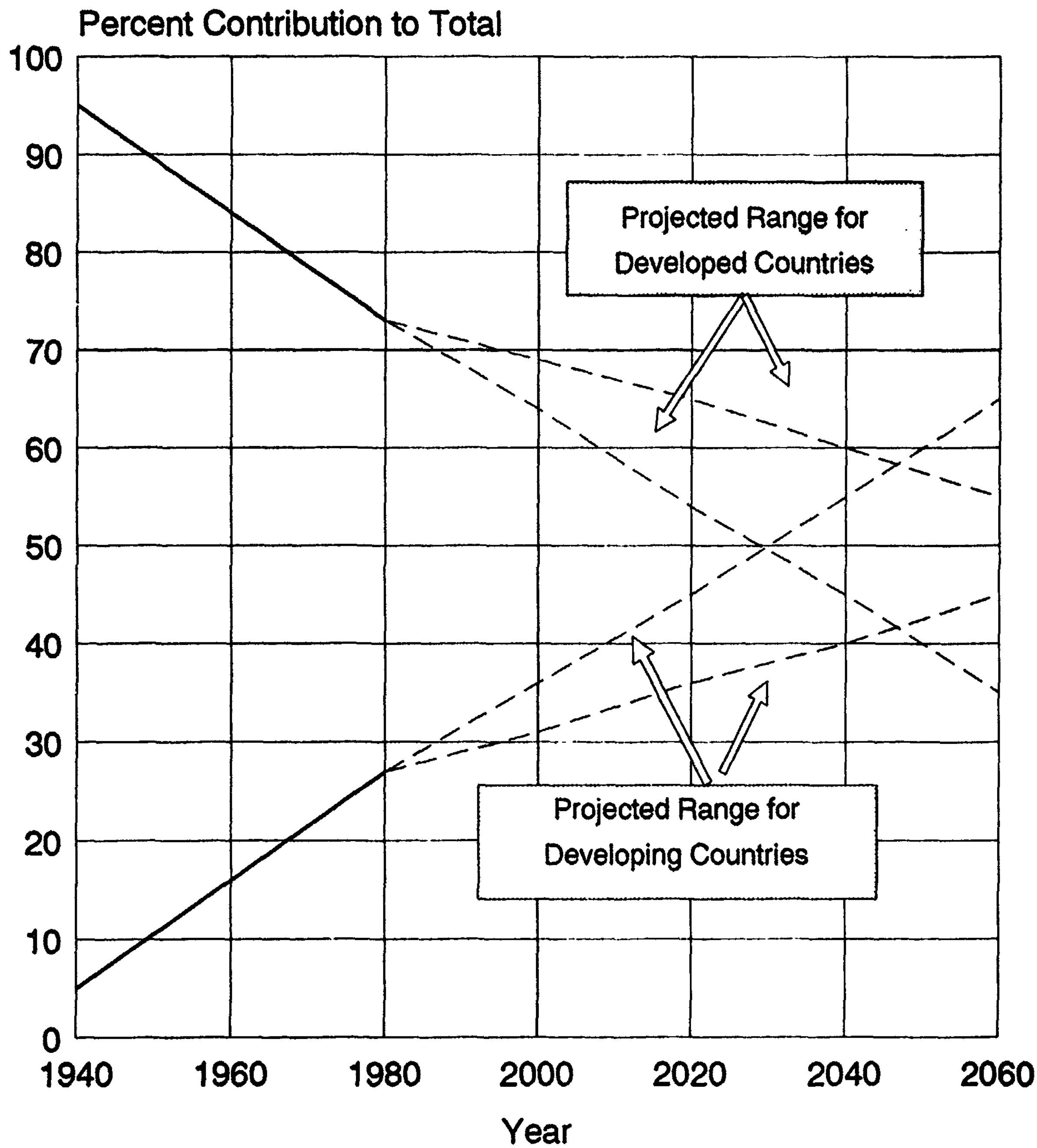
Source: WRI 1991

Figure 8.3
Examples of Net CO_2 Emissions, 1987



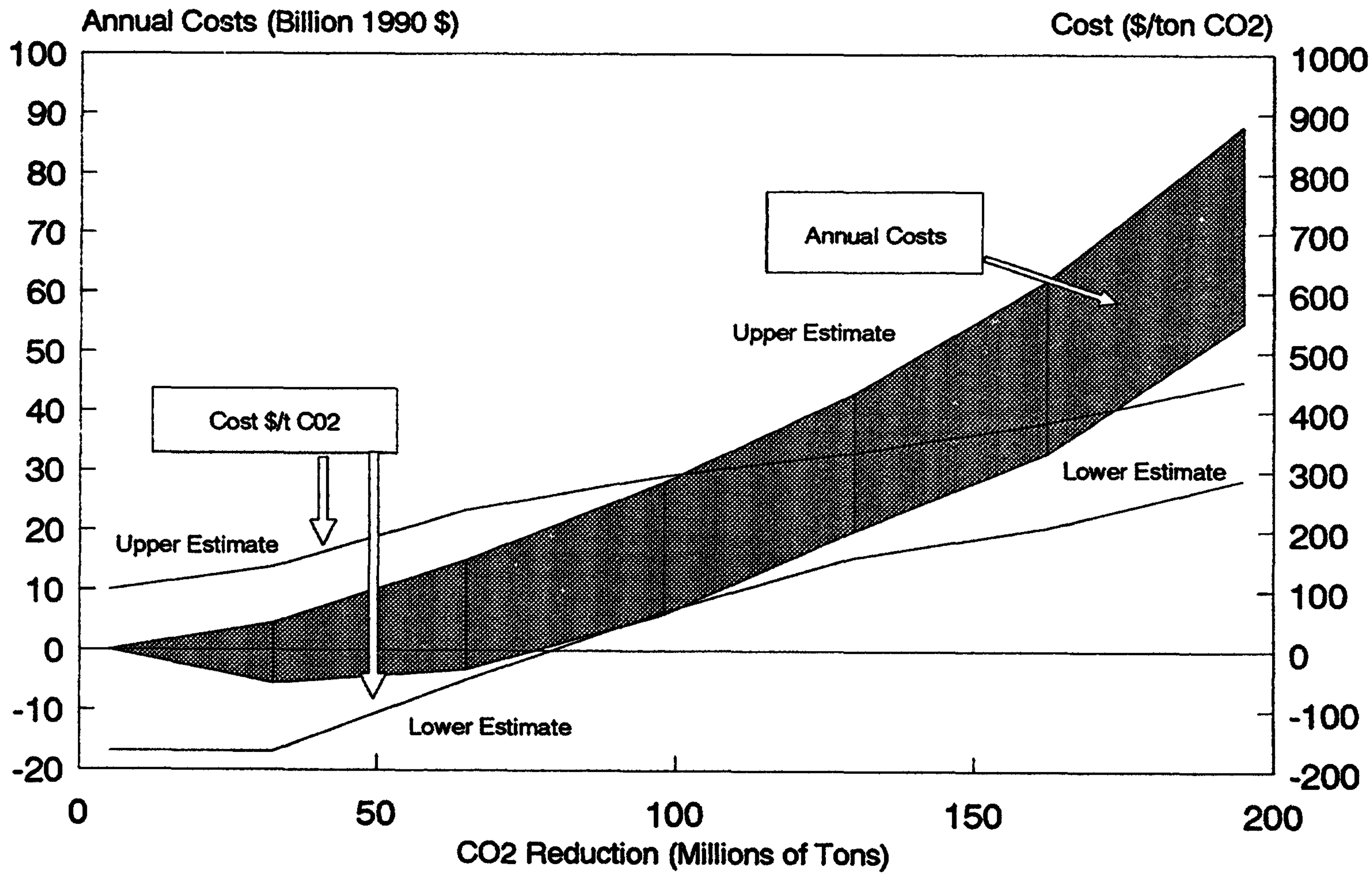
Source: WRI 1991

Figure 8.4
Contribution of Developed and Developing World to Total CO2 Emissions



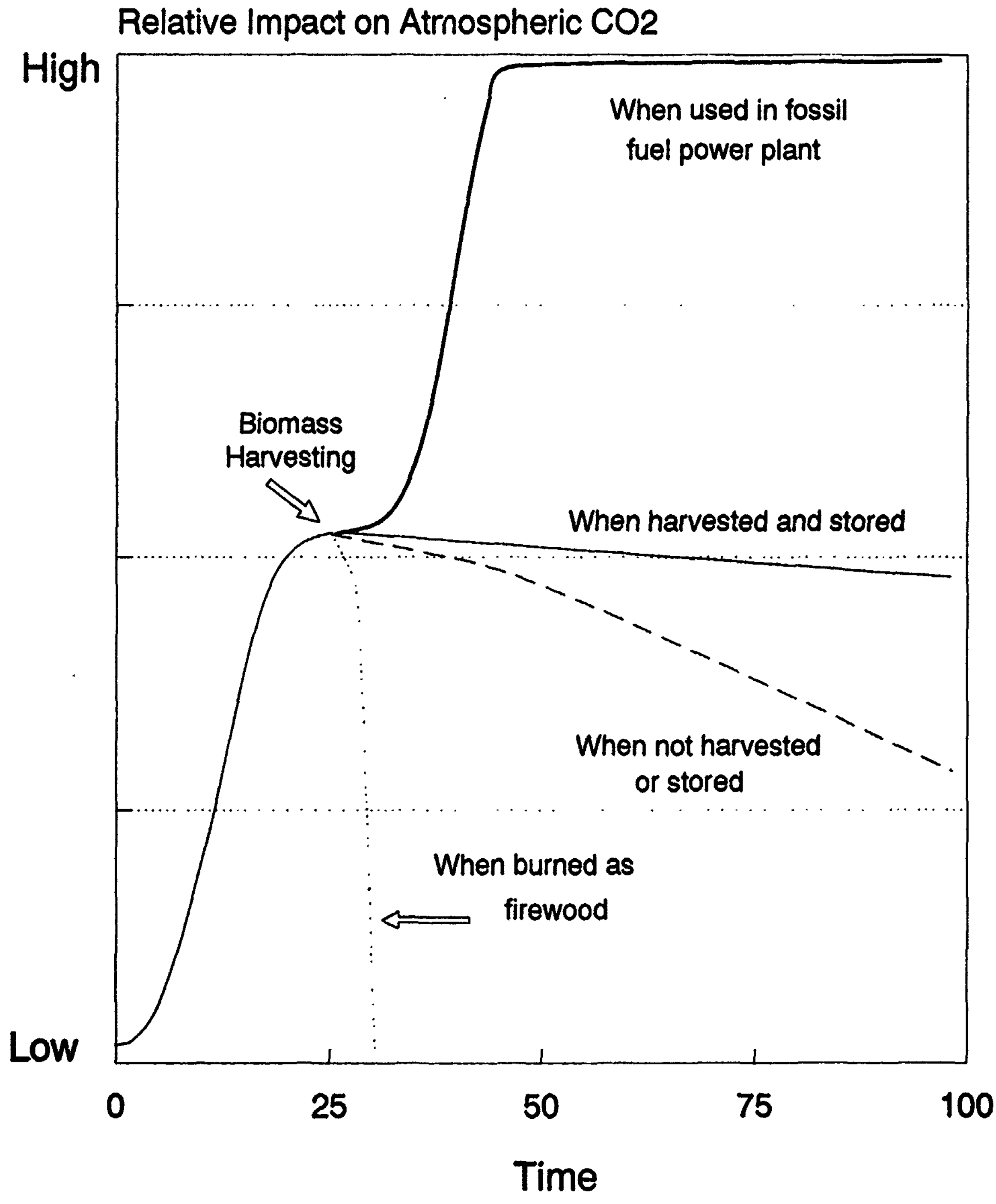
Source: Rotty & Masters 1985;
and Starr and Searl 1991.

Figure 8.5. Ranges of Short Term CO2 Reduction Costs in Year 2000 U.S. Electric Utility Industry



Data: EPRI 1991 and Van Orsdol 1992

Figure 8.6
Relative Impact of Biomass Use on Reducing Atmospheric CO2 Levels



CHAPTER IX

OPERATIONAL AND IMPLEMENTATION CONSIDERATIONS

9.1 Non-forest biomass crops can make a significant contribution to removing carbon from the atmosphere by increasing the productivity of desert areas, while simultaneously providing multiple economic and environmental benefits to the local community. The opportunities for using biomass to develop integrated approaches linking agriculture, industry, energy, health, and waste water management sectors, hold much promise. While the overall country program should take into consideration the domestic and global impacts of non-forest biomass projects, a sector by sector analysis would be most appropriate to evaluate the advantages and disadvantages of implementing these types of interventions.

9.2 Cultivation of indigenous species of seaweeds can be carried out from the subarctic zone in the north through the temperate zone down to the topical zone in the south, in both developed and developing countries. Cultivation of halophytes, however, is subject to more restrictions based on the local soil and water conditions. Tables 9.1 and 9.2 indicate the coastal and inland salt desert locations where halophytes can be grown. The total coastal desert land available for seawater irrigation of halophytes represents 494,000 km^2 and the inland salt desert suitable for brackish irrigation is 635,000 km^2. The total additional land of 1.3 million would be sufficient to sequester about 10% of annual carbon emissions. Data suggest that halophyte plantations are particularly suitable for the African, Middle East and South Asian regions, and to a lesser degree for the Latin American (Chile and Peru), Eastern European (former Soviet Union), and East Asian (China) regions (Figure 9.1).

9.3 Based on the analysis developed in this report, the main operational constraints involved in implementing biomass projects can be assigned to one of the following broad categories: technical, socio-economic, financial, and institutional.

PROJECT CONSIDERATIONS

Technical Concerns

9.4 Experience has shown that when indigenous macroalgal species and halophytes are used to capture atmospheric carbon the following conditions need to be considered in order to decide whether or not large scale development of biomass production will be possible.

- *Natural conditions*: Vast areas of shallow water or intertidal zones are necessary for large scale cultivation and production of seaweeds. Large scale halophyte cultivation is most suitable for large salinized areas with little or no natural vegetation, and access to salt or brackish water. In addition, a thorough understanding of the local and regional hydrological conditions is required.

- *Technological*: Continuous support and direction by phycological science and technology is the key link for setting up large scale production and utilization of seaweeds. Halophyte technology advancement would need input from multi-disciplinary teams consisting of irrigation specialists, hydrologists, agronomists, engineers, observation and monitoring specialists, and farmers.

9.5 Currently, because of the high installation and operating costs of seaweeds, particularly in open-oceans, it will be important to develop technologies whose costs are expected to decline greatly with experience in the field. Research is presently being undertaken in East Asia that has resulted in a large-scale prosperous macroalgal industry.

Socio-Economic Issues

9.6 **Employment and Income Generating Activity**: The production, harvesting and processing of seaweeds and halophytes is a labor intensive task and could be viewed as an important income generating opportunity for the local population in many developing countries. Studies in China, Korea and the Philippines have indicated that the production of seaweeds has contributed to the creation of about half a million family businesses employing over 1.5 million people (Neushul 1987). As is the case with most agricultural activities, biomass projects are subject to seasonal cycles, and at peak harvesting time, which for certain species occurs within a fairly short period, constraints of manpower, transport, and primary processing and storage need to be considered in the early stages of the project design phase.

9.7 In addition to evaluating the economic benefits, it will be equally important to determine the social impact of a biomass project on the local communities. For example, investments in coastal marine areas include restricted access to one or more of the sub-zones of the area, over-exploitation of species to meet demands of new markets, population displacement, and attraction of new settlements. Adjustment to these social changes often leads to additional environmental impacts elsewhere in the coastal marine zone. Therefore, it is suggested that an integrated approach be adopted to design a biomass project, to take into account the multi-sectoral, as well as transboundary impact of this type of operation.

9.8 **Health, Sanitation and Nutrition**: Certain products produced by the seaweeds and halophyte industries can have a beneficial impact on the diet of local populations, thus improving their health conditions. In China, *Laminaria* is used for seaweed cultivation because of its high nutritional value. Other microalgae (e.g. *Spirulina*), may be used to treat waste water, thus improving the local sanitary and ground water conditions. It is important to take into consideration the possibility of incorporating the use of biomass products and by-products into existing or new lending operations.

9.9 **Land and Water Regulations**: In many developing countries where traditional land tenure rules prevail, potential social conflict could occur between traditional land users and those developing large-scale plantations. In areas where halophytes are used to reclaim land, it is essential that the value be assessed and ownership be determined prior to the development (see Chapter 3, Box 3.3). Political issues surrounding international water regulations can also introduce an additional risk factor in the implementation of seaweed projects, particularly those undertaken in the open sea. For example, in Chile, there is at present no specific legislation governing the culture and harvesting of seaweeds for any genera, except *Gracilaria*. In the Philippines, and Indonesia, there are no effective formal mechanisms effectively regulating the harvesting/culture of *Eucheuma*. In general, the governmental bodies involved in addressing near-shore seaweed plantation issues are the ministries of economic development, fisheries and agriculture. Government participation in facilitating farmer leasing of production sites has been as much a barrier to success as a incentive. While halophyte plantations are grown on predominantly non-arable land, and seaweeds near or off-shore, these two production techniques do not compete for scarce agricultural land. However, measures should be taken early on in the project cycle to: (a) evaluate the environmental impact on soil and water, (b) assess the impact on plant and animal species loss, (c) clarify ownership issues, and (d) ensure that the needs of the local population are met.

Financial Issues

9.10 **Source of Foreign Exchange**: Biomass projects can be an important source of foreign income because of the commercialization of their products and by-products. For example, in the Philippines, the international market demand for the seaweed *Eucheuma* has stimulated the industry's development and increased foreign income revenues. Biomass can also be used as a source of renewable energy, thus reducing the country's dependence on imported fossil fuels.

Institutional Concerns

9.11 In the context of designing and implementing dual purpose projects, it is essential that: (a) the respective executing agencies, and beneficiary population groups be involved from the very beginning of the project cycle, and (b) their capacity to participate in decision-making, implementations, operations and evaluations be encouraged. The long-term benefits of biomass projects are an impact on the carbon dioxide levels in the atmosphere, while achieving at the domestic level a greater balance between the commercial exploitation of local resources to ensure that all development is environmentally sustainable.

9.12 A biomass project might require a global collaboration in terms of technology, institutional and policy developments to reduce the contribution of carbon dioxide in the atmosphere. For example, collaboration between carbon emitting companies in industrialized countries and NGOs, governments and development agencies in developing countries could be effective of limiting carbon levels through biotic sequestration, as was done in Guatemala (See Chapter VIII, Box 8.1). A similar mechanism could provide an opportunity for growing halophytes in arid or semi-arid regions to offset CO_2 emissions in other parts of the world.

OPERATIONAL WORLD BANK IMPLICATIONS

9.13 The rationale for GEF/GET funding of a biomass project is directly linked to the potential impact of such a project on the reduction and/or stabilization of greenhouse gases in the atmosphere, while simultaneously pursuing economic activities which will benefit to the society as a whole. While in theory, it is possible to allocate costs between domestic and global, in practice, the distinction between the two is less clear, because of our incomplete understanding, in particular, of the carbon cycle. In spite of these limitations, this cost allocation issue is critical in justifying funding from the global financing mechanism. In this context, given the limited availability of data on costs and benefits and because of the experimental character of this type of venture, it is suggested that pilot projects be implemented first to evaluate the success of biomass projects.

9.14 In order for biomass projects to be successful in developing countries, these operations should be designed within the context of an overall integrated developmental strategy linking the agricultural/fisheries and energy sector on the one hand, and industry, biotechnology and health on the other hand. The introduction of dual or multi-production systems (i.e. algae/shrimp/mussels) might be an method for raising productivity of the operation while reducing potential social conflicts and project risks.

Table 9.1

Coastal Desert Areas Usable for Seawater Irrigation of Halophytes

All areas met the following criteria: (1) flat topography below 100 m; (2) presently unused for agriculture; (3) having very low natural primary production (e.g. mangrove swamps were excluded); soil types feasible for halophyte cultivation. A (*) indicates areas that have been surveyed by halophyte collectors and (**) where test plots have been established.

Desert	Usable Area (km2)
1. Sorath Coast (Kawhiawar Peninsula, India)*	17,000
2. Little Rann of Kutch (India)*	5,000
3. Great Rann of Kutch (India)	125,000
4. Coastal Lowlands Surrounding Ranns (India)	3,300
5. Coastal Strip North of Gulf of Kutch (India)	6,600
6. Lower Indus Delta (Pakistan)*	10,000
7. Thar Desert along Indus (Pakistan)*	50,000
8. Las Bela and Makran Coast (Pakistan)	10,000
9. Plain of Dastiari (Pakistan/Iran)	5,000
10. Iranian Littoral of Arabian Gulf	2,500
11. Khuzistan Plain (Iran)	30,000
12. Mesopotanian Littoral (Iran/Iraq)	15,000
13. Hawr al Hammar (Iran/Iraq)	10,000
14. Arabian Littoral (Kuwait, Saudi Arabia,	
15. Quatar, United Arab Emirates)*,**	8,000
16. Sabkha Matti (United Arab Emirates)*	10,000
17. Al Kidan Sabkha (Saudi Arabia)	40,000
18. Coast of Gulf of Masirah (Oman)	10,000
19. Red Sea Coast, Aden to Jiddah (Saudi Arabia)*	9,000
20. Red Sea Coast, Port Sudan Area (Sudan)	2,500
21. Danakil Depression (Ethiopia)	5,000
22. Basso Guiba (Somali)*	4,000
23. Dead Sea (Israel/Jordan)*	1,000
24. Nile-Sinai Littoral (Egypt)*,**	6,000
25. Qattara Depression (Egypt)	
26. Birkat Qarum (Egypt)	1,000
27. Desert of Sirte (Libya)	10,000
28. Sabkha Al Qunayyim (Libya)	5,000
29. Chott Melrhor (Algeria)	5,000
30. Spanish Sahara & Mauritania Littoral	27,000

(cont.)

31. Angola Littoral & Namib Deser (Angola/	
32. South Africa)*	8,000
33. West Coast Australia*	26,000
34. South Coast Australia*	18,000
35. Vizcaino Desert (Mexico)*	500
36. Magdelena Desert (Mexico)*	500
37. Colorado Delta & Altar Desert (Mexico)*	1,000
38. Coastal Sonoran Desert (Mexico)*,**	3,600
39. Peruvian Lowlands & Loams, Atacama (Peru/ Chile)*	4,000
Total	494,500

Source: Glenn et al. (1991)

Table 9-2

Inland Desert Areas Usable for Seawater Irrigation of Halophytes

Areas met the same criteria as coastal lend except: elevation above seawater was not a factor; and irrigation supply was considered to be saline groundwater. A (*) indicates areas where germplasm has been collected; and (**) indicates where test plots have been established.

Desert	Usable Area (km2)
40. Caspaian/Aral Basin (USSR)	156,000
41. Kavir (Iran)	31,250
42. Lut (Iran)	10,500
43. Sistan (Iran)	12,500
44. Rajasthan (India)*	20,000
45. Niger Basin (Niger)	40,000
46. Salamat & Baquirmi (Chad)	15,000
47. Rift Valley (Kenya, Burundi)*	7,500
48. Darfur, Sudd & Upper Nile (Sudan)	45,000
49. Nukatini Flats (S. Africa)*	2,500
50. Tigris/Euprates Valley (Iraq)	8,500
51. Badiet esh Sham (Syria, Jordan)	20,000
52. Great Salt Lake (USA)*	2,500
53. Salars of Bolivia, Argentina, Chile, Peru *	92,500
54. Rio Grande del Norte (Brazil)*	9,000
55. Lop Nur (China)	5,000
56. Turfan Depression (China)	5,000
57. Quidam Pendi (China)	20,000
58. Lake Eure Basin (Australia)	120,000
Total	625,250

Source: Glenn et al. (1991)

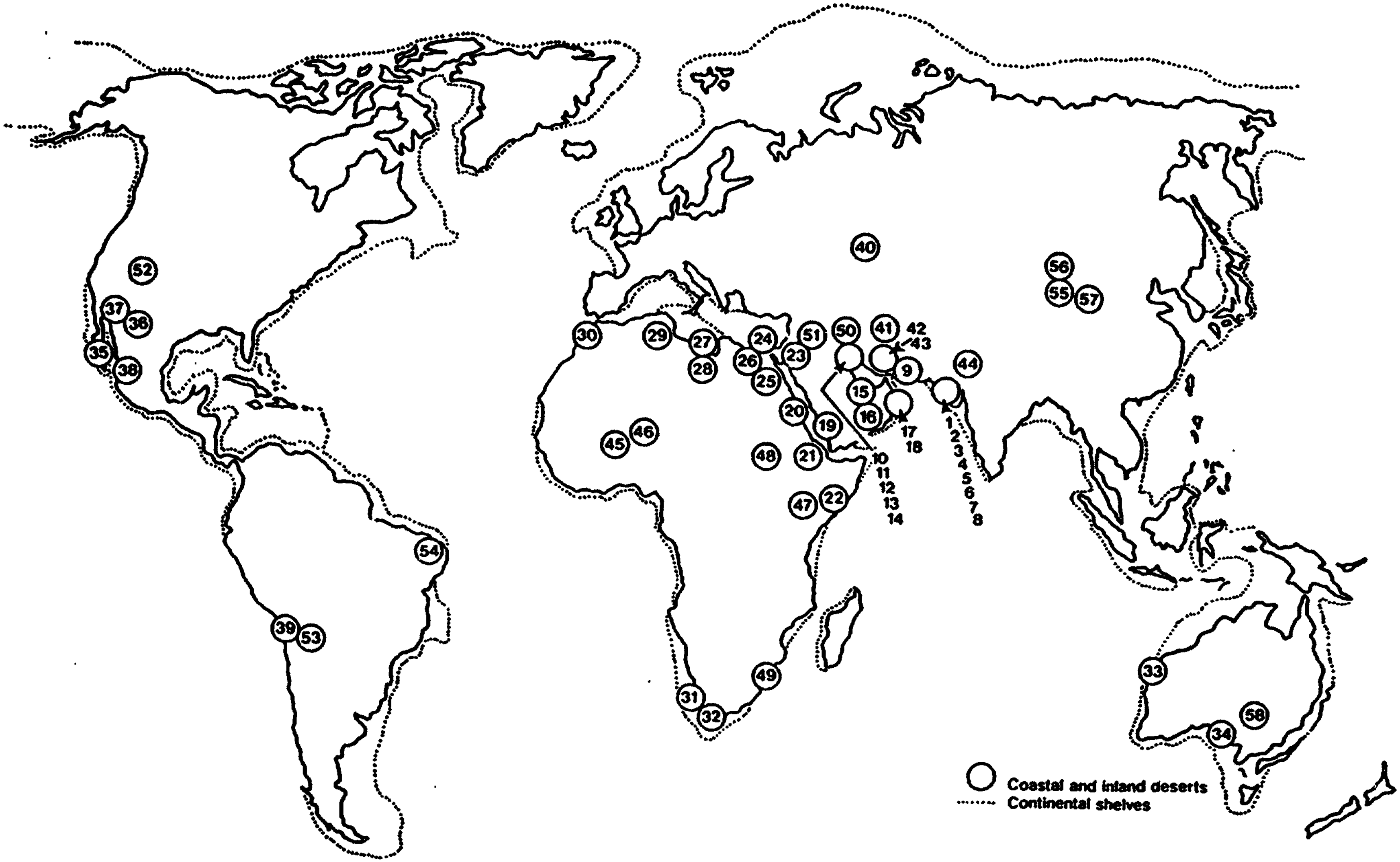


Figure 9-1. Coastal and inland desert locations where halophytes can be grown. Numers refer to sites in Tables 9-1 and 9-2 in text. (Source: Glenn 1991a)

CHAPTER X

CONCLUSIONS AND RECOMMENDATIONS

COMPARISON OF COSTS AND BENEFITS OF NON-FOREST BIOMASS PROJECTS

10.1 Biomass projects are labor intensive, providing employment opportunities in many developing countries. Biomass projects promote greater uses of local natural and human resources, which is consistent with the World Bank's overarching objective of reducing poverty. Additionally, non-forest biomass projects can have important domestic and global environmental benefits. This Chapter provides a summary and comparison of the costs and benefits of non-forest biomass projects for land reclamation, energy production, food production, chemical production and pollution monitoring. It also assesses the costs of sequestering CO_2 and evaluates the World Bank operational implications of implementing non-forest biomass projects. A summary comparison of the economic and environmental domestic and global costs and benefits of using non-forest biomass in the five project types is presented in Table 10.1.

Land Reclamation and Habitat Restoration.

10.2 Land reclamation with halophytes and habitat restoration through the use of halophytes and seaweed can have both global and domestic benefits depending on the fate of biomass produced. The global benefits reflect the proportion of biomass stored versus consumed, and depend on the development of long-term storage methods (e.g., plowing under of halophytes, deep sea storage of seaweeds). The practical duration of this storage, however requires further research. The existing data do suggest, that under saline conditions, long-term storage of carbon is feasible in terrestrial ecosystems.

The domestic benefits and costs are detailed below:

10.3 **Halophytes.** A number of species of halophyte can be used for land reclamation by reducing the salt levels of both intrinsically salinized soils and salt-affected soils resulting from secondary salinization. Such biological desalination has a very low domestic economic cost if irrigation is applied appropriately and efficiently, and/or species adapted to local nitrogen and water availability are used. Alternatively, modification of irrigation techniques with conventional crops includes construction or alteration of irrigation drainage networks and increased irrigation water for leaching the soils, both of which are associated with economic and environmental costs (e.g., negative impact on groundwater quality). Halophytes can be used to provide ground cover to stabilize soils in vegetationally barren land, such as dried up lakebeds and abandoned agricultural fields. Furthermore, reclamation or restoration projects using halophytes native to the project area can benefit from local botanical knowledge, require small technological inputs, and reduce the potential damage to local biological diversity through species invasions. Thus, reclamation and restoration projects are considered as having low costs and high domestic and global benefits.

10.4 The major potential domestic environmental cost of halophyte production in land reclamation and restoration efforts relates to the impact on ecosystem functions of the region. As with other types of reclamation, this constraint can be minimized by project managers selecting appropriate sites for the production, obtaining critical information necessary to an integrated groundwater management approach (Beltran 1978), and by the use of native species. Commercial availability of native species may limit restoration efforts. Therefore, the early establishment of nurseries for propagation of native plants, as well as field trials on the cultivation of these plants (Glenn et al. 1985) should increase the success of these projects.

Table 10.1

Summary of Costs and Benefits of Non-Forest Biomass Projects[1]

	Habitat Restoration	Energy Production	Food Production	Chemical Production	Pollution Monitoring
HALOPHYTES					
Domestic Costs:	LOW	HIGH	VARIABLE	N/A	LOW
Domestic Benefits:	HIGH	HIGH	HIGH	N/A	HIGH
Global Costs:	LOW	HIGH	LOW	N/A	LOW
Global Benefits:	HIGH	HIGH	NONE	N/A	HIGH
SEAWEEDS					
Domestic Costs:	HIGH	HIGH	LOW	LOW	VARIABLE
Domestic Benefits:	LOW	HIGH	HIGH	HIGH	HIGH
Global Costs:	VARIABLE	HIGH	VARIABLE	VARIABLE	HIGH

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[1] This summary table represents generalized estimates of the relative costs and benefits of the five project types. The estimates are based on the data compiled from case studies presented in this report, as well as from unpublished sources. The estimates represent the authors "best guess" as to the likely costs and benefits accruing from a project. However, these estimates may differ from those actually realized during a project, and will be impacted by project design, local environmental and economic conditions, and other external factors. Note: Due to methodological issues related to assigning global environmental costs and benefits an economic value, it is assumed that the global costs and benefits are solely environmental. The domestic costs and benefits, however, are both economic and environmental.

10.5 **Seaweeds.** Seaweeds have not been used extensively in habitat restoration, with the exception of seabed protection in and around harbors. In the developed world, the costs of such restoration have been linked with other economic benefits, such as the protection of high-value coastal lands. Thus, the costs of such restoration have been high in developed countries, and have been offset by local economic benefits. In the developing world, the costs would be lower, due to lower labor costs. The global costs are variable, depending on whether seaweed requires deep sea disposal for long-term carbon storage.

Energy Production

10.6 The use of halophytes and seaweeds in energy production can have a greater impact on reducing carbon emissions than any of the other techniques explored in this report, when the biomass fuel is used as a substitute to coal and other fossil fuels. The use of such renewable fuels appears to have the highest incremental global benefits in terms of carbon storage as well as the highest economic costs associated with the project startup. The domestic economic benefits of energy production are an increase in local employment opportunities, a reduction of importation of energy and petroleum products, a diversification of economic activity, and the opportunity for localizing energy production. The combustion of such biomass can be carried out using traditional combustion techniques, thus minimizing the need for expensive and risky importation of technology.

10.7 **Halophytes.** In the case of halophytes, the largest production cost is the irrigation cost which is composed largely of energy and labor. For these reasons, the domestic and global costs of cultivating halophytes for energy production are considered low. The domestic and global benefits are considered high because use of these fuels offsets the requirement of using fossil fuels in energy production. (See Table 10.1)

10.8 **Seaweed.** The cost effectiveness of energy production from seaweeds is largely determined by the operating costs for the fuel production, of which labor is the largest single item. With the low-cost labor available in many developing countries, this suggests that projects could leverage the profitability of an energy production system through the use of low-technology, labor intensive production techniques. As with halophytes, the global benefits are considered high, because of the offset in release of CO_2 from the burning of fossil fuel.

Agricultural Production

10.9 Food production projects have multiple domestic benefits for local communities. They provide job opportunities to small farmers, improve diets of the population, treat municipal wastes, and supplement the family income. Halophytes and seaweeds provide high nutritional value for food, fodder and forage without competing for arable land. As global demand for seaweed and halophyte food products increase in the developed countries, developing countries could produce these crops to shift away from conventional agricultural products (i.e. cocoa, coffee) which have deteriorated in price over the past two decades. The advantage of using halophytes and seaweeds for domestic agricultural production is that there are other uses to these biomass crops, reducing the domestic economy to the fluctuations of global food market prices.

10.10 While food production may have a number of domestic benefits, the global benefits are relatively small. Since much of the food production is consumed, the carbon stored in the plant is converted to methane and carbon dioxide in human and animal digestion. As a result, no long-term storage of carbon occurs and there are little or no long-term global benefits.

10.11 **Halophytes.** Halophytes have relatively low nitrogen demands in comparison to conventional agricultural crops. However, the level of fertilizers which are required may represent 35% of total production costs. The other major cost of halophyte production, irrigation, will also vary according to whether relatively low-cost seawater is available. As a result, the domestic costs of food production are variable, depending on the quantities of fertilizer required as well as irrigation techniques (Table 10.1).

10.12 **Seaweed.** Seaweed production in developing countries has largely been carried out by the private sector and artisanal groups. Therefore, the domestic benefits are greater than the domestic costs. This suggests that no incremental costs are related to the domestic production. However, since much of the carbon captured by seaweed is released through respiration, the global benefits of food production from seaweeds are low.

Chemical Production

10.13 **Halophytes.** Little work has been carried out on the use of halophytes for chemical production. As a result, no assessment of costs and benefits can be carried out at this time.

10.14 **Seaweeds.** The use of seaweeds in chemical production is already well advanced, with many corporations in the private sector developing significant business opportunities. While the costs of such production are proprietary, the high demand for such products does suggest that the use of seaweeds for chemical production is profitable. This suggests that the domestic benefits of chemical production are high, compared to domestic costs. Most of these private sector businesses collect wild seaweed and do not incur production costs. The few entities which farm seaweed for chemical production, such as in the case of Namibia, are profitable, indicating that the economic costs of production are lower than the economic benefits.

10.15 From the global perspective, the costs of seaweed production are dependent on the ultimate fate of carbon captured in the plant. Chemical production extracts the cell contents from the plant, leaving the cell walls and plant material as a by-product. As this by-production contains most of the carbon captured through sequestration, its disposal is a critical factor in estimating the global costs. At present, it appears that this by-product would need to be disposed of in deep-sea sediments, in order to ensure long-term carbon storage. Therefore, the global costs and benefits would be high if such disposal were carried out. Without such disposal, the global benefits would be minimal.

Pollution Control and Monitoring

10.16 **Halophytes.** Several species of halophytes show particular promise as biofilters for some pollutants. Though still experimental, the technique of using halophytes as a secondary pollution and desalinization system have relatively low domestic costs, except for the labor associated with building drainage and irrigation canals. However, with low labor costs in many developing countries, the costs associated with such construction are relatively low.

10.17 Perhaps the greatest environmental cost is the 50% leaching fraction associated with the initial experiments, resulting in the loss of half the water volume. This loss of water in the cleaning process may be critical in some areas.

10.18 The primary risks associated with such projects center on the ability of halophytes to effectively accumulate the pollutant in question, and the impact of such a project on local and regional water quality. However, if this information indicates that halophytes are appropriate for such a system, the low domestic costs (of labor) combined with the high global and domestic benefits, should promote the financing of such a project from global and local funding sources (See Table 10.1).

10.19 **Seaweed.** The biological basis for controlling and monitoring marine pollution using seaweeds is well known. The domestic costs could be relatively low, depending on how seaweed is to be treated for carbon storage. If long-term carbon storage requires the collection and disposal of biomass to prevent carbon release, then the additional costs of using the technique for pollution prevention would be relatively low. If, on the other hand, the natural sloughing off of seaweed is sufficient for carbon storage, the domestic costs of pollution control would be much higher. This is because the domestic need for harvesting the pollution and preventing it from accumulating in the food chain would be considered a domestic, rather than global, cost.

10.20 In summary, the available evidence suggests that energy production, and habitat restoration provide the greatest global benefits from halophyte and seaweed projects. Pollution monitoring and filtration may have global benefits, but these can only be determined with future field trials under controlled conditions. Land reclamation can lead to a broad spectrum of subsequent uses, including habitat restoration. The use of seaweeds and halophytes for food and chemical production have little or no global benefits on greenhouse gas abatement.

CARBON SEQUESTRATION COSTS OF BIOMASS PROJECTS

10.21 Global carbon emissions are currently estimated at approximately 5.5 billion tons annually. Both developed and developing countries are among the major producers of carbon dioxide. The major sources of carbon emissions are fossil fuel combustion and deforestation. A practical program to reduce the increases in atmospheric carbon, and other greenhouse gases, is required to prevent long-term global warming. Such a program will require both the reduction of emissions from fossil fuel combustion, as well as the use of carbon sequestration through biomass production. This program will require the participation of both developed and developing countries to be effective.

10.22 The sequestration of carbon through biomass production has been explored using tree plantations, halophyte plantations and seaweed production. The use of tree plantations is the most fully explored technique. The costs for this technique generally range between $10 and $40 per ton of carbon sequestered. The major constraint of carbon sequestration with trees is the limitation in arable, and potentially arable, land available for such plantations. Because of competition with agriculture for arable land, it appears unlikely that a substantial portion of carbon can be sequestered by tree plantations. Additionally, the costs of long-term carbon storage of such carbon and the practicality of storing massive amounts of wood and wood products requires additional exploration.

10.23 Halophyte sequestration, while showing promise, is still somewhat experimental. The costs of sequestering carbon through halophyte plantations is estimated at between $100 and $160 per ton of carbon. While more expensive than tree plantations, halophytes production does not require the use of arable land or fresh water, key limiting factors for carbon sequestration using trees. Halophytes use "free" resources: arid land and seawater or brackish water. However, halophytes may require some inputs traditional to agriculture, such as fertilizers. Long-term storage of carbon is relatively simple; plowing the biomass back into the soil aids in increasing long-term productivity of the soil and, under saline conditions, does not result in significant release of carbon from the soil (Glenn, pers. comm). Given the available land for halophyte production, this technique could realistically sequester up to 10% - 15% of the annual emissions of carbon from fossil fuel combustion and deforestation combined.

10.24 Seaweeds are the most experimental technique explored in this report. Theoretically, seaweeds could sequester upwards of 15% of annual carbon emissions. The primary constraint with seaweeds relates to the technique for long-term storage of carbon. If the natural sloughing off of seaweed biomass results in the long-term storage of carbon in ocean sediments, the cost of seaweed production is competitive with halophytes ($100 - $160 per ton of carbon). If, on the other hand, this storage mechanism is insufficient and the collection and deposition of seaweed biomass in the deep ocean is required for long-term storage, then the costs of sequestering carbon with seaweeds increases to about $300 per ton of carbon, making cost of this technique prohibitive using existing technology.

10.25 Biomass crops can also be used to develop local economies. All costs associated with the production of biomass can be classified as non-separable (both global and domestic) costs. Costs incurred for the development of the local economies involving land restoration, food -, energy -, industrial chemical production, and pollution control are strictly domestic, whereas costs incurred to reduce the emissions level of CO_2 are strictly global. These two categories of costs can be classified as separable. Limitations on the technical knowledge about using biomass for carbon sequestration as well as for domestic purposes, make it difficult to separate costs between local and global categories in some instances.

10.26 Developing biomass projects provide great domestic opportunities to reduce foreign dependence on energy sources and other traditional commodities (e.g. food and industrial products). Carbon sequestration projects, because of their multiple uses, are suitable for providing integrated approaches for food/feed/fuel byproducts as well as habitat restoration and pollution control. Evidence suggests that renewable energy biomass projects incur the greatest domestic incremental costs, but also provide the greatest global benefits. When selecting mutually exclusive projects for carbon sequestration, such as halophyte crops or tree plantation, it appears that despite the higher incremental costs associated with halophytes, the combined domestic and global benefits are higher, thus, introducing a comparative advantage for global funding mechanisms.

IMPLICATIONS FOR BANK OPERATIONS

10.27 Non-forest biomass projects can make a significant contribution to remove carbon from the atmosphere by increasing the productivity of desert areas, while simultaneously pursuing economic activities involving multiple benefits to the local communities. Research has pointed out that the cultivation of indigenous species of both seaweeds and halophytes could make productive use of 1.3 million km^2 (Glenn et al. 1991).

10.28 Because of the multi-dimensional character of these type of operations, it is suggested that integrated approaches be developed at the national level, and that a sector-by-sector strategy be adopted to implement the projects. Projects should be explored at a pilot basis to collect more information from design through evaluation phases. In addition, biomass components could be integrated into on-going lending operations to mitigate the negative impacts on the environment.

10.29 The major constraints to implement biomass projects can be identified as technical, socio-economic, financial and institutional.

- **Technical**. It is essential that natural conditions be appropriate for this type of cultivation. For halophytes, access to saline water is a critical prerequisite. Seaweeds are subject to fewer constraints, however, water pollution is a potential issue. New production technology have evolved which may make large scale production technically and economically feasible.

- **Socio-economic**. Biomass projects provide important employment and income generating activities, and intended beneficiaries should be identified prior to project design. As with other agricultural activities, biomass projects are subject to seasonal cycles, therefore it is important to take into account labor, transport, and distribution bottlenecks. All issues related to land ownership, international water and land regulations need to be addressed early on in the project cycle to avoid failure in the implementation.

- **Financial**. Biomass project can be an important source of foreign income as a result of the product and by-product commercialization or provide export savings by replacing imported fossil fuels with renewable local biomass energy.

- **Institutional**. The respective government institutions (e.g. Ministry of Agriculture, Fisheries, Planning, Environment, etc.), NGOs as well as local associations need to be involved at all levels of the project cycle to ensure project sustainability.

10.30 This study suggests that biomass projects for energy production and habitat restoration have the greatest global benefit. Other biomass projects for food and chemical production are not truly "dual-use" operations because their global benefits are less to the extent that the majority of the biomass (carbon) is harvested and consumed instead of stored. The challenge is to balance these proportions of biomass consumed versus stored for any given dual purpose project at a given sight (e.g., combination of food and energy production). As a result, these type of hybrid interventions are more likely to meet the selection criteria for global funding. This report recommends that non-forest biomass projects be explored as potential Bank investments in the future, despite the methodological limitations of separating and quantifying global from domestic costs and benefits, as well as the technical, institutional and socio-economic constraints involved in the implementation of such hybrids. Using non-forest biomass (particularly halophyte plantations) for carbon sequestration, as well as a substitute for fossil fuels reduces the increases in atmospheric carbon and other greenhouse gases, and increases the availability of land for agricultural and pastoral activities.

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