UNIVERSITY OF CALGARY

Developing an Eco-Industrial Park in the Lloydminster Area

by

Sumita Majumdar

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

CALGARY, ALBERTA

MARCH, 2001

0-612-65002-2

Abstract

Eco-Industrial Parks (EIPs) offer a means to use one facility's waste as another's input, thereby reducing raw materials required and waste generated. This study identified potential byproduct synergies and resource linkages in the Lloydminster area. A feasibility study was conducted to determine the best facilities to colocate in the Lloydminster EIP. Economic and environmental benefits were calculated for the entire EIP, along with a sensitivity analysis. In addition, an impact assessment was conducted using fuzzy cognitive mapping, accompanied by a sensitivity analysis.

The Fish Farm, Greenhouse and Warehouse were determined to be the highest ranked facilities to colocate within the Lloydminster EIP. The development of this EIP would result in significant cost savings and greenhouse gas emission reductions. The impact assessment found that utilizing byproducts/wastes provided by existing facilities significantly decreases waste disposal, but may lead to increased pollution due to increased activity level as additional businesses are established.

Acknowledgments

I would like to extend my deepest gratitude to my supervisor, Dr. Gopal Achari, for his advice, guidance, and continuous support throughout this thesis project. I would like to thank my thesis examiners, Dr. Patrick Hettiaratchi and Mr. Jim Leslie for their constructive criticisms, which have helped improve this thesis. I am also very grateful for the financial support from the sponsor of this project, Husky Energy Inc., and all the employees who provided information and help for this study in various ways. Special thanks to Barry Worbets, Dave Kay, and Ron Schmitz for their kind help, support and valuable suggestions from the initiation of this project. And for all the other people who have helped me along the way, their contribution to this research is very much appreciated. Finally, I wish to express my deepest gratitude to my family, fiancée and my loved ones for their patience, tolerance and understanding during my studies at the University of Calgary. Their love and support was the inspiration upon which this thesis was built. Thank you.

Dedication

To my family and fiancée, for all your love and support.

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CHAPTER 1

INTRODUCTION

1.1 Background

The earth has a finite amount of raw materials and there is a limit to the amount of pollution and waste the earth can absorb. Recognition of these limitations leads us into the field of industrial ecology. Industrial ecology is defined as "an approach based upon systems engineering and ecological principles that integrates the production and consumption aspects of the design, production, use and termination (decommissioning) of products and services in a manner that minimizes environmental impact while optimizing utilization of resources, energy and capital" (Manahan, 1999). Industrial ecology is a sustainable development concept that seeks to minimize waste generation and promotes byproduct utilization in industrial areas, reducing the impact of human activity on ecosystems. One of the most important concepts in industrial ecology is to develop symbiotic relationships between industries by making one facility's waste another's raw material. This is the basis of Eco-Industrial Parks (EIPs) (Frosch, 1995). EIPs are characterized by a network of synergistic resource linkages among facilities within a defined geographical area.

EIPs are designed such that industrial areas are developed mimicking a natural ecosystem. Natural ecosystems are self-contained and self-sustaining. They produce zero waste through complex interactions of food chains. EIPs adopt a similar integrated approach that provides industries with the potential to minimize wastes. This involves routing waste materials and energy from the sources of those wastes to other facilities that use them as feedstock. This results in a shift from wasteful open-linear systems to efficient closed-loop systems (Garner & Keoleian, 1995).

The development of an EIP offers a number of advantages to industries. Byproduct synergy decreases the amount of virgin resources consumed, and in many cases secures less expensive sources of input materials. EIPs can decrease the volume of waste that requires disposal. In the process of developing an EIP potential markets for byproducts may be identified. Therefore, EIPs turn environmental concerns into possible business opportunities.

EIPs also promote cooperation between companies. Companies working together facilitate the creation of new solutions and methods to deal with waste streams. Cooperation also allows companies to pool together similar waste streams that individually would not be feasible to use as input for another facility.

The waste exchange networks of EIPs are formed by engineered systems or self-organized systems. Self-organized networks are formed as needed to meet the needs within that area. A self-organized EIP is the result of gradual development of cooperation between neighboring facilities and the local municipality. Engineered systems emphasize local and regional resource and energy flows and seek maximal efficiency in their interactions (Cote & Cohen-Rosenthal, 1998). The goal of engineered EIPs is to produce zero waste.

1.2 Objectives

The principle goal of this project is to develop an EIP for the Lloydminster area. The specific objectives of this project are:

- Evaluate the various facilities in the Lloydminster area in terms of their input requirements and waste byproducts;
- Determine the synergistic relationship between various facilities in the Lloydminster area;
- Develop an engineered EIP in the Lloydminster area; and
- Assess the impacts of the EIP.

1.3 Scope

This study focused on industries located in the Lloydminster area, from township 49 to 50 and range 1 in Alberta to range 27 in Saskatchewan. The study area is depicted using AccuMap in Figure 1.1.

The Lloydminster area was chosen for this study because it reflects a typical industrial area in the process of increasing development and growth. Lloydminster has increased in population from four thousand people in 1951 to over twenty thousand people in 1998 (Lloydminster Economic Development Authority, 1998).

The Lloydminster area is both energy and agriculturally intensive, which makes a unique blend for an EIP. Lloydminster holds the distinction of being the only Canadian city dually incorporated in two provinces.

The Husky Lloydminster Upgrader (HLU) was chosen as the anchor facility for the Lloydminster EIP due to its large size, due to its role as an integral and critical member of the EIP, and because the land to colocate other facilities in the Lloydminster EIP is owned by the HLU. Lloydminster has grown largely due to local developments in oil production. HLU is key to the economy of the Lloydminster area because it made oil the largest industry in the Lloydminster area.

1.4 Thesis Organization

Chapter 1 provides background information on EIPs and the specific objectives and scope of this thesis project. It also provides a description of each chapter of this document.

Chapter 2 reviews literature on the key concepts associated with EIPs and the economic, environmental and social advantages they offer to the environment, industries and communities. Chapter 2 also covers the regulatory, technical, economic, informational,

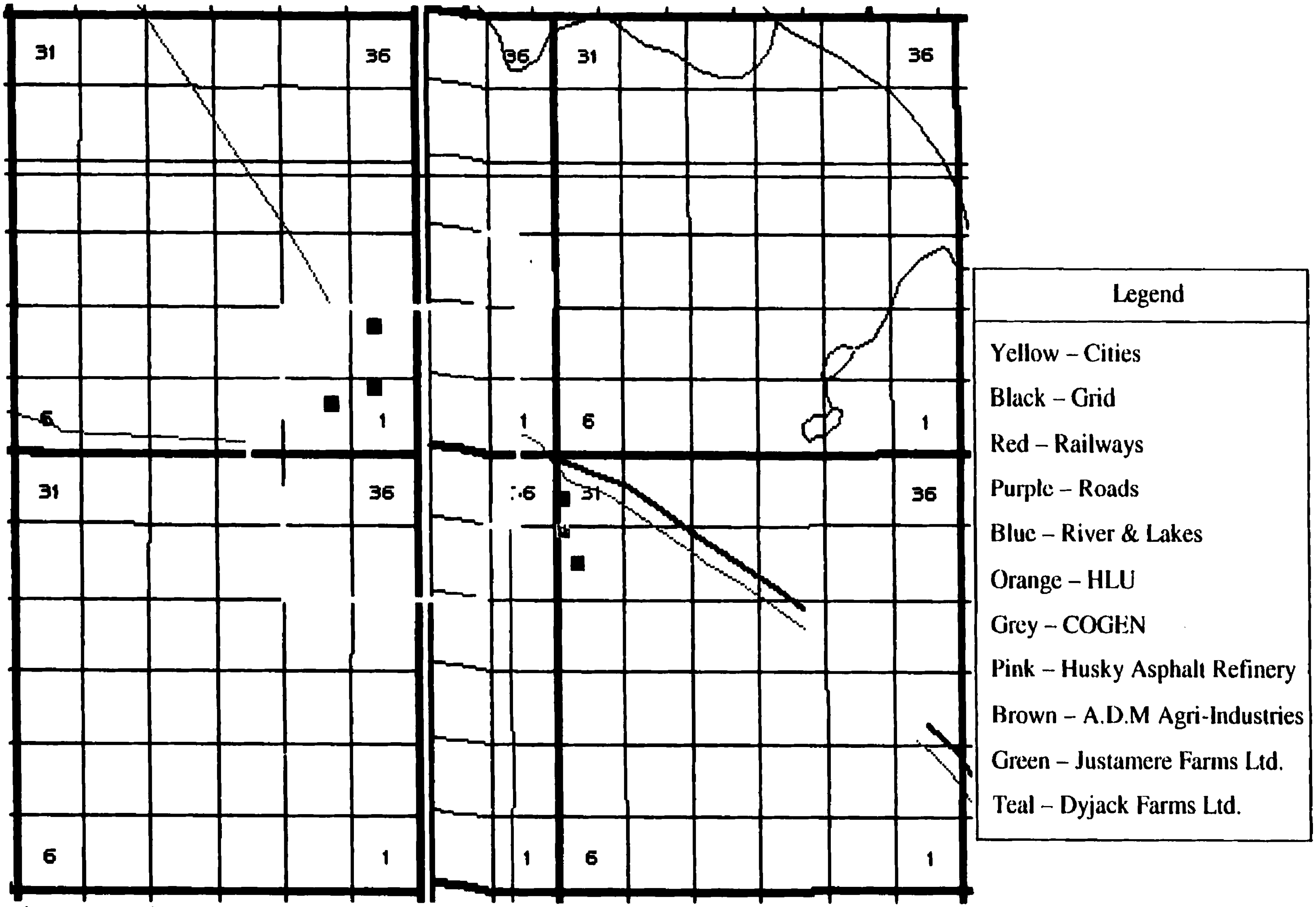


Figure 4.1. Existing facilities in the Lloydminster area chosen to be EIP members *(not to scale).*

organizational, legal and conceptual barriers that prevent or limit the successful development of EIPs. Examples of existing EIPs are provided. In addition, the concepts of impact assessments, cognitive mapping and fuzzy cognitive mapping are explained.

Chapter 3 explains the five-stage methodology used in this study: data collection, identification of potential synergies, feasibility study, data analysis and impact assessment.

Chapter 4 analyses the data and provides the results of this study. This chapter discusses the existing and possible synergies within the Lloydminster area. It evaluates the feasibility of the potential synergies using systemic ranking. Chapter 4 also provides information regarding the supply and demand of resources within the EIP. It analyzes the economic benefits of a facility to locate in the EIP and calculates the cost savings for each EIP member and the combined profit to the anchor facility. In addition, the overall cost savings for the EIP is determined. The environmental benefits for each facility and for the entire EIP are also provided. In addition, this chapter assesses the impacts of an EIP using cognitive mapping and fuzzy cognitive mapping.

Chapter 5 discusses the conclusions of this study and provides recommendations and further research topics.

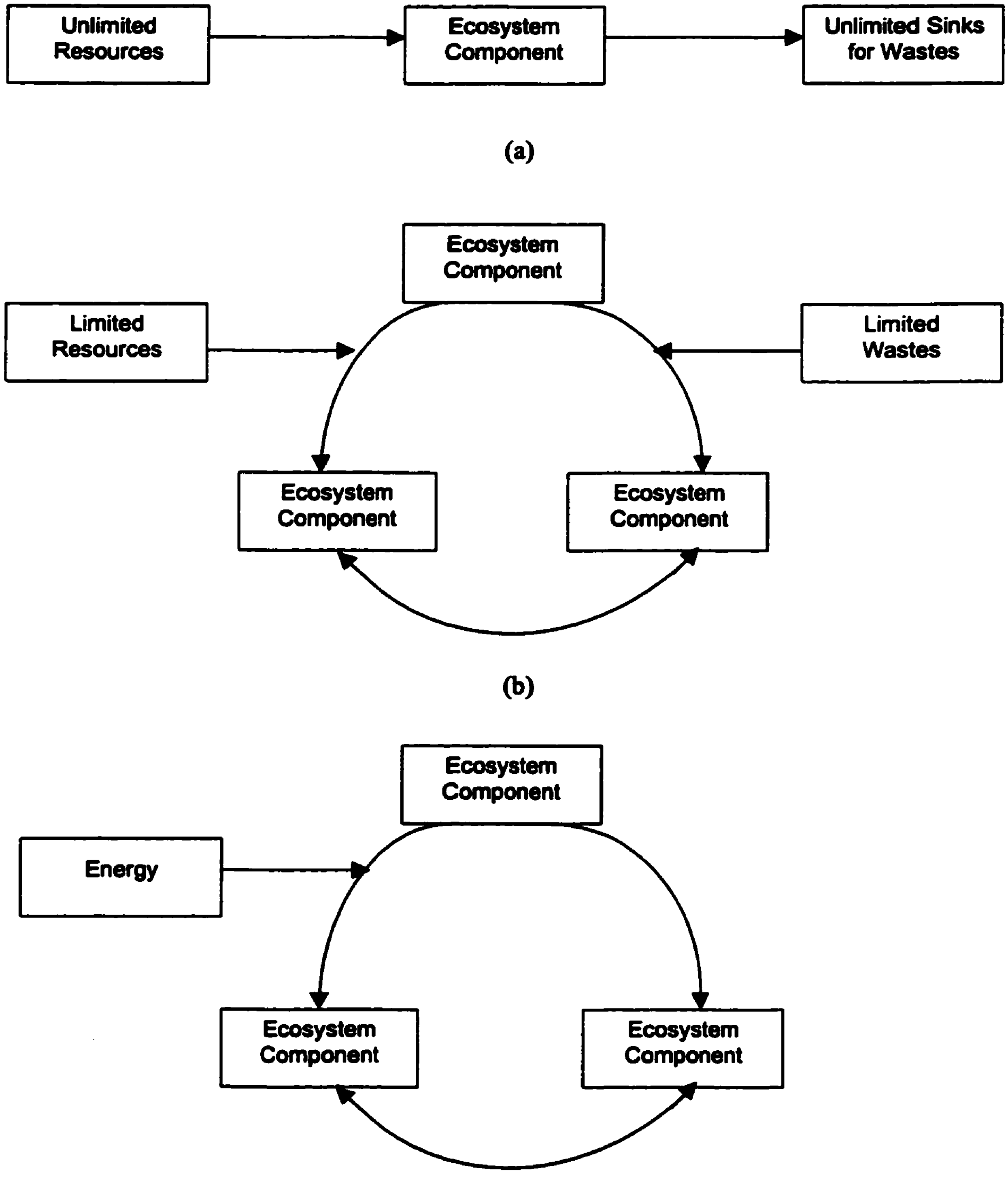
CHAPTER 2

LITERATURE REVIEW

2.1 Eco-Industrial Park Concept

There are three types of industrial systems (Garner & Keoleian, 1995). A Type I system is a linear process where materials are extracted, products and wastes are created, and wastes are disposed of (Figure 2.1). Because wastes and byproducts are not recycled or reused, this system relies heavily on a large and constant supply of virgin resources. This type of system not only assumes that there are unlimited resources, but also unlimited sinks to assimilate the wastes that are produced. Type I industrial systems were common in the past, when society for the most part was not concerned about recycling and reuse. A Type II system represents present-day industrial systems, whereby some recycling and reusing is occurring. But there are still significant quantities of damaging wastes being dissipated into the environment. In a Type III system, energy and wastes are constantly recycled and reused. A Type III system is a highly integrated closed-loop system that represents an ideal sustainable state, and is the goal of EIPs.

The waste exchange networks of EIPs are formed by engineered systems or self-organized systems. Engineered systems emphasize local and regional resource and energy flows and seek maximal efficiency in their interactions (Cote & Cohen-Rosenthal, 1998). It is assumed in engineered EIPs that intelligent, profit-maximizing industries will seek to operate in this manner. Self-organized networks come together as required to meet the needs within an area (Cote & Cohen-Rosenthal, 1998). A self-organized EIP is a result of gradual development of cooperation between neighboring industries and the local municipality.



(c)

Figure 2.1. Three types of industrial systems: (a) Type I system; (b) Type II system; and (c) Type III system (Garner & Keoleian, 1995).

2.1.1 Advantages of Eco-Industrial Parks

EIPs offer a number of advantages economically, environmentally and socially. They decrease the amount of raw materials required by industry, which is not only economically beneficial, but also environmentally and socially advantageous due to the reduced consumption of the earth's resources (Indigo Development, 1998). Limiting the use of natural resources will increase the number of future generations that will have the opportunity to use them.

EIPs decrease the volume of waste being generated that are non-reusable or require disposal (Indigo Development, 1998). This reduces the amount of waste being landfilled or incinerated, and the pollution caused by it. Since regulatory compliance is becoming increasingly costly, EIPs are beneficial economically for businesses. An EIP is not only economically beneficial, the community around it also enjoys a cleaner environment. EIPs are further beneficial as they increase energy efficiency of industries. This leads to reduced energy use in the whole community.

EIPs promote cooperation between industries (Cohen-Rosenthal, 1996). Cooperation facilitates teamwork and open exchange of information between companies. This is key for the sustainability of communities. The collective benefit of working together is greater than the sum of the individual benefits each industry would acquire if it optimized only its own interests. Communication between the companies will enable them to learn from each other's efforts in the pursuit of sustainable strategies. The companies involved in an EIP will together create new solutions and methods to deal with certain waste streams. Cooperation allows for companies to pool together similar waste streams that individually would not be feasible to use as input for another industry.

In addition, EIPs increase the amount and types of process outputs that have a market value, which in turn promotes the development of new businesses and job opportunities (Cohen-Rosenthal, 1996). Many waste materials require chemical or physical processing to be marketable (Lowe, 1996). Therefore, entrepreneurs can set up local businesses in these niches.

The businesses and the community involved in an EIP receive positive publicity. They are seen as being environmentally responsible, socially progressive, as well as innovative. This is not only socially advantageous, but may provide businesses with a competitive edge (Indigo Development, 1998).

One of the most important advantages of EIPs is that they strive towards sustainability by fostering eco-efficiency. In other words, EIPs help communities self-perpetuate over the long term. They aim to use resources at a rate that does not exceed the rate at which they can be replenished by the earth. Furthermore, they try to produce wastes at a rate that does not exceed that at which they can be absorbed by the environment.

2.1.2 Limitations and Barriers of Eco-Industrial Parks

A number of barriers exist that prevent or limit the successful development of EIPs. These barriers can be grouped into seven general categories: regulatory, technical, economic, informational, organizational, legal and conceptual. Strategies still need to be developed to overcome these barriers.

Once a substance is classified as hazardous waste, it can become more difficult to utilize than a similar raw material that is sold in the open market (Frosch, 1995). This is because there are stringent regulations in place for handling hazardous wastes for recycling (Environment Canada, 1999). This encourages the use of new materials and the disposal of old materials rather than reusing materials.

Technical barriers limit the waste exchange linkages that can be formed between industries. This makes it difficult if not impossible to get a truly closed-loop system. Certain wastes and byproducts contain contaminants that impedes their reuse and/or makes them dangerous to handle (Frosch, 1994). A lack of methods for converting/purifying certain waste streams into a form that is useable by other industries as input is a hindrance.

Economic barriers prevent many companies from becoming involved in byproduct synergy projects. Costs are involved in collecting and transporting wastes and byproducts. In addition, many waste and byproduct steams are comprised of a number of different materials. To reuse those materials it is necessary to separate them, which incurs additional costs (Frosch, 1995). This also requires information, effort and energy, which all have an accompanying dollar value. In addition, capital barriers may exist that result in a time lag, postponing the involvement in byproduct synergies. A company may not have an easy source of new investment, especially if they have already made a heavy investment in their business.

Informational barriers often stifle the progress of byproduct synergy projects. Systems for acquiring and disseminating cost information within many organizations are poor (Frosch, 1994). Information about cost is usually not available to all individuals in a company who may be able to utilize it for the good of the company. It is often the case that the answer to "who might need the information?" is not clear. Furthermore, standard management practices do not often track costs in a manner that is useful to product or process engineers.

Organizational barriers within a company can prevent some companies from becoming involved in EIPs. Many companies do not keep good track of waste and energy flows within their own companies (Peck & Callaghan, 1997). And the addition of new criteria for byproduct synergy to the design process may not fit the ideas on which the company operates. In addition, some companies are hesitant to become involved in EIPs due to their "tunnel vision". These companies are only looking at the short-term benefits, not the potential long-term gains. Furthermore, companies hesitate to be part of an EIP due to confidentiality and trade secrecy concerns. Companies tend to be secretive about their waste streams because if competitors know about their byproducts, they may deduce protected trade secrets (Frosch, 1995).

Under current legal practice, liability considerations for hazardous materials can favor disposal over selling and/or transferring the material for reuse. The original seller of any material used in a product implicated in a damage suit can be held liable, even if the material has been remanufactured and transformed by a number of different parties to produce the final product (Frosch, 1994). Damages in a lawsuit may be distributed according to the wealth of various parties rather than their actual responsibility for the harm. Therefore, it is obvious why many companies decide to dispose wastes and byproducts instead of selling and/or transferring them to industries that could use them.

Conceptual barriers can prevent the successful development of an EIP. The notion that things that are secondhand are second rate may prevent companies from using wastes and byproducts from other industries (Frosch, 1994). In addition, some companies are not interested in using wastes and byproducts from other industries because of the tendency to focus on outputs rather than inputs. Industries focus on outputs because environmental policy focuses on the "end-of-the-pipe".

Furthermore, people erroneously reduce the concept of EIP to a system of solely trading wastes. In most cases, eliminating wastes earlier in the cycle rather than trading them is the preferred solution.

2.1.3 Examples of Existing Eco-Industrial Parks

2.1.3.1 Kalundborg, Denmark

The Kalundborg, Denmark EIP is a classic example of an EIP. Figure 2.2 depicts the linkages between the different facilities. The coal-fired ASNAES electrical power plant supplies steam to Novo Nordisk pharmaceuticals plant and Statoil petroleum refinery

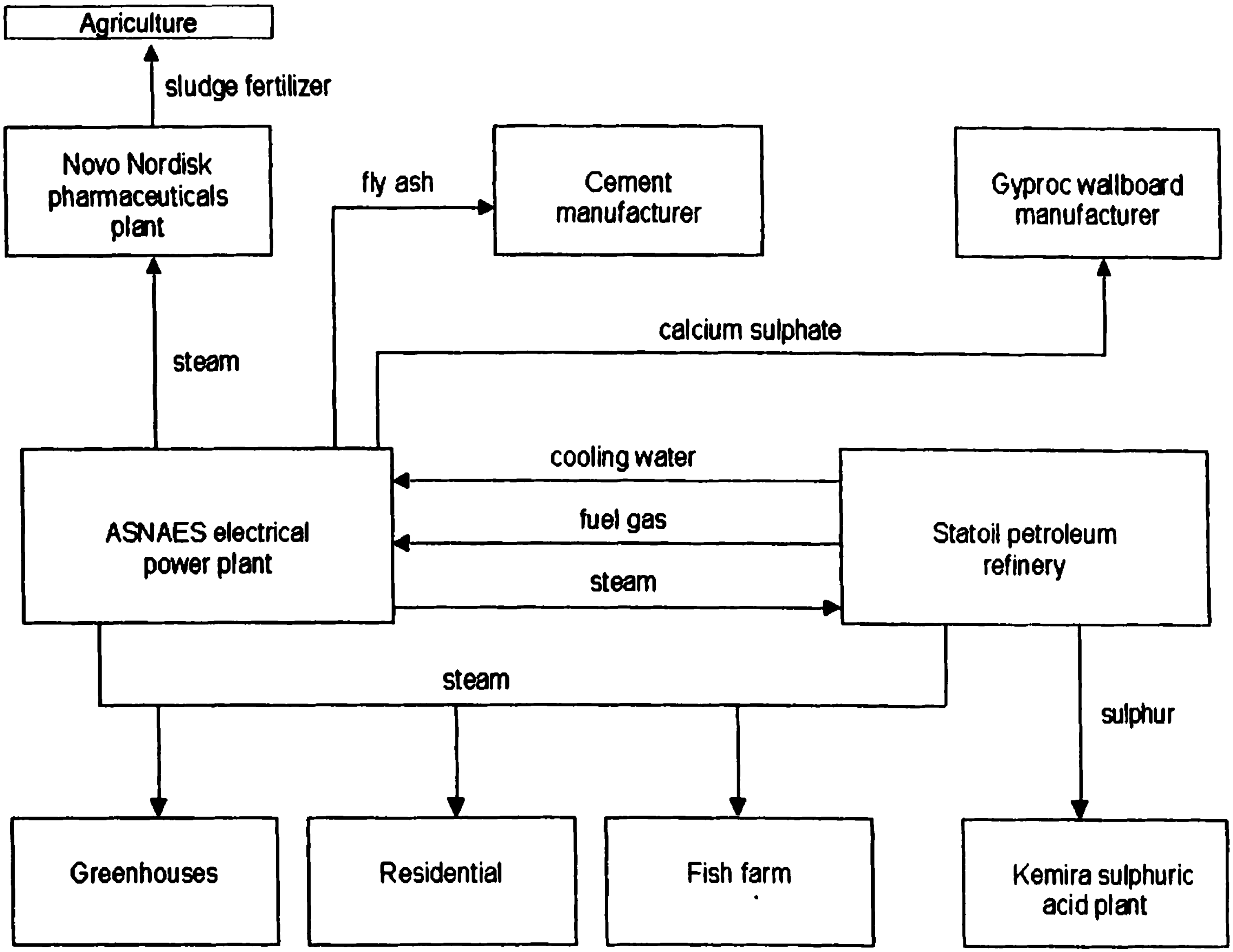


Figure 2.2. Waste exchange schematic of the Kalundborg, Denmark EIP.

(Manahan, 1999; Lowe et al., 1997). Byproduct steam from ASNAES electrical power plant and Statoil petroleum refinery is provided to the fish farm, greenhouse and the nearby homes. Statoil petroleum refinery removes sulphur from its natural gas, selling it to Kemira sulphuric acid manufacturer, resulting in a cleaner gas that is sold to ASNAES electrical power plant. ASNAES electrical power plant sells its fly ash to the cement plant and calcium sulphate (gypsum) to Gyproc wallboard manufacturer. Statoil petroleum refinery's wastewater feeds ASNAES electrical power plant, and sludge from the Novo Nordisk pharmaceuticals plant is used as fertilizer by local agriculture.

The Kalundborg, Denmark EIP is an example of a self-organized EIP. A series of businesses formed a complex network of waste and energy exchanges that resulted in a number of significant achievements (Table 2.1). There were significant reductions in the consumption of energy and utilities (e.g. coal, oil, and water) (Garner & Keoleian, 1995). There were also reductions in sulphur dioxide and carbon dioxide emissions, and in the volume of effluent water. Wastes such as sulphur, fly ash, biological sludge, and gypsum were converted into inputs for production. In addition, a systematic environmental "way of thinking" was developed, and Kalundborg was given a positive image as being a clean industrial city. Over a five-year period, 120 million dollars in cost savings and revenues were realized on a 60 million-dollar investment for this EIP infrastructure (Peck & Callaghan, 1997).

2.1.3.2 Brownsville, Texas

In 1994, the President's Council on Sustainable Development (PCSD) in the United States designated four communities as demonstration sites for EIPs (Cohen-Rosenthal, 1996). Brownsville, Texas is one of the four sites. Brownsville, located on the US/Mexico border, is rampant with poverty and unemployment. A project team consisting of researchers from the Research Triangle Institute and Indigo Development were brought together to build an economic and environmental model to simulate the benefits and costs of an EIP. The process uncovered the possibility of creating the EIP at

Table 2.1. Achieved annual results of Kalundborg, Denmark Eco-Industrial Park: (a) reduction of resource consumption; (b) reduction in emissions; and (c) re-use of waste products.

Reduction of Resource Consumption	
Oil	19,000 tonnes
Coal	30,000 tonnes
Water	1,200,000 m^3

(a)

Reduction in Emissions	
CO_2	130,000 tonnes
SO_2	25,000 tonnes

(b)

Re-use of Waste Products	
Fly Ash	135,000 tonnes
Sulphur	2,800 tonnes
Gypsum	80,000 tonnes
Nitrogen from Biosludge	800 tonnes
Phosphorus from Biosludge	400 tonnes

(c)

the Brownsville Port (Lowe et al., 1997). The anchors for this potential EIP could be an electric power plant and a petroleum refinery. The power plant would provide steam to the refinery, and the refinery would provide gas to the power plant. An asphalt plant would use residual oil from the refinery and steam from the power plant. A wallboard company would use gypsum from the power plant. A tank farm would use steam from the power plant. A number of other facilities were also considered, such as a water pretreatment plant and an oil recycler.

2.2 Impact Assessment

Impact assessment is a technique to aid the decision making process through generating information that identifies, predicts and assesses the effects of implementing a project (Smith, 1993). Impact assessments involve three steps:

1) Baseline data collection that reflects the current state;
2) Development of a means to describe changes due to the project; and
3) Forecasting of changes to the current state with and without the project, including qualitative and quantitative aspects.

Five common types of methods that have been used for impact assessment are:

- Checklists
- Interaction matrices
- Overlay maps
- Simulation models
- Networks

Checklists are one of the earliest and simplest approaches developed for assessing impacts (Smith, 1993). Checklists are standard lists of features that may or may not be affected by the project at hand. This method of impact assessment is useful in aiding a systematic consideration of possible impacts (Petts, 1999). However, due to the inherent simplicity of checklists, they are not able to identify indirect effects or interactions between impacts.

Interaction matrices acknowledge that different project characteristics and actions result in different impacts, and therefore, this method of impact assessment is valuable in providing comparative information for the different project alternatives (Petts, 1999; Smith, 1993). The weakness of interaction matrices is that the numerical scoring of impacts is largely subjective.

Overlay mapping is a technique used to examine and visually display the spatial nature of impacts (Smith, 1993). It is a particularly useful method for planning linear developments and for comparing alternatives (Petts, 1999). The drawback of this method of impact assessment is that it does not take into account the likelihood of impact occurrence nor indirect impacts.

Simulation modeling involves developing, visualizing and assessing different impact scenarios, usually with the aid of computers (Smith, 1993). Simulation models are simplified representations of the systems being investigated. This method of impact assessment involves explicit assumptions on the behavior of the system. The largest weakness of this method is that it can be misinterpreted, and therefore, requires a thorough understanding of modeling (Petts, 1999).

Networks are directional diagrams that consist of linked impacts that are used to trace the cause and effect relationships of various project actions (Smith, 1993). Networks provide a visually understandable representation of the complex web of impacts (Petts, 1999). This method of impact assessment identifies indirect impacts. Networks, however, only estimate (do not establish) the magnitude or significance of relationships or the extent of any change.

2.3 Cognitive Mapping

Cognitive mapping is the process of constructing a cognitive map (CM) from a certain environment or system. CMs are a type of network that offers a means to model interrelationships or causalities among concepts. Robert Axelrod (1976) proposed CMs as a tool for decision making. He suggested that a CM is a representation of an individual's stated values and causal beliefs. CMs can be utilized for strategic planning, prediction and explanation.

CMs graphically describe a system in terms of two basic types of elements: concept variables and causal relations. Nodes represent concept variables, C_x, where $x = 1, \ldots, N$. A concept variable at the origin of an arrow is a cause variable, whereas a concept variable at the endpoint of an arrow is an effect variable.

Arrows represent the causal relations between concept variables, e_{ij}. These causal relations can be positive or negative. In a positive causal relationship an increase in the cause variable results in an increase in the effect variable, whereas a decrease in the cause variable results in a decrease in the effect variable. For a negative causal relationship an increase in the cause variable causes a decrease in the effect variable, and a decrease in the cause variable causes an increase in the effect variable. Therefore, a positive causal relationship means that the changes occur in the same direction.

A path between two variables, i and k, denoted by P(i,k), is a sequence of all the nodes which are connected by arrows from the first node (variable i) to the last node (variable k) (Figure 2.3a) (Kosko, 1986). A cycle is a path that has an arrow from the last point of the path to the first point. A positive cycle is deviation amplifying, whereas a negative cycle is deviation counteracting.

Indirect Effect

The indirect effect of a path from a cause variable (i) to an effect variable (k), which is denoted by I(i,k), is the product of the causal relationships that form the path from the cause variable to the effect variable. If a path has an even number of negative arrows, then the indirect effect is positive. If the path has an odd number of negative arrows, then the indirect effect is negative.

In Figure 2.3a the indirect effect of cause variable i on the effect variable k through path P(i,j,k) is negative.

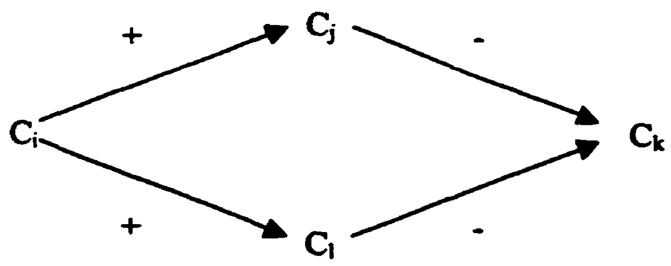
Total Effect

The total effect of a cause variable (i) on an effect variable (k), which is denoted by T(i,k), is the sum of all the indirect effects of all the paths from the cause variable to the effect variable. If all the indirect effects are positive, the total effect is positive. If all the indirect effects are negative, so is the total effect. If some indirect effects are positive and some are negative, the sum is indeterminate.

In Figure 2.3a the total effect of cause variable i to effect variable k is the sum of the indirect effect of i to k through the paths P(ijk) and P(ilk). Both indirect effects are negative in this case, which means the total effect is negative.

Adjacency Matrix

A CM can be transformed into a matrix called an adjacency matrix (Figure 2.3b) (Kosko, 1986). An adjacency matrix is a square matrix that denotes the effect that a cause variable (row) given in the CM has on the effect variable (column). In other words, the adjacency matrix approach for a CM with n nodes uses an n×n matrix in which an entry, for example, in the (i, j) elements denotes an arrow between nodes i and j.



(a)

$$E = \begin{array}{c} \\ C_i \\ C_j \\ C_k \\ C_l \end{array} \begin{array}{c} \begin{array}{cccc} C_i & C_j & C_k & C_l \end{array} \\ \begin{pmatrix} 0 & + & 0 & + \\ 0 & 0 & - & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & - & 0 \end{pmatrix} \end{array}$$

(b)

Figure 2.3. (a) A cognitive map, and (b) the resulting adjacency matrix (Kosko, 1986).

Threshold Function

Concept states are held within defined boundaries through the threshold function. The type of threshold function chosen determines the behavior of a CM. A bivalent threshold function requires concepts to have a value of 1 or 0, which is equivalent to "on" or "off".

$$f(x_i) = 0,\ x_i \leq 0 \qquad (2.1)$$
$$f(x_i) = 1,\ x_i > 0$$

The trivalent threshold function includes negative activation. Therefore concepts have a value of 1, 0 or –1, which is equivalent to "positive effect", "no effect" and "negative effect", respectively.

$$f(x_i) = -1,\ x_i \leq -0.5 \qquad (2.2)$$
$$f(x_i) = 0,\ -0.5 < x_i < 0.5$$
$$f(x_i) = 1,\ x_i \geq 0.5$$

Concepts are multiplied by their connecting causal relation weights to give the total input to the effect concept. In cases where there are multiple paths connecting a concept, the sum of all the causal products is taken as the input (Tsadiras & Margaritis, 1996):

$$x_i = \sum_{\substack{j=1 \\ j \neq i}}^{n} C_j\, w_{ji} \qquad (2.3)$$

where,

x_i = input

C_j = concept state

w_{ji} = weight of the causal relations

Categories of Cognitive Maps

CMs are categorized by their target worlds. Visual CMs have target worlds that are physical and visible. Conceptual CMs have target worlds that are conceptual and invisible.

Types of Cognitive Maps

There are different types of CMs. These include:

- Signed digraphs
- Weighted CMs
- Functional CMs

In signed digraphs, each relationship is assigned a sign (Kardaras & Karakostas, 1999). Therefore, signed digraphs model simply the direction of the change. In weighted CMs, positive or negative numbers are assigned on each relationship, thus modeling not only the direction, but also the magnitude of the change. Weighted CMs eliminate the indeterminacy problem of signed digraphs. Functional CMs assign specific functions on each relationship in order to represent more accurately the magnitude and direction of change.

Advantages

CMs offer a number of advantages. These include the following:

- clear way to visually represent causal relationships
- expanded range of complexity that can be managed
- allow users to rapidly compare their mental models with reality
- make evaluations easier
- promote new ways of thinking

2.4 Fuzzy Cognitive Mapping

Bart Kosko (1986) introduced fuzzy CMs (FCMs) as weighted CMs with fuzzy weights. CMs fall into the realm of crisp logic, whereas FCMs incorporate fuzzy logic. Crisp logic is black and white, whereas fuzzy logic covers shades of gray. In crisp logic truth is binary; a proposition is either true or false. Computers function in this binary domain. Either an event occurs, taking a value of 1, or does not occur, taking a value of 0. In fuzzy logic all truths are partial or approximate. Therefore, fuzzy logic is multi-valued logic in which there are degrees of truth between true and not true. This is similar to how the human brain works. FCMs are extremely forgiving of uncertain information due to the incorporation of fuzzy logic elements.

Membership Function

A fuzzy membership function is the degree to which an element belongs to a set. In crisp sets the transition of an element in the universe between membership and non-membership in a given set is well defined. An element x in the universe X is either a member of some crisp set A or it is not (Ross, 1995). This binary issue of membership is mathematically represented with the indicator function,

$$X_A(x) = \begin{cases} 1, & x \in A \\ 0, & x \notin A \end{cases} \qquad (2.4)$$

The membership function for this crisp set A is depicted in Figure 2.4a.

In fuzzy sets, the transition of an element in the universe between membership and non-membership in a given set can be gradual. The notation used for the value on the unit interval that measures the degree to which element x belongs to fuzzy set $\underset{\sim}{A}$ is,

$$\mu_{\underset{\sim}{A}}(x) \in [0,1]$$

Figure 2.4b shows the membership function for this fuzzy set. The boundaries of the fuzzy sets are vague and ambiguous. Therefore, members of a crisp set are members because their membership is complete and full, whereas members of a fuzzy set need not be complete. Crisp sets are thus a special form of fuzzy sets.

Concept Values

The strength value of a concept can be represented in a number of ways depending on the user's preference. Traditionally the strength value of a node ranges from 0, signifying no strength, to 1, signifying full strength. Therefore, this unipolar range is [0,1].

Due to the limited range of fuzzy numbers, Kosko (1986) proposed converting negative influences into positive influences by using dis-concepts or dis-factors. Therefore, every $C_i \xrightarrow{-} C_j$ is replaced with $C_i \xrightarrow{+} \sim C_j$. The disadvantages in using dis-concepts are that it doubles the size of the concept set. This results in redundancy in knowledge representation, in higher cognitive complexity, and higher storage space.

Zhang & Chen (1989) proposed a system called POOL2. In this system, negative and positive assertions are weighted and kept separately based on the negative-positive-neutral (NPN) interval [-1,1]. In this bipolar system values range from –1, representing the maximum negative, to 0, for ambivalence, to +1, for the maximum positive representation.

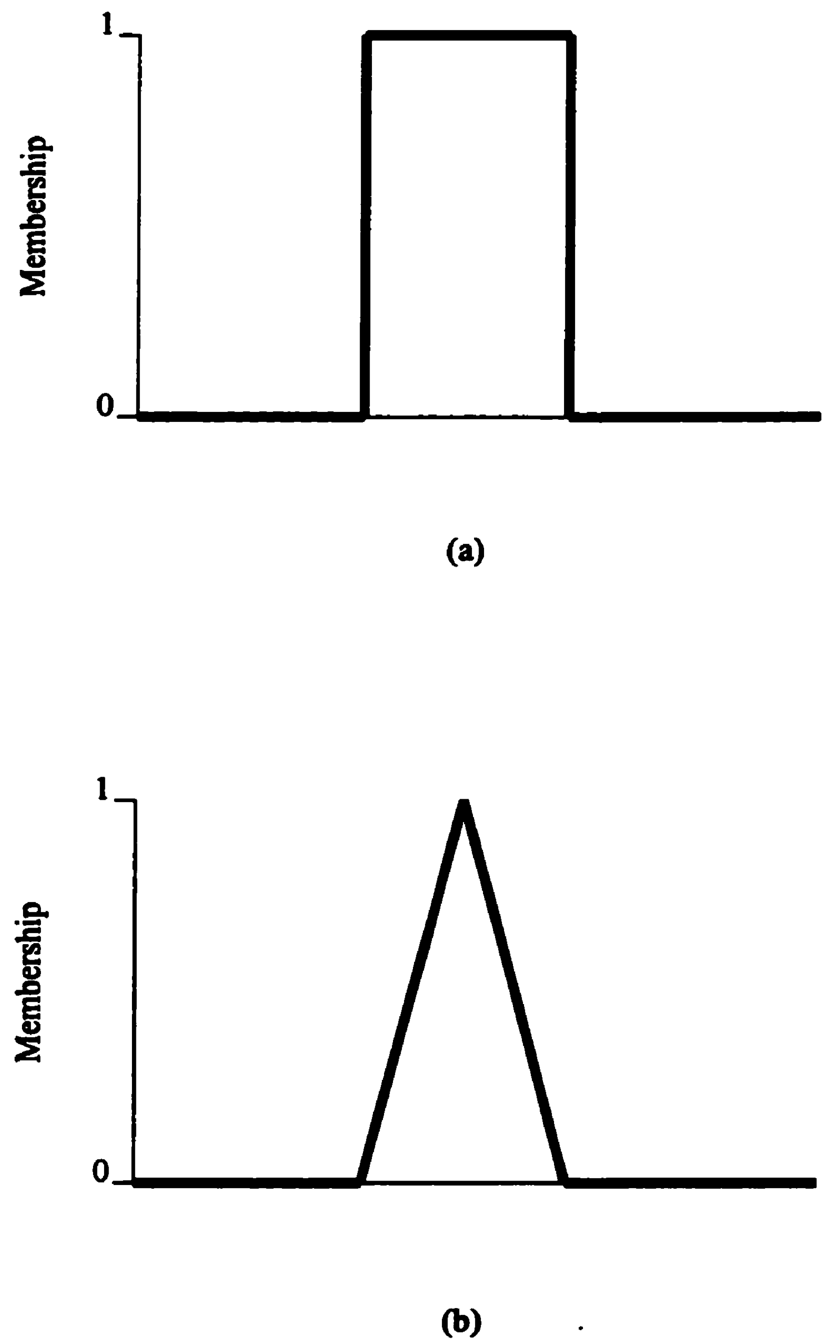


Figure 2.4. Membership function for (a) crisp set A, & (b) fuzzy set $\underset{\sim}{A}$ (Ross, 1995).

Feedback

FCMs model dynamic systems that can cycle, and therefore, feedback is allowed. Each concept variable is given an initial value based on the belief of the expert(s) of the current state. The FCM is then free to interact until a fixed-point equilibrium, limit cycle, or chaotic attractor is exhibited (Kosko, 1997). A fixed-point equilibrium occurs when a new state is equal to the previous state. A limit cycle and a chaotic attractor are reached when the new state equals any previously encountered state.

Min-Max Inference Approach

The min-max inference approach can be utilized to evaluate linguistic variables (Pelaez & Bowles, 1995). The minimum value of the links in a path is considered to be the path strength. If more than one path exists between the cause variable and the effect variable, the maximum value of all the paths is considered to be the conclusion. In other words, the indirect effect amounts to specifying the weakest linguistic variable in a path, and the total effect amounts to specifying the strongest of the weakest paths. For instance, P = {none < some < much < a lot} and the FCM is shown in Figure 2.5:

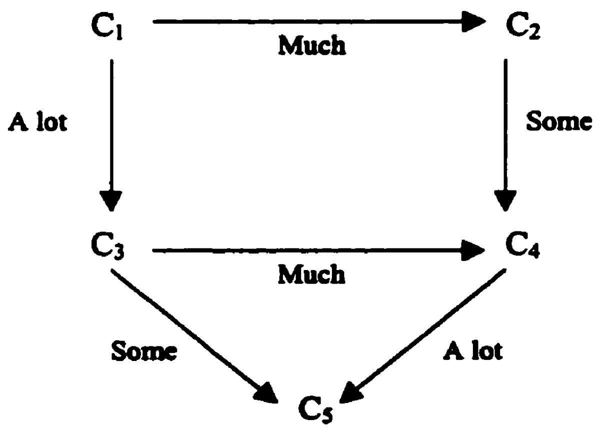


Figure 2.5. A fuzzy cognitive map (Kosko, 1986).

Three paths that exist from the cause variable (C_1) to the effect variable (C_5) are (1,3,5), (1,3,4,5), and (1,2,4,5). The indirect effects of C_1 on C_5 are (Kosko, 1992):

$$I_1(C_1,C_5) = \min\{e_{13}, e_{35}\} = \min\{\text{a lot, some}\} = \text{some} \quad (2.5)$$

$$I_2(C_1,C_5) = \text{much}$$

$$I_3(C_1,C_5) = \text{some.}$$

Therefore, the total effect is:

$$T(C_1, C_5) = \max\{I_1(C_1,C_5), I_2(C_1,C_5), I_3(C_1,C_5)\} = \max\{\text{some, much, some}\} = \text{much.} \quad (2.6)$$

Uses of FCMs

FCMs are commonly applied in soft knowledge domains such as political science, history, organization theory and international relations (Kosko, 1986). Fuzzy cognitive mapping have been used for a number of different situations, such as decision making, explanation, forecasting and strategic planning (Tsadiras & Margaritis, 1996). Specific examples include failure modes effects analysis (i.e. determining how a system will behave in the event of a device failure) (Pelaez & Bowles, 1995; 1996), strategic planning of information systems (Kardaras & Karakostas, 1999), estimation of expert credibility (Taber & Siegel) and for qualitative electronic circuit analysis (Styblinski & Meyer, 1991).

In this study, fuzzy cognitive mapping provides a new approach to using networks for impact assessments.

CHAPTER 3

METHODOLOGY

This study involved the following phases:

- Data Collection
- Identification of Potential Synergies
- Feasibility Study
- Data Analysis
- Impact Assessment

The research design is shown in Figure 3.1.

3.1 Data Collection

The data collection phase involved determining the types of facilities, utilities and transportation that are located in the Lloydminster area. The Lloydminster Business Directory (Lloydminster Economic Development Authority, 1999) provides a comprehensive list of industries situated in this area. Of the existing facilities in the area, those that were close in proximity to the Lloydminster EIP site or had easy access to the site (ex. locating beside the railway) were chosen to be part of the Lloydminster EIP. Relevant information that was gathered on the chosen existing facilities included energy requirements, water requirements, material inputs, product outputs, non-product outputs, labour requirements, physical size and basic processes. Personal interviews were conducted to obtain some of the data. Existing linkages between these facilities were also identified.

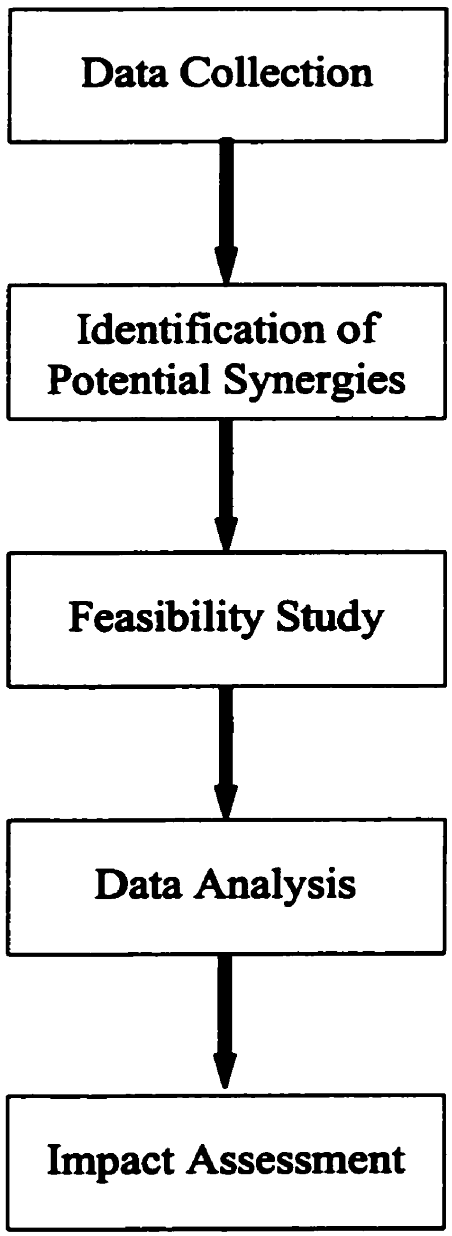


Figure 3.1. Research design showing the five phases involved.

3.2 Identification of Potential Synergies

Possible linkages between existing facilities were identified by comparing the input and output information for the existing facilities (gathered in the data collection phase) and determining if there are any matches. Following this, potential buyers and uses were identified for the existing facilities' outputs, by researching which facilities require these materials as inputs into their process. Potential sources were also identified for the existing facilities' inputs. All other possible linkages among and between the existing and potential facilities were then identified.

3.2 Feasibility Study

The facilities were ranked systemically to prioritize the order in which the facilities should be pursued to set up in the Lloydminster EIP. The feasibility study involved ranking facilities according to the following three criteria:

1) Sufficiency of Material Inputs
2) Sufficient Markets for Product Outputs
3) Economic Sustainability

The availability in Lloydminster of sufficient inputs is crucial for a particular facility to function and setup in the area. These inputs include everything from material resources to energy and water requirements. Sufficient markets in Lloydminster for the product output of a facility is important for the facility to be feasible. Economic sustainability refers to how long an industry could survive in the Lloydminster market. If the expected lifetime of an industry is deemed to be relatively short, it will not fit well within the EIP because facilities rely on one another. Technical feasibility was not considered in this study.

For this study, those facilities that were ranked the highest were chosen to be the first facilities to colocate in the Lloydminster EIP. A weighted scoring system was utilized for prioritizing the co-location of facilities in the Lloydminster EIP:

$$\text{Total Score, } a_i = w_{ix}s_{ix} + w_{iy}s_{iy} + w_{iz}s_{iz} \qquad (3.1)$$

where,

i = industry

s_x = sufficiency of material inputs = $\begin{cases} 1 = \text{sufficient} \\ 0 = \text{insufficient} \end{cases}$

s_y = sufficient markets for product outputs = $\begin{cases} 1 = \text{sufficient} \\ 0 = \text{insufficient} \end{cases}$

s_z = economic sustainability = $\begin{cases} 1 = \text{sustainable} \\ 0 = \text{not sustainable} \end{cases}$

w_x, w_y, w_z = weight = 1

Total Score = $\begin{cases} 0 = \text{no rank} \\ 1 = \text{low rank} \\ 2 = \text{intermediate rank} \\ 3 = \text{high rank} \end{cases}$

For those facilities that were deemed most feasible (i.e. high rank), data were collected on energy requirements, water requirements, material inputs, product outputs, non-product outputs, labour requirements, physical size and basic processes.

The amount of low-pressure steam required by each of the feasible potential facilities was determined assuming a heating value of 1845 kJ/kg from the low-pressure steam (adopted from Wendell James, Alberta Research Council, personal communication):

$$\text{Low-pressure steam (kg/s)} = \frac{\text{Annual heating requirement (kW)}}{1845 \text{ kJ/kg}} \quad (3.2)$$

3.3 Data Analysis

3.4.1 Economic Analysis

Supply and Demand

Within the Lloydminster EIP there exists a demand for a certain amount of each resource. The supply of each resource available within the EIP is limited. This section determines whether the supply does in fact meet the demand within the Lloydminster EIP. In determining the supply and demand for each resource, the proximity of consumers and sources were taken into account. Consumers obtain resources from the closest source as long as the properties of that resource meet requirements.

Economic Profile

A generic economic profile for each type of facility was adopted from various sources, and alterations were made as deemed appropriate for this study based on information specific to the Lloydminster area and personal communications. Based on the economic profile generated for each facility, a discounted payback period was calculated for five alternative situations:

1. locating in the Lloydminster area, but not in the EIP (non-EIP member);

2. locating within the EIP, in which companies sell one another their materials and resources (including byproducts and wastes) at a mark-up of 70% of the difference between the cost to the buyer and seller (70%-EIP member);

The following equation was developed through discussions with Dave Kay, Husky Energy Inc.:

$$(\text{purchase price})_{\text{Buyer}} = (\text{purchase price})_{\text{Seller}} + 0.7\,[\,(\text{market price}) - (\text{purchase price})_{\text{Seller}}] \qquad (3.3)$$

3. locating within the EIP, in which companies sell one another their materials and resources (including byproducts and wastes) at a mark-up of 50% of the difference between the cost to the buyer and seller (50%-EIP member);

4. locating within the EIP, in which companies sell one another their materials and resources (including byproducts and wastes) at a mark-up of 30% of the difference between the cost to the buyer and seller (30%-EIP member);

5. locating within the EIP, in which there is free trading between the members (i.e. base case - there is no cost for supply of materials and resources) (free-trade-EIP member).

A payback period is an estimate of whether a project is worthwhile, and is often quoted for business investments (ReVelle et al., 1997). It is the amount of time required to recover the project cost and is given as (Hedges & Wood, 1997):

$$\text{Payback} = \frac{\text{Initial Cash Outflow}}{\text{Per Year after Tax Cash Inflow}} = \frac{\text{Capital Investment}}{\text{Gross Revenue} - \text{Operating \& Maintenance Costs} - \text{Taxes}} \qquad (3.4)$$

A discounted payback period analysis was used because it provides an estimate of the amount of time it takes for the industry to recover the project cost, while taking into account the time value of money (Brealey & Myers, 1996). To calculate the discounted payback period, set the initial capital cost of the project equal to the present value of the stream of payments generated by the project and solve for the amount of time required to payback the initial capital cost (Figure 3.2). All calculations are done using real net cash flows and a real rate of interest, adjusted for inflation (Brealey & Myers, 1996).

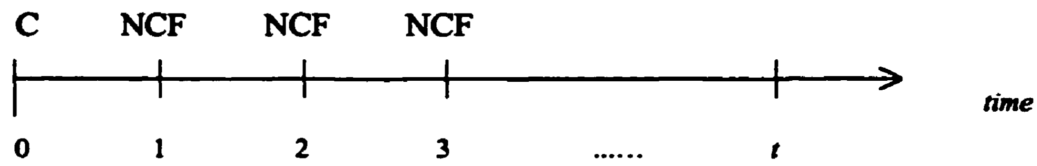


Figure 3.2. Cash flow diagram.

$$C = NCF/(1+i) + NCF/(1+i)^2 + \ldots + NCF/(1+i)^t \qquad (3.5)$$

$$C = NCF\ (a_{\overline{t}|i})$$

where,

C = capital cost

NCF = real net cash flow

= inflow - outflow

= gross revenue – operating & maintenance costs – taxes

t = time (years)

i = real interest rate

$a_{\overline{t}|i} = (1 - v^t) / i$ = annuity immediate (Kellison, 1991)

$v = 1 / (1 + i)$

Cost Savings and Profit

The cost savings for each facility to colocate within the Lloydminster EIP were calculated, along with the combined profit to the anchor facility. In addition, the overall cost savings for the EIP as a whole was compiled.

Sensitivity Analysis

A sensitivity analysis is conducted to determine the effect that changes in parameters have on the solution. Those items in the economic profile for each facility that had large costs or low confidence levels were varied by ±10% to determine their effect on the discounted payback periods.

3.4.2 Environmental Analysis

A concentration of facilities in one area results in a number of environmental concerns, such as pollution and smog. This in turn results in health concern, not only for wildlife, but also for humans.

In the Lloydminster area, many facilities burn natural gas to generate heat, which results in large amounts of flue gas being emitted into the atmosphere. Flue gas is comprised of CO_2, CO, NO_x, N_2O and CH_4 (CAPP, 1999). Of these gases, CO_2, N_2O and CH_4 are considered to be greenhouse gases.

The "CAPP Guide to Baselines and Calculating Greenhouse Gas Emissions" (CAPP, 1999) was used to analyze the environmental benefits of reducing air pollution due to establishing the Lloydminster EIP.

The following equation was used to determine the greenhouse gas emission reduction, in carbon dioxide equivalents (CO_2E), that result from eliminating the need for natural gas fired boilers for co-locating facilities and/or from injecting the flue gas into underlying coalbeds in the study area (CAPP, 1999):

$$\text{GHG Emissions} = \text{Fuel usage} * \text{Emission factor} \tag{3.6}$$

Assuming that boilers are uncontrolled with no low NOx burners and no flue gas recirculation, the emission factor is (CAPP, 1999):

1.907 kg/m^3 if heat input < 2900 kW
1.910 kg/m^3 if heat input = 2900 to 29,000 kW
1.940 kg/m^3 if heat input > 29,000 kW

Pollution and Waste Reduction

The reduction in greenhouse gas emissions in terms of tonnes CO_2E/yr was calculated for each facility and the overall reduction in greenhouse gas emissions was calculated for the entire Lloydminster EIP. In addition, the reduction in waste disposal was determined for the Lloydminster EIP as a whole.

Sensitivity Analysis

An environmental sensitivity analysis was conducted to determine how sensitive greenhouse gas emission reductions are to:

- the quantity of heat the EIP member facilities require; and
- the quantity of flue gas that can be injected into the underlying coalbed.

3.5 Impact Assessment

In assessing the impacts of an EIP a trivalent state FCM was developed to identify the tangible cause-effect relationships. Thus, the values {-1,0,+1} were used along with linguistic weights.

Causal flow in the FCM was determined with repeated vector matrix operations and thresholding (Pelaez & Bowles, 1995). The new state is the old state multiplied by the connection matrix (Pelaez & Bowles, 1996):

$$[C_1 C_2 \ldots C_n]_{new} = [C_1 C_2 \ldots C_n]_{old} \bullet \begin{pmatrix} C_{11} & \ldots & C_{1n} \\ \vdots & \ddots & \vdots \\ C_{n1} & \ldots & C_{nn} \end{pmatrix} \quad (3.7)$$

The values of the state vector were thresholded to keep their values in the set {-1,0,1}, and the activated concept was reset to 1 after each matrix multiplication.

A program was developed using MATLAB to perform the repeated vector matrix operations and thresholding required to stabilize the FCM. MATLAB is a powerful computation data analysis and visualization software (Hanselman & Littlefield, 1997). The software allows one to solve many technical problems, especially those involving matrices and vectors.

Once the FCM was stable, the min-max inference approach was used to evaluate the total effect of any cause variable on an effect variable. For the purposes of this thesis, the total effect that existing facilities providing byproducts and wastes to other facilities to use as inputs would have on pollution and on waste disposal was determined.

Sensitivity Analysis

A sensitivity analysis was conducted on the impact assessment to determine the effect that changes in linguistic weights assigned to causal relationships have on the final solution. Linguistic weights were altered for those relationships that had the lowest confidence.

CHAPTER 4

RESULTS & DISCUSSION

4.1 DATA COLLECTION

4.1.1 Current Facilities in the Lloydminster Area

There are many existing facilities in the Lloydminster area. Those that were located in close proximity to or had easy access to the Lloydminster EIP site were chosen to be EIP members. These included the following:

- Husky Lloydminster Upgrader (HLU)
- Meridian Cogeneration Plant (COGEN)
- Husky Asphalt Refinery
- A.D.M. Agri-Industries
- Justamere Farms Ltd.
- Dyjack Farms Ltd.

The geographical locations of these facilities are shown in Figure 4.1. All the gathered data pertaining to each of the facilities can be found in Appendix A. Material and resource flow diagrams for each facility are provided in Appendix B. A summary of each of the chosen existing facilities is provided in Table 4.1.

Table 4.1 shows that:

- The Husky Lloydminster Upgrader *(named HLU from this point forward)* is a heavy oil upgrading plant that takes heavy oil feedstock and processes it into light sweet synthetic crude oil through fractionation, hydrocracking, hydrotreating and delayed coking. The synthetic crude oil is used as a feedstock for refining into premium transportation fuels in Canada and the United States.

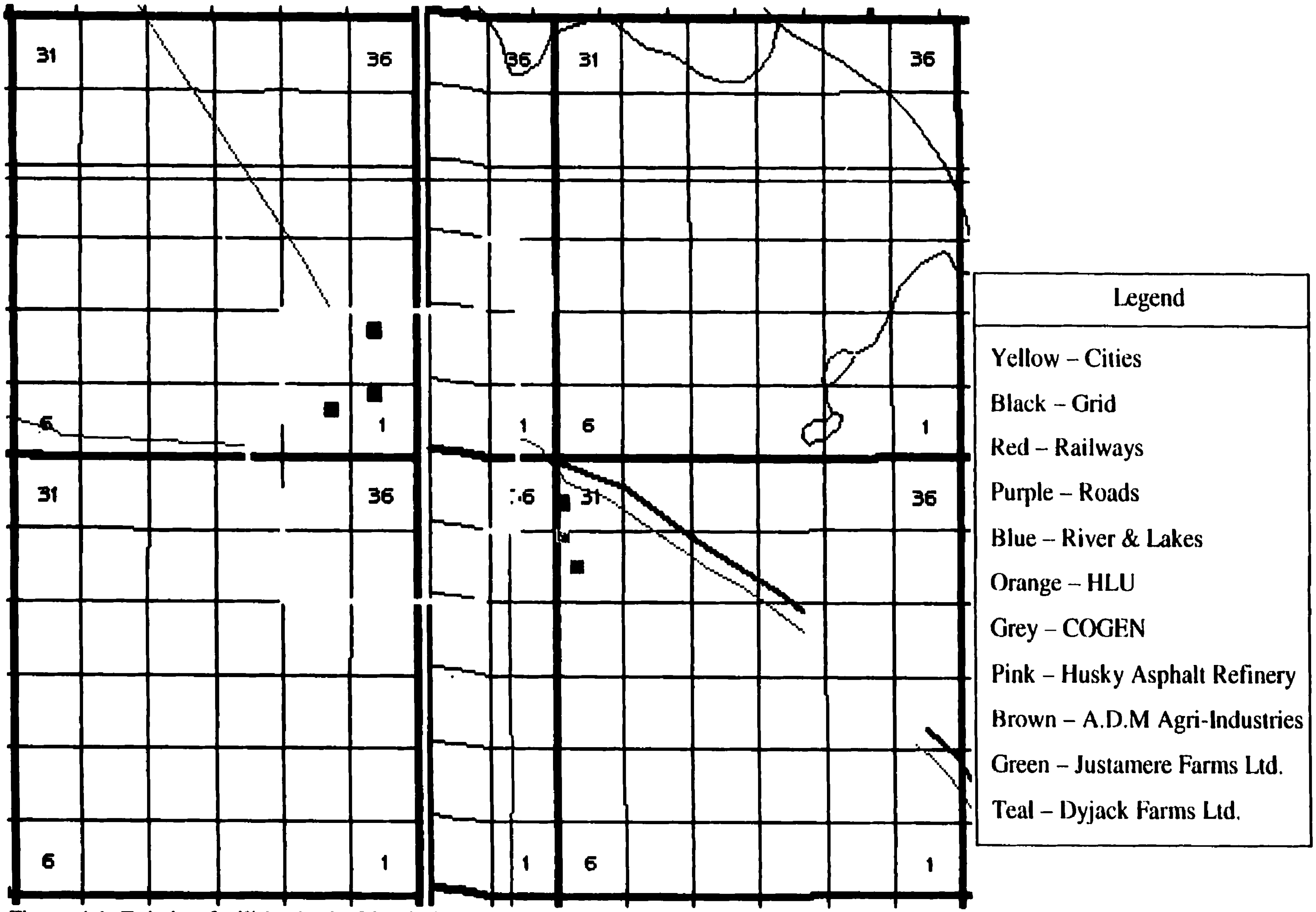


Figure 4.1. Existing facilities in the Lloydminster area chosen to be EIP members *(not to scale)*.

Table 4.1. Summary information on chosen existing facilities.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Husky Lloydminster Upgrader	Heavy oil upgrading plant	Lloydminster EIP site	Fractionation, hydrocracking, hydrotreating, delayed coking	Heavy oil	Light sweet synthetic crude
Meridian Cogeneration Plant	215 MW combined cycle cogeneration plant	Lloydminster EIP site	Cogeneration	Natural gas	Heat and power
Husky Asphalt Refinery	Asphalt refinery	NW corner of study area (next to railway)	Refining	Heavy oil	Asphalt
A.D.M Agri-Industries	Canola plant	NW corner of study area (next to railway)	Crushing, meal processing, oil extraction	Canola seed	Crude canola oil and canola meal
Justamere Farms Ltd.	Cropland	Lloydminster EIP site	Farming	Seeds	Oats and barley
	Feedmill		Grain processing	Oats and barley	Feed
	Feedlot		Grazing	Feed	Cattle
Dyjack Farms Ltd.	Cropland	NW corner of study area (next to railway)	Farming	Seeds	Wheat and canola

- The Meridian Cogeneration Plant *(named COGEN from this point forward)* is a 215 MW Combined Cycle Cogeneration facility located next to the HLU. Cogeneration refers to the sequential production of heat and power from a single fuel source. COGEN has two natural gas turbines and one steam turbine that generate power that is sold to SaskPower, and steam (heat) that is sold to HLU.

- Husky Asphalt Refinery *(named Asphalt Refinery from this point forward)* processes heavy oil to produce asphalt. It is located on the northwest corner of the study area, but is connected well with the Lloydminster EIP site due to the railway.

- A.D.M. Agri-Industries is a canola plant that uses canola seed to produce crude canola oil and canola meal. Due to confidentiality concerns, a typical Canola Plant with generic values will be used throughout this study. This facility is located in the northwest corner of the study area next to the Asphalt Refinery.

- Justamere Farms Ltd. includes cropland *(named Crop I from this point forward)*, a Feedmill and a Feedlot, which are all interconnected through product and non-product linkages. It is located in the Lloydminster EIP site. Oats and barley are the primary crops grown on Crop I. The Feedlot consists solely of cattle and the Feedmill generates feed for the cattle.

- Dyjack Farms Ltd. is a crop producer *(named Crop II from this point forward)*. This farm grows primarily wheat and canola. It is located close to the Asphalt Refinery and Canola Plant, on the northwest corner of the study area.

Salt caverns are geological formations located in the Lloydminster area that could be incorporated in the Lloydminster EIP. Salt caverns are currently washed out with effluent from HLU and sand is injected inside the caverns. The salt caverns act as holding tanks for the sand, which is produced in large volumes during the extraction of heavy oil.

Coalbeds are another geological formation located in the Lloydminster area. These subsurface coalbeds exist in the Mannville formation.

In regards to utilities, SaskPower Corporation and ATCO Electric are the primary sources of electricity, ATCO Gas is the primary source of natural gas, and the City of Lloydminster provides water.

The primary transportation infrastructure pertinent to the subject area includes Canadian National Railway, Canadian Pacific Limited, Highway #16 and Highway #17.

4.1.2 Existing Synergies Amongst Current Facilities

Table 4.2 provides of summary of the following existing synergies in the Lloydminster area:

- COGEN provides the HLU with high-pressure steam, which the HLU uses in the heavy oil upgrading process.

- Crop II (Dyjack Farms Ltd.) provides the Canola Plant with 20 t/yr of canola grain. The Canola Plant requires approximately 365,000 t/yr of canola grain as its primary input. Therefore, the remaining quantity of canola grain required is obtained from various other suppliers.

- The Feedlot (Justamere Farms Ltd.) generates manure that is land applied as a soil amendment at the Feedlot and at Crop I (Justamere Farms Ltd.).

Table 4.2. Summary of existing synergies.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
High-Pressure Steam (4500 kPa)	COGEN	HLU	Upgrading process	1,506,720 t/yr
Canola	Crop II (Dyjack Farms Ltd.)	Canola Plant	Primary input	20 t/yr
Manure	Feedlot (Justamere Farms Ltd.)	Crop I (Justamere Farms Ltd.)	Soil amendment	750 t/yr
Oats	Crop I (Justamere Farms Ltd.)	Feedmill (Justamere Farms Ltd.)	Primary input	77 t/yr
Barley	Crop I (Justamere Farms Ltd.)	Feedmill (Justamere Farms Ltd.)	Primary input	109 t/yr
Straw	Crop I (Justamere Farms Ltd.)	Feedlot (Justamere Farms Ltd.)	Cattle bedding	499 t/yr
Feed	Feedmill (Justamere Farms Ltd.)	Feedlot (Justamere Farms Ltd.)	Substitute for grazing during winter months	156 t/yr

- Crop I provides oat grain and barley grain to the Feedmill (Justamere Farms Ltd.).
- Crop I provides the Feedlot with straw, which is used for cattle bedding.
- Feedmill produces feed, of which about half is used by the Feedlot during the winter months.

Figure 4.2 depicts the information summarized in Table 4.2 as a material flow diagram. This visual representation provides a snapshot of the existing facilities chosen to participate in the Lloydminster EIP, along with the existing linkages.

4.2 IDENTIFICATION OF POTENTIAL SYNERGIES

4.2.1 Potential New Facilities Identified

The facilities that have been identified as having the potential to colocate and be part of the Lloydminster EIP include:

- Concrete Admixture Plant
- Ethanol Plant
- Fish Farm
- Greenhouse
- Meat Packer / Slaughterhouse
- Metals Recovery Plant
- Pharmaceuticals Plant
- Plastics Plant
- Salt Plant
- Strawboard Plant
- Sulphuric Acid Plant
- Tire Recycling Plant
- Tree Nursery
- Warehouse
- Waste Lube Recycling Plant

The potential new facilities and existing facilities for the Lloydminster EIP are depicted in Figure 4.3. This diagram visually highlights what the Lloydminster EIP could be.

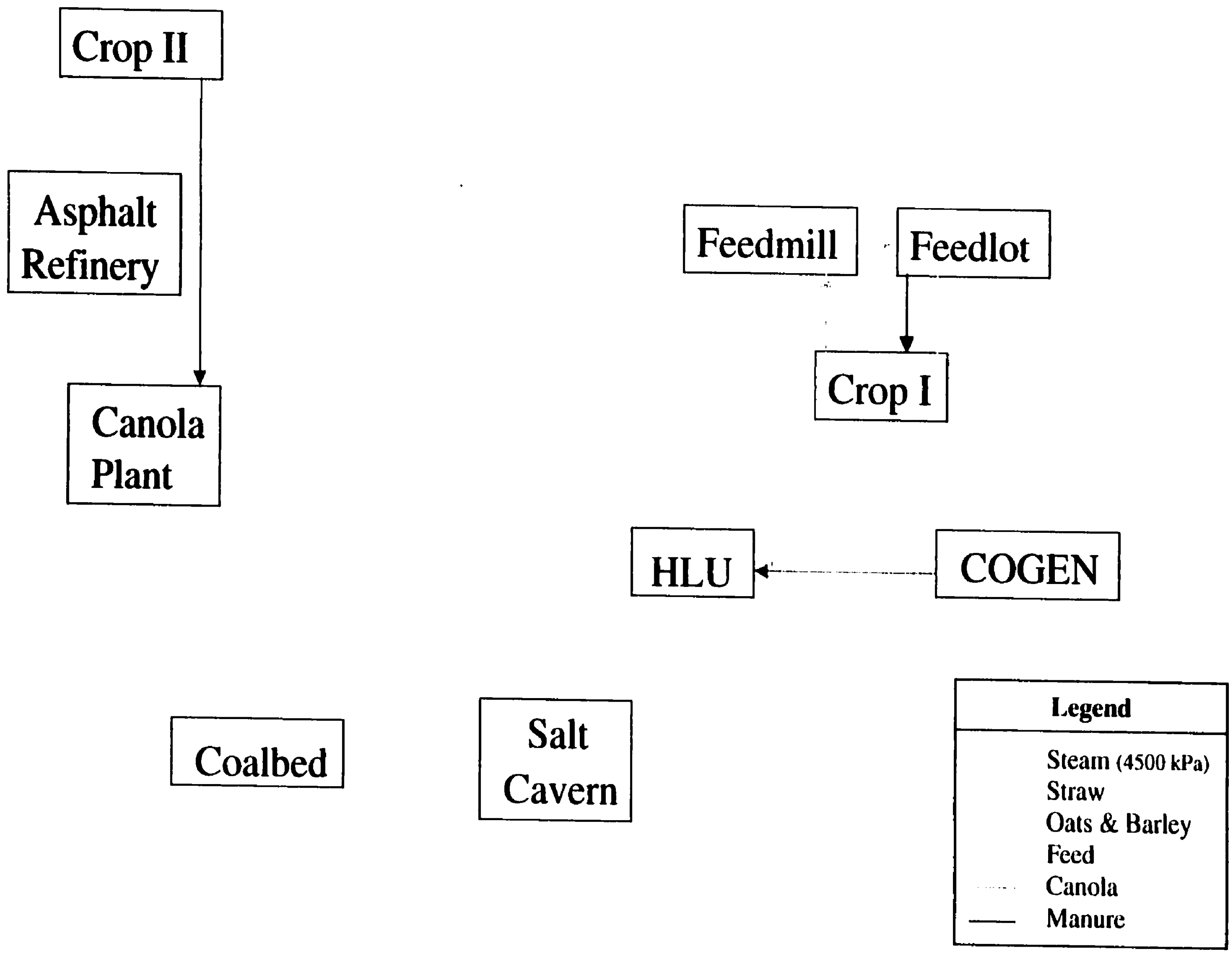


Figure 4.2. Existing synergies in the Lloydminster area (yellow = existing facility; clear = geological formation).

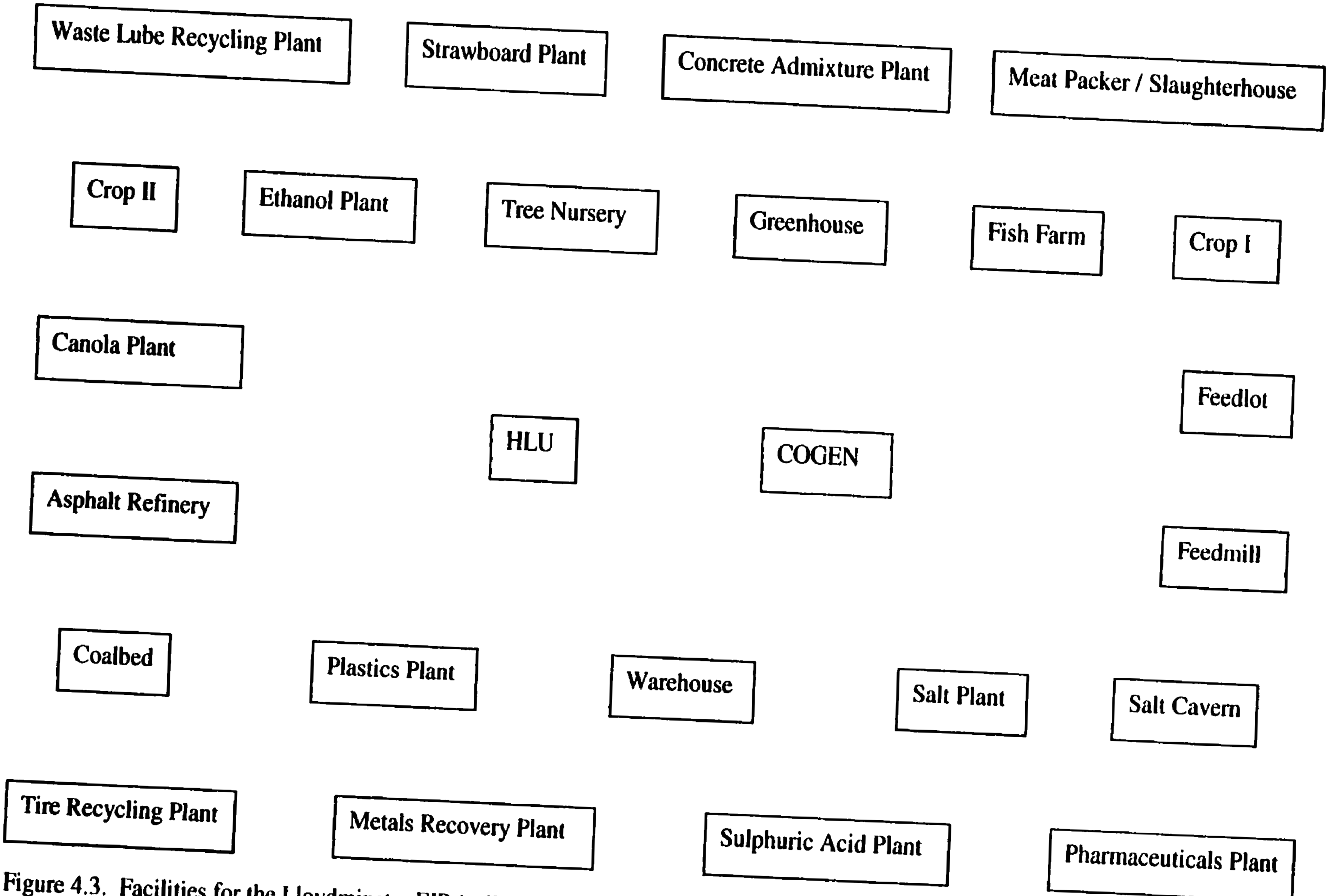


Figure 4.3. Facilities for the Lloydminster EIP (yellow = existing facility; green = potential facility; clear = geological formation).

4.2.2 Potential New Synergies

This section solely concentrates on identifying possible synergies between and amongst the existing and potential new facilities. Feasibility, economics, etc. are addressed in later sections within this study. Figure 4.4 (a-g) shows all the potential synergies identified, which includes:

- Steam
- Electricity
- Natural Gas
- Oats & Barley
- Wheat & Canola
- Straw
- Feed
- Petroleum Coke
- Tires
- Waste Lube Oil
- Sulphur
- Brine Water
- Wastewater
- Manure
- Spent Lime
- Water
- Spent Hydrocracker Catalyst
- Naturally Occurring Radioactive Material
- Naphtha
- Flue Gas
- Distiller's Dried Grains with Solubles
- Ethanol
- Clarifier Sludge
- Cattle
- Hydrocracking Residue
- Transportation Corridor

The following is a brief description of each of the potential synergies:

- Steam: The quantity of low-pressure waste steam released into the atmosphere from COGEN (262,800 t/yr) is fairly consistent and therefore, is an ideal source of steam that could be utilized by the potential new facilities for heating. This would reduce the amount of natural gas facilities require to produce their own steam, and likely would reduce the cost associated with steam. The HLU does not produce a consistent flow of low-pressure waste steam (0 to 306,600 t/yr), and therefore could only be used as a backup source of steam for the facilities supplied by COGEN.

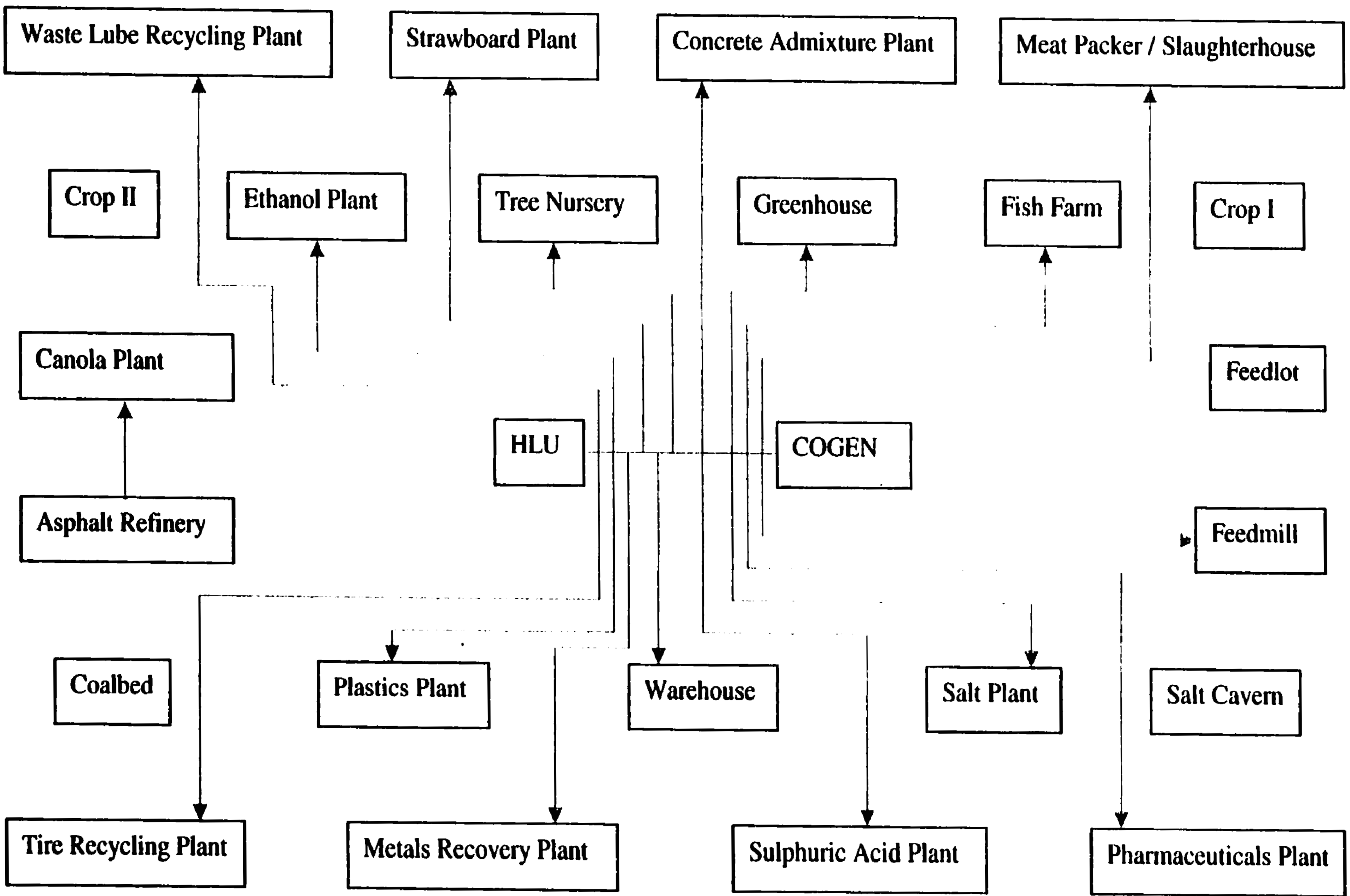


Figure 4.4(a). Potential linkages for the Lloydminster EIP: steam.

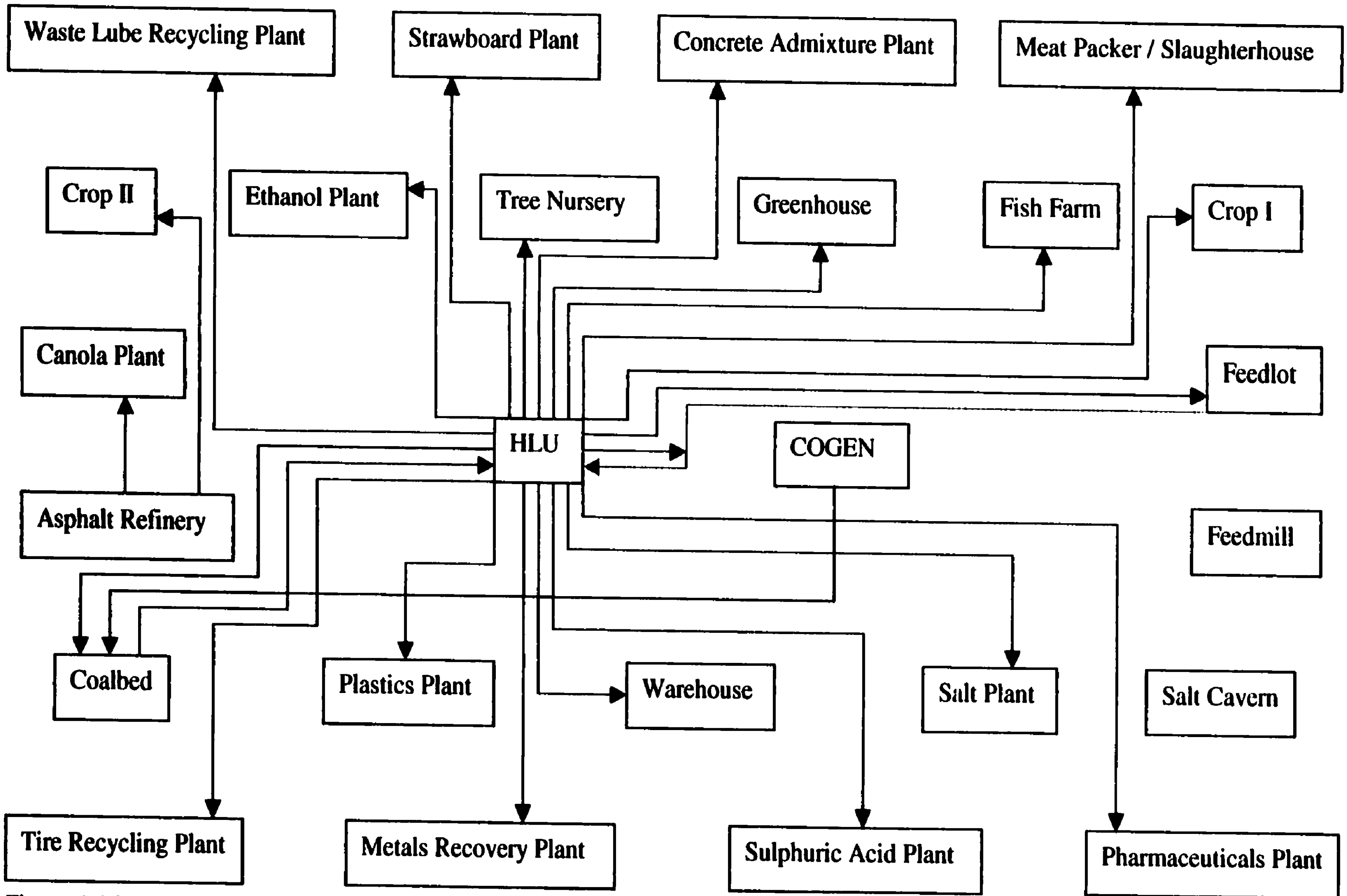


Figure 4.4(b). Potential linkages for the Lloydminster EIP: natural gas, flue gas, manure and spent lime.

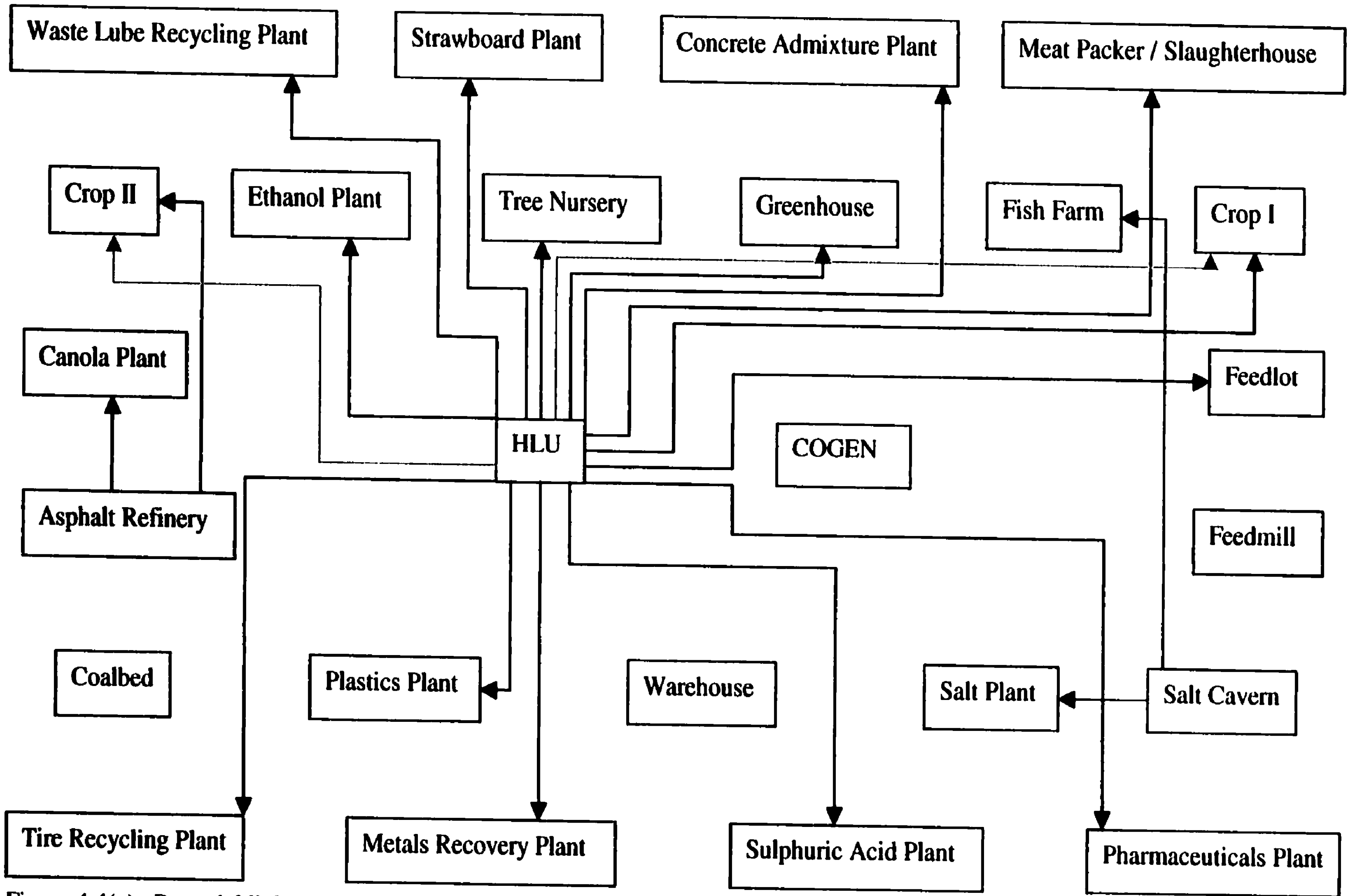


Figure 4.4(c). Potential linkages for the Lloydminster EIP: water, wastewater & brine water.

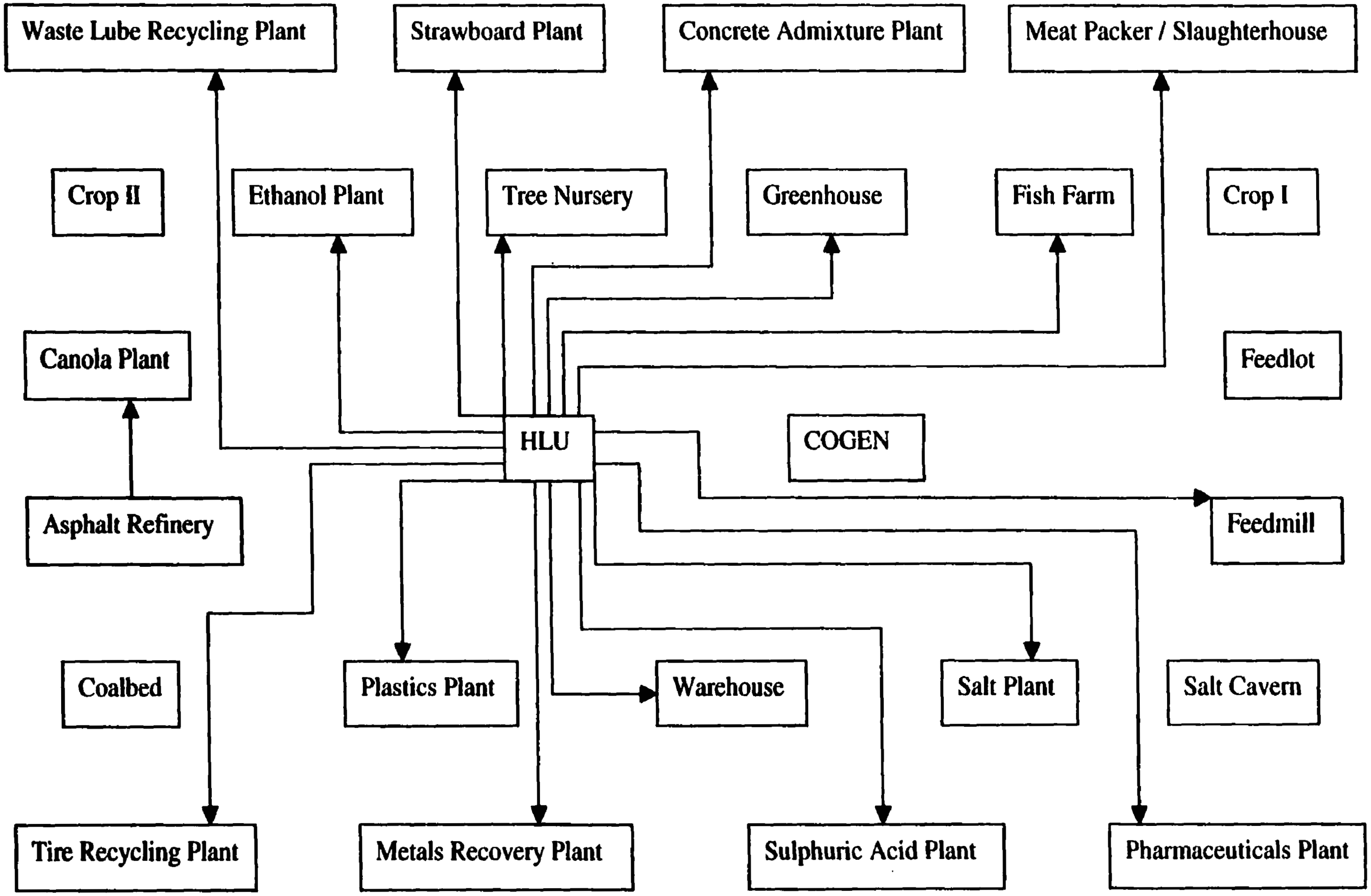


Figure 4.4(d). Potential linkages for the Lloydminster EIP: electricity.

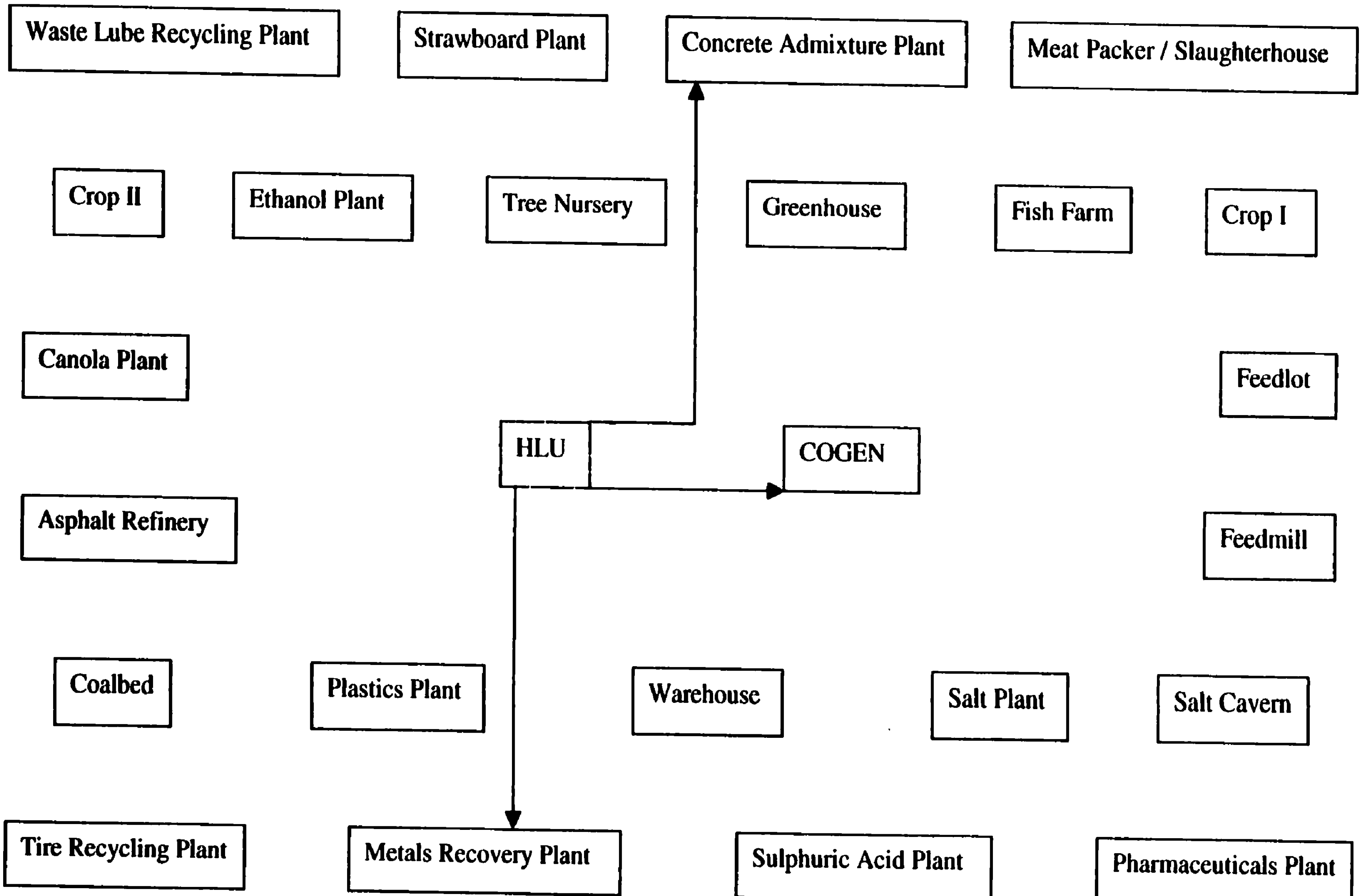


Figure 4.4(e). Potential linkages for the Lloydminster EIP: , spent hydrocracker catalyst, hydrocracking residue and petroleum coke.

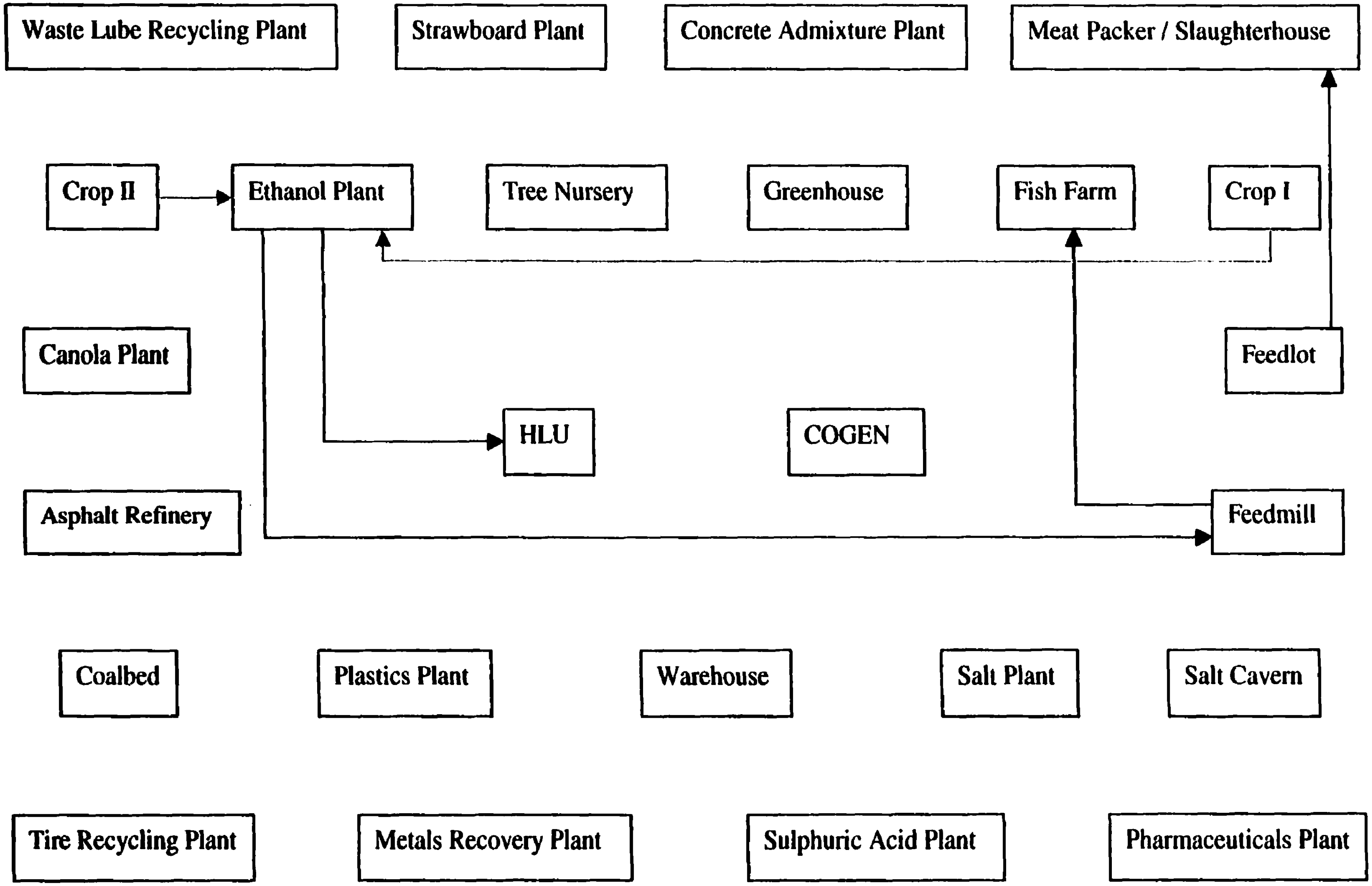


Figure 4.4(f). Potential linkages for the Lloydminster EIP: cattle, grain, , DDGS, ethanol and feed.

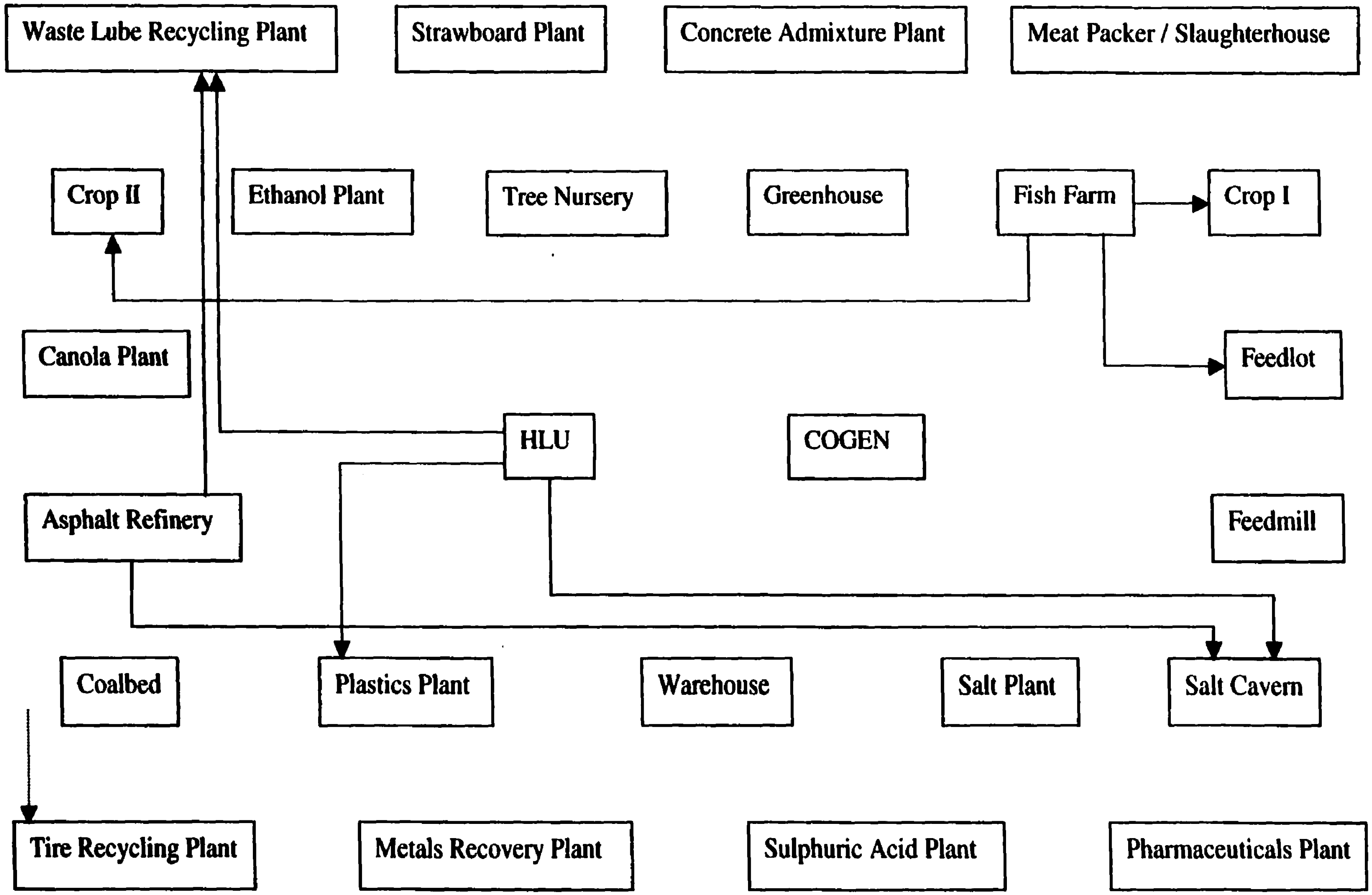


Figure 4.4(g). Potential linkages for the Lloydminster EIP: waste lube oil, NORM, naphtha, clarifier sludge and tires.

If a facility requires high-pressure steam, COGEN could provide this. The Asphalt Refinery also produces low-pressure waste steam (47 t/yr) that could be used by the Canola Plant.

- Electricity: Excess electrical power that could be supplied to the HLU could be used by the potential new facilities. Electrical power could be supplied at a reduced cost compared to the cost charged by SaskPower because the HLU receives electricity at a reduced rate.

- Natural Gas: Excess natural gas that could be supplied to the HLU and the Asphalt Refinery could be sold to the potential new facilities at a lower cost than that supplied by the pipelines. The HLU receives natural gas at a lower cost than the market price because it purchases this resource in bulk. In addition to heating, natural gas could also be used by the potential Greenhouse in the natural gas burner to produce carbon dioxide that is required since the concentration of carbon dioxide inside the Greenhouse is below that in the atmosphere.

- Oats & Barley: Currently, grain from Crop I is being used as the primary input into the Feedmill. These grains could be used as material input for the potential Ethanol Plant, which may be a more economical choice. Especially poor quality grain (weather damaged or immature), which are less suitable for livestock use, are excellent for ethanol production (Canadian Renewable Fuels Association, 1999).

- Wheat & Canola: Currently, the Canola Plant is using canola grain from Crop II. All the wheat grain is sent to Saskatchewan Wheat Pool grain elevator. Poor quality wheat and canola grain (weather damaged or immature) could also be used as material input for the potential Ethanol Plant.

- Straw: Straw from Crop I are currently being used for bedding cattle. Straw produced from Crop II is put through the combine and land applied to Crop II. It may be more economical to use straw as the main material input for the potential

Strawboard Plant. At a Strawboard Plant, straw is pressed under intense heat and pressure to create a fiberboard (Roseboro, 1998). Resins found naturally in straw acts as glue under pressure bonding it into a hard material. Strawboard can be used for floor underlayment, siding, trim, furniture, cabinets, etc.

- Feed: The Feedmill currently provides feed to the Feedlot. It could also provide feed to the potential Fish Farm.

- Petroleum Coke: Petroleum coke, commonly known as spent charcoal or carbon black, is produced in the HLU Coker unit. The majority of the petroleum coke is currently transported to overseas markets where it is utilized as a source of energy. This material could be used by COGEN for energy, which could be more economical due to the elimination of large transportation costs. The current problem with the combustion of petroleum coke is the associated SO_x and NO_x emissions. Alberta Sulphur Research Ltd. has developed a novel approach to utilize oil sands coke and refinery residues in which H_2S is used as a reducing agent for SO_2, NO_x and O_2 present in the off-gases of coke/residue combustion (Clark et al., 2001). This is currently in the testing phase.

- Tires: Tires from the study area could be collected and brought to the potential Tire Recycling Plant instead of landfilled. A Tire Recycling Plant can produce shred that can be used in many construction projects (road stabilization, leachate collection, etc.) and crumb that can be used for playgrounds, sportsfields and molded products (rubber matting, truck box liners, etc.).

- Waste Lube Oil: Waste lube oil from all the facilities in the study area could be collected and brought to the potential Waste Lube Oil Recycling Plant. The HLU and the Asphalt Refinery both generate waste lube oil. Another potential alternative is for the HLU to use the waste lube oil within its own process.

- Sulphur: Sulphur from HLU could be land applied to the soils in the area if they are sulphur deficient. Lickacz (1999) applied contaminated sulphur reclaimer tailings and byproduct gypsum as sulphur sources for forage crops. Sulphur could also be used as an input for the Sulphuric Acid Plant and/or the Pharmaceuticals Plant. In addition, sulphur could be used in the production of concrete admixtures (Sawatzky et al., 1996).

- Brine Water: Brine water produced from washing the salt caverns could be used by a Salt Plant to produce industrial salt (for example deicing salt) or by a Fish Farm to provide a salt water aquatic environment for marine fish. As effluent from the HLU is used to wash out the salt caverns, hydrocarbon contamination of the brine water may be a concern depending on the intended use. This could be rectified by treating the effluent before washing out the salt cavern, or filtering out the hydrocarbons from the brine water.

- Wastewater: Wastewater from the HLU and any other facility could be used in place of freshwater to irrigate cropland in the study area, including Crop I and II.

- Manure: Manure from the Feedlot could be anaerobically digested to produce biogas (methane) (Li & Abboud, 1999; Fulhage et al., 1993).

- Spent Lime: Spent lime from HLU and the Asphalt Refinery could be added to the anaerobic digestion of manure to maintain pH required for methane bacteria. Spent lime could also be used as a stomach buffer for acidic cattle feed. In addition, spent lime could be added to neutralize acidic soils, potentially for Crop I and II and the Feedlot.

- Water: Water from HLU is purchased at a reduced bulk rate from the City of Lloydminster. Excess water that could be supplied to the HLU could be used to irrigate Crop I and the Feedlot, and could be used by all the potential new facilities. Excess water that could be supplied to the Asphalt Refinery could be supplied to the

Canola Plant at a lower cost than supplied by the City of Lloydminster. In addition, this water from the Asphalt Refinery could be used to irrigate Crop II. Further investigation is required to determine the amount of water the Asphalt Refinery could obtain beyond that which it requires itself.

- Spent Hydrocracker (H-Oil) Catalyst: This spent catalyst is currently transported to the United States and recycled by CS Metals. The spent catalyst could be used by a Metals Recovery Plant in the Lloydminster EIP, which would significantly reduce transportation costs.

- Naturally Occurring Radioactive Material (NORM): NORM comprises of radioactive elements found in the environment. Although the concentration of NORM in most natural substances is usually low, higher concentrations may result due to human intervention (Canadian NORM Working Group, 1998). NORM is found in scaling in pipes, sludge, contaminated produce water and contaminated soil. The HLU and Asphalt Refinery could potentially have NORM. NORM from the study area could be injected into the washed out salt cavern along with the sand that is currently injected, instead of paying companies to dispose of it.

- Naphtha: Naphtha produced from HLU could be used in the process of producing plastics at a Plastics Plant.

- Flue Gas: Flue gas from burning natural gas and fuel gas at the HLU and from burning natural gas at COGEN could be injected into coalbeds (in the study area coalbeds are located in the Mannville sands). This will result in dewatering and lowering of the pressure in the coalbeds, which in turn will release methane that is trapped in the pore matrix of the coal seams (Alberta Research Council, 1998; Wong and Gunter, 1999). This methane can then be captured and utilized, which is economically advantageous. In addition, the flue gas would not be released into the atmosphere, thereby reducing greenhouse gas emissions.

- Distiller's Dried Grains with Solubles (DDGS): DDGS, commonly known as mash, is produced at the Ethanol Plant and could be used as high protein supplement in feed that is produced at the Feedmill.

- Ethanol: The Ethanol Plant could utilize grains (especially poor quality) in the area to produce ethanol to be used by the HLU to manufacture ethanol grade gasoline. Ethanol blended gasolines offer a number of advantages over petroleum fuels. There is a reduction in carbon monoxide emissions due to a more complete combustion of the fuel since it is an oxygenated gasoline (Canadian Renewable Fuels Association, 1999). There is a net reduction in carbon dioxide entering the atmosphere because more carbon dioxide is absorbed by crop growth (oats, barley, wheat and/or canola) than is released by manufacturing and using ethanol. The addition of ethanol to gasoline can permit the reduction or removal of aromatic hydrocarbons and other hazardous high-octane additives commonly used to replace tetra-ethyl lead in Canadian gasoline. Adding ethanol to gasoline also results in an overall reduction in exhaust ozone-forming potential, and therefore, a reduction in ground level ozone that causes human respiratory stress and damage to vegetation.

- Clarifier Sludge: The Fish Farm produces clarifier sludge as a byproduct that could be land applied as soil amendment within the study area, including Crop I and II and the Feedlot.

- Cattle: Cattle from the Feedlot could be used as the primary input for a Meat Packer / Slaughterhouse. Currently, there are no existing meat packers or slaughterhouses in the Lloydminster area. Setting up this type of facility in the Lloydminster EIP would eliminate large transportation costs.

- Hydrocracking Residue: Hydrocracking residue (pitch) produced from the HLU is currently being coked with a 2/3 return and a low value byproduct (coke). Hydrocracking residue could be used in the production of concrete admixtures, specifically water reducers or superplasticizers (Sawatzky et al., 1996).

- Transportation Corridor: The transportation infrastructure in the study area includes direct access to rail and truck for transport of materials by all the potential facilities.

4.3 FEASIBILITY STUDY

4.3.1 Systemic Ranking of Potential New Facilities

The systemic ranking of each of the potential new facilities discussed in section 4.2 is given in Table 4.3. The following provides an explanation for each facility's rank. Note that the market evaluation for each product was limited to the study area for this project.

- Concrete Admixture Plant: The formation of concrete admixtures (water reducers or superplasticizers) using hydrocarbon residues and sulphur products is currently in the testing phase. Laboratory testing has been conducted and has given positive results (Sawatzky et al., 1996). If pilot testing proves to be successful and this technology is used, the hydrocarbon residues are available from the HLU. Sulphur is also available from the HLU, which can be sulphonated to SO_3 feed by the Sulphuric Acid Plant. The market in the Lloydminster area for concrete admixtures is not significant because concrete is not in high demand in this largely agricultural and oil related area. This type of facility is sustainable because concrete admixtures are an important component in the concrete business at present and in the foreseeable future. This facility's potential ties, primarily with the HLU, also contribute to its sustainability as a business in this area.

Table 4.3. Systemic ranking of potential new facilities.

Potential New Facility	Sufficiency of Material Inputs	Sufficient Markets for Product Outputs	Economic Sustainability	Total
Concrete Admixture Plant	1	0	1	2
Ethanol Plant	1	0	1	2
Fish Farm	1	1	1	3
Greenhouse	1	1	1	3
Meat Packer / Slaughterhouse	1	1	0	2
Metals Recovery Plant	0	1	0	1
Pharmaceuticals Plant	0	1	1	2
Plastics Plant	0	1	1	2
Salt Plant	1	1	0	2
Strawboard Plant	0	0	1	1
Sulphuric Acid Plant	1	0	1	2
Tree Nursery	1	0	1	2
Tire Recycling Plant	0	1	0	1
Warehouse	1	1	1	3
Waste Lube Recycling Plant	0	1	1	2

- Ethanol Plant: Wheat and canola grain are available from Crop II and oats and barley grain are available from Crop I. Additional requirements for grains should be met by other existing crops in the area and by the SaskPool grain elevator. There is a market for ethanol blended gasoline in the areas that the HLU delivers to, but the Lloydminster market is small in comparison to the output of a typical ethanol plant. Due to the fact that this study focuses on the Lloydminster area, considering the market outside of Lloydminster (which may in fact be large) is beyond the scope of this study. The Ethanol Plant should be a sustainable business due to its direct connection with the HLU for its product output. It is also sustainable due to the fact that it can rely heavily on poor quality grain and the study area is largely agricultural based.

- Fish Farm: Water is one of the largest inputs for the Fish Farm, and it is readily available due to the Saskatchewan River. The Fish Farm could purchase the water through the HLU or directly from the City of Lloydminster. Heat is another important requirement for the Fish Farm, which could be met by using the waste steam from COGEN and HLU. As for the market for trout in the study area, it is fairly good because there are no other fish farms and there are no large bodies of water like lakes or oceans from which to catch the fish (Wendell James, Alberta Research Council, personal communication). Currently, trout in the City of Lloydminster is imported from other areas. The Fish Farm is a sustainable business because it provides an edible product that will always be used by the people in the City of Lloydminster and because it uses a water recirculation system making it efficient and cost-effective.

- Greenhouse: One of the largest inputs into the Greenhouse is water, which is readily available from the Saskatchewan River. The Greenhouse could purchase the water through the HLU or directly from the City of Lloydminster. Waste steam from COGEN and HLU could provide the heat that is required. The market for tomatoes in the study area is fairly good because there are no other tomato greenhouses in the area and because tomatoes are an edible product that is used by the people in the City of

Lloydminster (Dr. Mirza, Crop Diversification Centre North, personal communication). The Greenhouse is sustainable because there always will be a demand for the product being produced.

- Meat Packer / Slaughterhouse: The Feedlot produces cattle that could be sent to the Meat Packer / Slaughterhouse. There is a market for slaughtering and packaging meat because there are no other meat packers / slaughterhouses in the study area, and yet there are a number of feedlots in the surrounding area (Jack Hill, Dyjack Farms Ltd., personal communication). This facility is not sustainable due to its size. Meat packing and slaughtering is a volume-based business (Brian Barrett, Red Deer Lake Meat Processing Ltd., personal communication). This facility would be relatively small due to inputs compared to the large commercial meat packers / slaughterhouses who dominate this business.

- Metals Recovery Plant: HLU produces spent hydrocracker catalyst as a byproduct that could be used by the Metals Recovery Plant, but the quantity is not substantial to set up this sort of business. Currently, there are no metal recovery plants in the Lloydminster area (or Canada), so there is a market for this type of business. This type of business does not seem to be very sustainable because it relies heavily on the supply of an input (spent hydrocracker catalyst) that does not have a guaranteed stable inflow.

- Pharmaceuticals Plant: Sulphur is available for the Pharmaceuticals Plant from the HLU, but many of the other chemicals and materials are not readily available. There is a market for pharmaceutical products because of the concentration of people situated in the City of Lloydminster. This type of business is sustainable because there will always be a demand for sulphur drugs.

- Plastics Plant: Naphtha from the HLU can be utilized by the Plastics Plant, but the supply does not justify setting up this type of business. There is a market for plastics in the City of Lloydminster. Furthermore, this type of business is sustainable due to the vast use of plastics in almost all facets of everyday life.

- Salt Plant: Brine water produced from washing the salt caverns could be used as the primary input for the Salt Plant. There is a market for salts in the Lloydminster area, and there are no other salt companies in the area. But this facility is not sustainable because salt manufacturing is a volume-based business and there is not enough brine water for this facility to produce the amount of salt produced by other salt companies. Salt cavern #1 is washed at about 40 m^3/hr for 10 hours while sand is being injected. At night (the remaining 14 hours) it is washed at 100 m^3/d. Salt cavern #2 is washed at a rate of 100 m^3/hr for 24 hours. Therefore, 4200 m^3/d of effluent is used to washout the salt caverns. For a first estimate, let us assume that all the effluent used to washout the caverns is recovered. This brine water is approximately 23% saturated and has a density of about 1.18 g/m^3 (Brian Gettis, Husky Energy Inc., personal communication). The calculated amount of salt that can be produced from the brine water is about 5 kg/d, which is insignificant compared to a typical salt plant. For example, the Windsor Salt Plant produces approximately 440 tonnes of salt per day (Ken Palamarek, Windsor Salt Plant, personal communication). Therefore, the larger salt companies would put this one out of business. If there was enough brine water to support a large salt plant, then it would be a sustainable business because salt caverns would be continuously washed in order to dispose of sand that is continuously produced.

- Strawboard Plant: Straw from Crop I is currently being used for bedding cattle. Strawboard could be used for constructing homes, but there is no existing market for strawboard in the City of Lloydminster. If strawboard were more readily used, this could be a sustainable business in the study area due to the large amount of croplands in the surrounding area that could potentially provide straw.

- Sulphuric Acid Plant: Sulphur, which is the main input for the Sulphuric Acid Plant, is readily available from the HLU. But there is not a large market for sulphuric acid in the study area. If the Concrete Admixture Plant or a fertilizer plant were part of the EIP, then there would be a larger market. The Sulphuric Acid Plant is a sustainable business because sulphuric acid is a chemical that will always be required.

- Tree Nursery: Water and heat are the primary requirements for the Tree Nursery. Water is available either directly from the City of Lloydminster, or from the HLU. Heat could be provided by COGEN's and HLU's waste steam. The market for tree seedlings is saturated within the study area (Al Nanka, Forestry Canada: Northern Forestry Center, personal communication). There are a number of tree nurseries in close proximity to the study area. This industry is sustainable due to logging requirements (i.e. trees will always be required).

- Tire Recycling Plant: At one time, tires were stockpiled, but there are no longer an abundance of used tires (Ian O'Neil, Alberta Tire Recycling, personal communication). There are three tire-recycling facilities in Saskatchewan. There are a number of new markets for tire recycling as new value-added products and uses have been created. But this industry is not sustainable, as the quantity of used tires available continues to decrease.

- Warehouse: The most important aspect of the Warehouse is transportation. The transportation corridor in the study area is ideal for establishing a storage Warehouse. The market for importing and exporting materials is huge due to the study area being predominately oil & gas and agriculture related. The Warehouse is a sustainable business because materials will always need to be stored and transported from one location to another.

- Waste Lube Recycling Plant: There are substantial amounts of waste lube oil generated in the study area, but companies involved in collection and recycling (such as Litter Dipper, NewAlta) already exist that limit the availability of the waste lube oil (Jim Watt, Hazco, personal communication). These companies are not located within the study area and therefore, transportation costs are significant. There is a market for recycled waste lube oil in the study area, and this industry is sustainable because waste lube oil will continue to be generated.

The following were deemed to have the highest ranking according to Table 4.3:

- Fish Farm
- Greenhouse
- Warehouse

The medium ranked facilities included:

- Concrete Admixture Plant
- Ethanol Plant
- Meat Packer / Slaughterhouse
- Pharmaceuticals Plant
- Plastics Plant
- Salt Plant
- Sulphuric Acid Plant
- Tree Nursery
- Waste Lube Recycling Plant

The lowest ranked facilities from this study were:

- Metals Recovery Plant
- Strawboard Plant
- Tire Recycling Plant

The remainder of this study focuses on the Lloydminster EIP constituting of the selected existing facilities and the feasible facilities (the highest ranked potential facilities). For each of the feasible facilities, the gathered information is listed in Appendix C and the annual material and resource flow diagrams are shown in Appendix D.

4.3.2 Feasible Synergies

Based on the selected most feasible facilities and from further evaluation of individual possible synergies, the following was determined:

- Low-Pressure Steam: Low-pressure steam could be provided from COGEN (HLU being a backup source) to the Warehouse, Fish Farm and Greenhouse for heating.

- Electricity: Excess electricity that could be supplied to the HLU could be provided to the Feedmill, Warehouse, Fish Farm and Greenhouse.

- Natural Gas: Excess natural gas that could be supplied to the HLU could be provided to the Greenhouse for the natural gas burner.

- Water: Excess water that could be supplied to the HLU could be provided to the Fish Farm and Greenhouse. If the Asphalt Refinery's water supply permits, it could provide this resource to the Canola Plant. At present, Crop I and II have successfully relied on rainwater, and therefore fixing a supply of water to the croplands is not necessary.

- Flue Gas: Flue gas emitted to the atmosphere from the HLU and COGEN could be reduced by subsurface injection into deep coalbeds located in the study area. This would reduce greenhouse gas emissions and enhance coalbed methane production. Methane production from coalbed methane reservoirs is affected by a number of reservoir and geologic factors, such as permeability, water saturation, reservoir pressure, sorption rate and gas content (Hunt & Steele, 1992). An extensive geological and economic study is required to determine if flue gas injection is a viable option in this area.

- Spent Lime: Feed produced at the Feedmill is not very acidic, and therefore, spent lime is not required as a stomach buffer for cattle (John Fox, Justamere Farms Ltd., personal communication). Spent lime could be added to acidic soils. This would be economically advantageous because the spent lime would no longer have to be landfilled, and therefore, disposal costs would be eliminated. A study is required investigating the pH of the soils in the Lloydminster area to determine if the soils are in fact acidic.

- Clarifier Sludge: A study is required to determine if clarifier sludge produced from the Fish Farm should be land applied.

- Sulphur: A study is required to determine if the soils are sulphur deficient in the study area. If the soils are found to be sulphur deficient, than sulphur from the HLU could be added to the soil.

- NORM: A study is required to determine the concentrations of NORM within the facilities in the study area. NORM could be injected into the salt cavern, and the HLU owning the salt cavern could make a profit by charging other companies a fee. Currently facilities pay companies such as NORMCAN to collect NORM from their facilities and dispose of them. These NORM disposing companies usually either landfill NORM or deep-well inject NORM. Further research is required to address environmental issues, liability issues, etc. in injecting NORM into salt caverns.

- Petroleum Coke: Research done by the Alberta Sulphur Research Ltd. shows that there is a potential to combust coke and the refinery residues using H_2S as a reducing agent (Clark et al., 2001). Further research is required to determine if it is feasible to utilize petroleum coke by COGEN for energy.

- Brine Water: Brine water produced from washing the HLU's salt cavern is currently disposed of through deep well injection. Investigation into the contaminants in this brine water are required to determine if it does in fact meet the specifications required for a marine Fish Farm. If it does not meet the requirements, options to treat the brine water should be evaluated (such as skimmers).

- Wastewater: Wastewater from the Lloydminster area is already being used to irrigate land. Wastewater produced within the Lloydminster EIP could be accepted by the HLU and used for washing the salt caverns.

- Waste Lube Oil: Further research is required to determine if waste lube oil can be utilized within the upgrading process at the HLU without compromising the system.

- Oats & Barley, Wheat & Canola, Straw, Feed and Manure: All grain, straw, feed and manure are being fully utilized at this time by the existing facilities in the area.

Figure 4.5 provides a depiction of the Lloydminster EIP at this point.

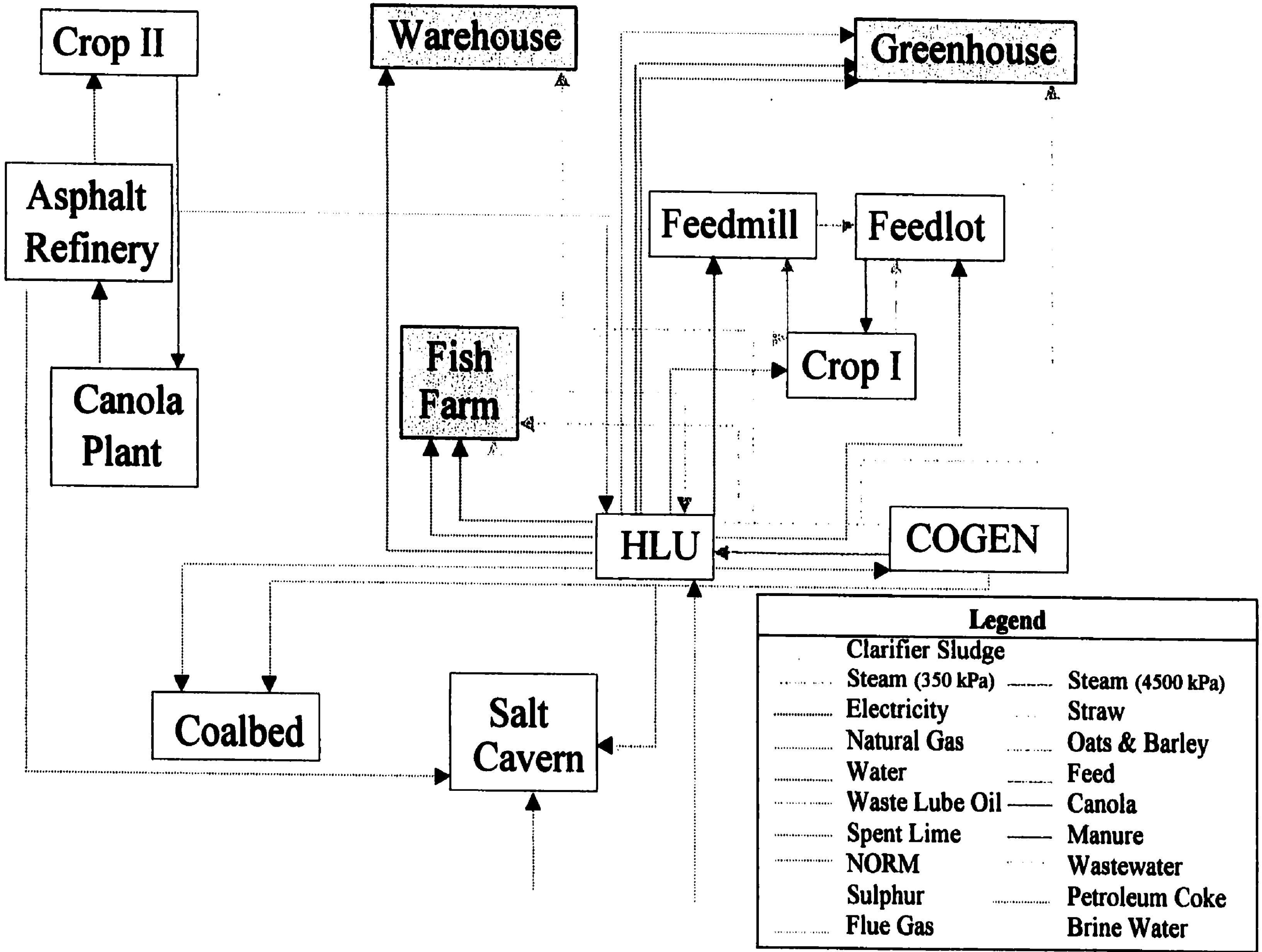


Figure 4.5. The Lloydminster EIP (yellow = existing facility; blue = feasible facility; clear = geological formation).

4.4 ECONOMIC ANALYSIS

4.4.1 Supply and Demand within Eco-Industrial Park

Table 4.4 provides information regarding the supply and demand of resources within the Lloydminster EIP. This includes the following supply-demand relationships:

- COGEN provides an ample supply of low-pressure steam to meet the demands of the Fish Farm, Greenhouse and Warehouse. Low-pressure steam from the HLU is used to supplement (backup) COGEN's supply. High-pressure steam from COGEN is not required for heating due to the sufficient supply of low-pressure steam.

- The Asphalt Refinery cannot provide enough low-pressure steam to meet the demand of the Canola Plant.

- The HLU can provide more than enough water to meet the requirements of both the Fish Farm and the Greenhouse. Information is not available regarding the amount of water the Asphalt Refinery could supply to the Canola Plant.

- Natural gas requirements exclude that which is required for boilers because waste steam is being used in its place. HLU has the capability to supply quantities of natural gas in excess of what is required by the Greenhouse.

- The demand for electricity by the Fish Farm, Greenhouse, Warehouse and Feedmill are more than met by the amount of electricity the HLU can provide.

- The Fish Farm's wastewater can be absorbed by the HLU's effluent stream that is currently used to washout salt caverns for sand disposal.

Table 4.4. Demand and supply of resources within the Lloydminster EIP.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Low-Pressure Steam	HLU COGEN	0-306,600 t/yr 262,800 t/yr	262,800 t/yr	Fish Farm	1,026 t/yr	8,584 t/yr
				Greenhouse	7,008 t/yr	
				Warehouse	550 t/yr	
	Asphalt Refinery	47 t/yr	47 t/yr	Canola Plant	244,940 t/yr	244,940 t/yr
High-Pressure Steam	COGEN	876,000 t/yr	876,000 t/yr	*Not required due to ample low-pressure steam*		
Water	HLU	5,526,684 m3/yr	5,526,684 m3/yr	Fish Farm	2,133 m3/yr	5,839 m3/yr
				Greenhouse	3,706 m3/yr	
	Asphalt Refinery	*Not available*	*Not available*	Canola Plant	77,291 m3/yr	77,291 m3/yr
Natural Gas (excluding requirements for boilers)	HLU	9,541,000 GJ/yr	9,541,000 GJ/yr	Greenhouse	3,230 GJ/yr	3,230 GJ/yr
Electricity	HLU	131,400,000 kWh/yr	131,400,000 kWh/yr	Fish Farm	186,880 kWh/yr	546,796 kWh/yr
				Greenhouse	100,916 kWh/yr	
				Warehouse	56,000 kWh/yr	
				Feedmill	200,000 kWh/yr	
Wastewater Disposal	HLU	700,800 t/yr	700,800 t/yr	Fish Farm	2,000 m3/yr	2000 t/yr
Land	HLU	200 ac	200 ac	Fish Farm	1 ac	6 ac
				Greenhouse	4 ac	
				Warehouse	1 ac	

- The HLU can provide ample land for co-location of the Fish Farm, Greenhouse and Warehouse in the Lloydminster EIP.

It is apparent from Table 4.4 that the supply of resources meets the demand of resources within the Lloydminster EIP, except for low-pressure steam and maybe water (because supply information is not available) from the Asphalt Refinery to the Canola Plant. Therefore, these are the only linkages that will not be pursued further past this point of the study.

4.4.2 Economic Profile of Each Facility

Conservative estimates of market prices were used for product sale prices for each facility. The economic profile and discounted payback periods generated for each facility are presented in Table 4.5 (a-c).

Generic economic profiles were altered, as explained below, to fit with the Lloydminster EIP. Items that are shaded indicate these were added to the generic profiles from which the economic profiles were adopted. All dollar values that were altered from the generic economic profiles are also shaded. All item costs are estimates, and therefore, the values have been rounded to even hundreds.

- Property cost is a part of the capital investment for non-EIP members. This is not the case for EIP members because they would rent land from the anchor facility. The anchor facility has approximately 200 acres of available land that can be leased. The assumed property cost is $100,000 per acre for non-EIP members and the assumed annual property rent is $3,000 per acre for profit-EIP members (70%-, 50%- and 30%-EIP members) (Dave Kay, Husky Energy Inc., personal communication). Property tax, which applies to non-EIP members is $1000 yearly per acre. Free-trade-EIP members do not pay a capital property cost nor an

Table 4.5(a). Economic profile of Fish Farm (adopted from James, 1997).

Item	Non-EIP Member Capital Investment	EIP Member 70% Markup Capital Investment	EIP Member 50% Markup Capital Investment	EIP Member 30% Markup Capital Investment	EIP Member Free Trading Capital Investment
Property	$100,000	none	none	none	none
Building - insulated pole barn	$55,700	$55,700	$55,700	$55,700	$55,700
Indoor drain plumbing	$4,200	$4,200	$4,200	$4,200	$4,200
Building plumbing	$8,800	**$6,100**	**$6,100**	**$6,100**	**$6,100**
Effluent system	$4,200	**$1,000**	**$1,000**	**$1,000**	**$1,000**
Electrical	$10,000	$10,000	$10,000	$10,000	$10,000
Pumps	$4,000	$4,000	$4,000	$4,000	$4,000
Reservoir tank	$2,100	$2,100	$2,100	$2,100	$2,100
Biofilter & media	$2,500	$2,500	$2,500	$2,500	$2,500
Clarification system	$3,000	$3,000	$3,000	$3,000	$3,000
Room for ozone equipment	$2,000	$2,000	$2,000	$2,000	$2,000
Feeding system (mechanical)	$3,800	$3,800	$3,800	$3,800	$3,800
Harvesting equipment	$2,800	$2,800	$2,800	$2,800	$2,800
Water quality monitoring	$6,500	$6,500	$6,500	$6,500	$6,500
Emergency oxygen system	$2,000	$2,000	$2,000	$2,000	$2,000
Backup generator	$8,000	$8,000	$8,000	$8,000	$8,000
Oxygen generator	$15,000	$15,000	$15,000	$15,000	$15,000
Air compressor	$6,500	$6,500	$6,500	$6,500	$6,500
Ozone generator	$20,000	$20,000	$20,000	$20,000	$20,000
Hatching equipment	$3,000	$3,000	$3,000	$3,000	$3,000
Early rearing tanks	$4,000	$4,000	$4,000	$4,000	$4,000
Truck	$30,000	$30,000	$30,000	$30,000	$30,000
Tanks	$17,900	$17,900	$17,900	$17,900	$17,900
Total	**$316,000**	**$210,100**	**$210,100**	**$210,100**	**$210,100**
	Maintenance Costs	**Maintenance Costs**	**Maintenance Costs**	**Maintenance Costs**	**Maintenance Costs**
Total	$5,700	$5,700	$5,700	$5,700	$5,700
Item	**Operating Costs**	**Operating Costs**	**Operating Costs**	**Operating Costs**	**Operating Costs**

	Costs	Costs	Costs	Costs	Costs
Total	$5,700	$5,700	$5,700	$5,700	$5,700
Item	**Operating Costs**	**Operating Costs**	**Operating Costs**	**Operating Costs**	**Operating Costs**
Property Rental	none	$3,000	$3,000	$3,000	none
Property Tax	$1,000	none	none	none	$1,000
Steam	none	$4,200	$3,000	$1,800	$0
Natural Gas	$5,600	none	none	none	none
Electricity	$14,016	$11,800	$10,300	$8,800	$6,600
Water	$4,500	$3,300	$2,500	$1,700	$600
Oxygen	$5,500	$5,500	$5,500	$5,500	$5,500
Eggs	$3,400	$3,400	$3,400	$3,400	$3,400
Feed	$164,300	$164,300	$164,300	$164,300	$164,300
Ozonation	$2,700	$2,700	$2,700	$2,700	$2,700
Telephone	$3,000	$3,000	$3,000	$3,000	$3,000
Pharmaceutical	$1,000	$1,000	$1,000	$1,000	$1,000
Diesel	$600	$600	$600	$600	$600
Fees & Licenses	$3,100	$3,100	$3,100	$3,100	$3,100
Insurance	$1,500	$1,500	$1,500	$1,500	$1,500
Advertising	$1,000	$1,000	$1,000	$1,000	$1,000
Travel	none	none	none	none	none
Truck Ins. & License	$500	$500	$500	$500	$500
Fuel	$1,000	$1,000	$1,000	$1,000	$1,000
Payroll	$110,000	$110,000	$110,000	$110,000	$110,000
Miscellaneous	$2,000	$2,000	$2,000	$2,000	$2,000
Total	$324,716	$321,900	$318,400	$314,900	$307,800
Item	**Gross Revenue**	**Gross Revenue**	**Gross Revenue**	**Gross Revenue**	**Gross Revenue**
fish	$398,600	$398,600	$398,600	$398,600	$398,600
Total	$398,600	$398,600	$398,600	$398,600	$398,600
Net Revenue	$68,184	$71,000	$74,500	$78,000	$85,100
Taxes (30%)	$20,455	$21,300	$22,350	$23,400	$25,530
After Tax Cash Flow	$47,729	$49,700	$52,150	$54,600	$59,570
Discounted Payback Period	13.96	6.25	5.83	5.47	4.86

Table 4.5(b). Economic profile of Greenhouse (adopted from Mirza, 1998).

	Non-EIP Member	EIP Member 70% Markup	EIP Member 50% Markup	EIP Member 30% Markup	EIP Member Free Trading
	Capital Investment	Capital Investment	Capital Investment	Capital Investment	Capital Investment
Boiler	$14,000	$0	$0	$0	$0
Property	$400,000	$0	$0	$0	$0
Other	$440,900	$440,900	$440,900	$440,900	$440,900
Total	$854,900	$440,900	$440,900	$440,900	$440,900
Item	Maintenance Costs	Maintenance Costs	Maintenance Costs	Maintenance Costs	Maintenance Costs
Auto Fuel & Repairs	$3,000	$3,000	$3,000	$3,000	$3,000
Building & Machinery Repairs	$14,000	$14,000	$14,000	$14,000	$14,000
Total	$17,000	$17,000	$17,000	$17,000	$17,000
Item	Operating Costs	Operating Costs	Operating Costs	Operating Costs	Operating Costs
Property Rental	none	$12,000	$12,000	$12,000	none
Property Tax	$4,000	none	none	none	$4,000
Steam	none	$28,100	$20,000	$12,100	$0
Natural Gas	$47,800	$9,500	$9,500	$9,500	$9,400
Electricity	$7,600	$6,400	$5,600	$4,800	$3,600
Water	$7,800	$5,800	$4,400	$3,000	$1,000
Growing Media, Seed/Cuttings	$17,100	$17,100	$17,100	$17,100	$17,100
Fertilizer & Chemicals	$25,800	$25,800	$25,800	$25,800	$25,800
Telephone	$2,300	$2,300	$2,300	$2,300	$2,300
Insurance	$9,100	$9,100	$9,100	$9,100	$9,100
Auto Insurance & Registration	$500	$500	$500	$500	$500
Accounting & Legal	$1,700	$1,700	$1,700	$1,700	$1,700
Office Supplies	$600	$600	$600	$600	$600
Travel, Advertising & Soil Testing	$1,100	$1,100	$1,100	$1,100	$1,100
Marketing Costs & Freight	none	none	none	none	none
Payroll	$150,000	$150,000	$150,000	$150,000	$150,000
Miscellaneous	$51,300	$51,300	$51,300	$51,300	$51,300
Total	$326,700	$321,300	$311,000	$300,900	$277,500

Payroll	$150,000	$150,000	$150,000	$150,000	$150,000
Miscellaneous	$51,300	$51,300	$51,300	$51,300	$51,300
Total	$326,700	$321,300	$311,000	$300,900	$277,500
Item	**Gross Revenue**	**Gross Revenue**	**Gross Revenue**	**Gross Revenue**	**Gross Revenue**
tomatoes	**$477,000**	**$477,000**	**$477,000**	**$477,000**	**$477,000**
Total	**$477,000**	**$477,000**	**$477,000**	**$477,000**	**$477,000**
Net Revenue	$133,300	$138,700	$149,000	$159,100	$182,500
Taxes (30%)	**$39,990**	**$41,610**	**$44,700**	**$47,730**	**$54,750**
After Tax Cash Flow	**$93,310**	**$97,090**	**$104,300**	**$111,370**	**$127,750**
Discounted Payback Period	**Never Pays Out**	**6.95**	**6.25**	**5.69**	**4.72**

Table 4.5(c). Economic profile of Warehouse (adopted from Tompkins, 1988).

	Non-EIP Member	EIP Member	EIP Member	EIP Member	EIP Member
		70% Markup	50% Markup	30% Markup	Free Trading
Item	Capital Investment	Capital Investment	Capital Investment	Capital Investment	Capital Investment
Building	$3,150,000	$3,147,300	$3,147,300	$3,147,300	$3,147,300
Racks	$2,100,000	$2,100,000	$2,100,000	$2,100,000	$2,100,000
One-Time Expense	$800,000	$800,000	$800,000	$800,000	$800,000
Property	$100,000	none	none	none	none
Total	$6,150,000	$6,047,300	$6,047,300	$6,047,300	$6,047,300
Item	O & M Costs	O & M Costs	O & M Costs	O & M Costs	O & M Costs
Property Rental	none	$3,000	$3,000	$3,000	none
Property Tax	$1,000	none	none	none	$1,000
Steam	none	$2,400	$1,700	$1,000	$0
Natural Gas	$3,000	none	none	none	none
Electricity	$4,200	$3,500	$3,100	$2,700	$2,000
Payroll	$110,000	$110,000	$110,000	$110,000	$110,000
Miscellaneous	$72,000	$72,000	$72,000	$72,000	$72,000
Total	$190,200	$190,900	$189,800	$188,700	$185,000
Item	Gross Revenue	Gross Revenue	Gross Revenue	Gross Revenue	Gross Revenue
	$2,292,878	$2,292,878	$2,292,878	$2,292,878	$2,292,878
Total	$2,292,878	$2,292,878	$2,292,878	$2,292,878	$2,292,878
Net Revenue	$2,102,678	$2,101,978	$2,103,078	$2,104,178	$2,107,878
Taxes (30%)	$630,803	$630,593	$630,923	$631,253	$632,363
After Tax Cash Flow	$1,471,875	$1,471,385	$1,472,155	$1,472,925	$1,475,515
Discounted Payback Period	6.14	6.00	5.99	5.99	5.97

annual property rent, but they do have to cover the tax on the property, which the anchor facility would otherwise have to pay.

- Natural gas is no longer required for the Fish Farm and Warehouse if they are EIP members because steam is used for heating instead of natural gas driven boilers. This is also the case for the Greenhouse, except for 20% that is required for the natural gas burner. The anchor facility purchases natural gas at a bulk price, and thus is able to supply it to the EIP member Greenhouse at a lower price than the non-EIP member Greenhouse would receive from ATCO Gas:

$$\text{purchase price} = \text{HLU cost} + \%\text{markup}\,(\text{ATCO cost} - \text{HLU cost}) \quad (4.1)$$

- Low-pressure steam from the anchor facility can be used to heat buildings, water, etc. Therefore, boilers and associated natural gas are no longer required for EIP members, and were subtracted from the capital cost and operating cost, respectively. For the free-trade-EIP member, low-pressure steam is free. For other EIP members the cost is calculated using the following equations (adopted from Brealey & Myers, 1996):

$$PV = B + NG/(1+i) + NG/(1+i)^2 + \ldots NG/(1+i)^t \quad (4.2)$$
$$= B + NG((1-v^t)/i)$$
$$= B + NG(a_{\overline{t}|i})$$

Since cost of steam for an EIP member is a certain percentage of the avoided cost:

$$ST(a_{\overline{t}|i}) = \%\text{markup}\,(B + NG(a_{\overline{t}|i})) \quad (4.3)$$

where,
PV = present value
B = boiler cost *(see Table 4.6)*
NG = natural gas cost

ST = steam cost

$a_{\overline{t}|i}$ = annuity immediate (Kellison, 1991)

i = internal rate of return *(assumed to be 12%)*

t = boiler life *(assumed to be 20 years)*

v = 1 / (1 + i)

Table 4.6. Estimated costs for various boilers.

Facility	Heating Requirement (kW)	Boiler Cost ($)
Fish Farm	60	2,700
Greenhouse	410	14,000
Warehouse	32	2,700

Table 4.6 provides estimated costs for the various boilers according to heating requirements (Gerry Williscroft, Allied Engineering Company, personal communication). The heating requirement for each facility was determined from the amount of natural gas utilized for heating.

- As seen in Table 4.4, the anchor facility can provide the EIP members with water, and it can do so at a lower cost than the City of Lloydminster. This is because the anchor facility purchases water at a bulk price. The water cost for free-trade-EIP members is equivalent to this bulk cost, and for the other EIP members is assumed to be:

(4.4)

purchase price = HLU cost + %markup (City of Lloydminster cost – HLU cost)

- Electricity requirements by EIP members can also be fulfilled by the anchor facility, as evident in Table 4.4. The anchor facility also purchases electricity at a lower cost than that charged by SaskPower. The cost of electricity is this bulk cost for the free-trade-EIP members. For EIP members it is assumed to be:

$$\text{purchase price} = \text{HLU cost} + \text{\%markup}\,(\text{SaskPower cost} - \text{HLU cost}) \tag{4.5}$$

- The effluent system was assumed to cost much less for an EIP member than a non-EIP member. This is because the anchor facility can absorb the EIP member's effluent into its own effluent stream that is used to washout the salt cavern. Therefore, it is assumed that all of the effluent from the Fish Farm could be taken by the anchor facility (resulting in an assumed effluent system saving of $3,200). The anchor facility is in the process of beginning to wash a new salt cavern, therefore a large increase in water (effluent) supply will be required.

- Travel, marketing and freight costs were assumed to not be required in this study for EIP and non-EIP members due to the location of the facilities being close to the market, the City of Lloydminster.

- Payroll was assumed to be $50,000 per year for management level positions, $40,000 per year for skilled labour and $30,000 for general labour.

- Auto insurance, registration, repair and fuel consumption were assumed to be lower than the generic economic profiles due to the close proximity of the facilities to the Lloydminster market.

The discounted payback periods are graphically depicted in Figure 4.6 (a-c).

Fish Farm

There is a significant difference in discounted payback periods between a Fish Farm co-locating in the Lloydminster EIP or locating outside the EIP, as shown in Figure 4.6(a). For a non-EIP member, the discounted payback period is more than double of that of a 70%-EIP member.

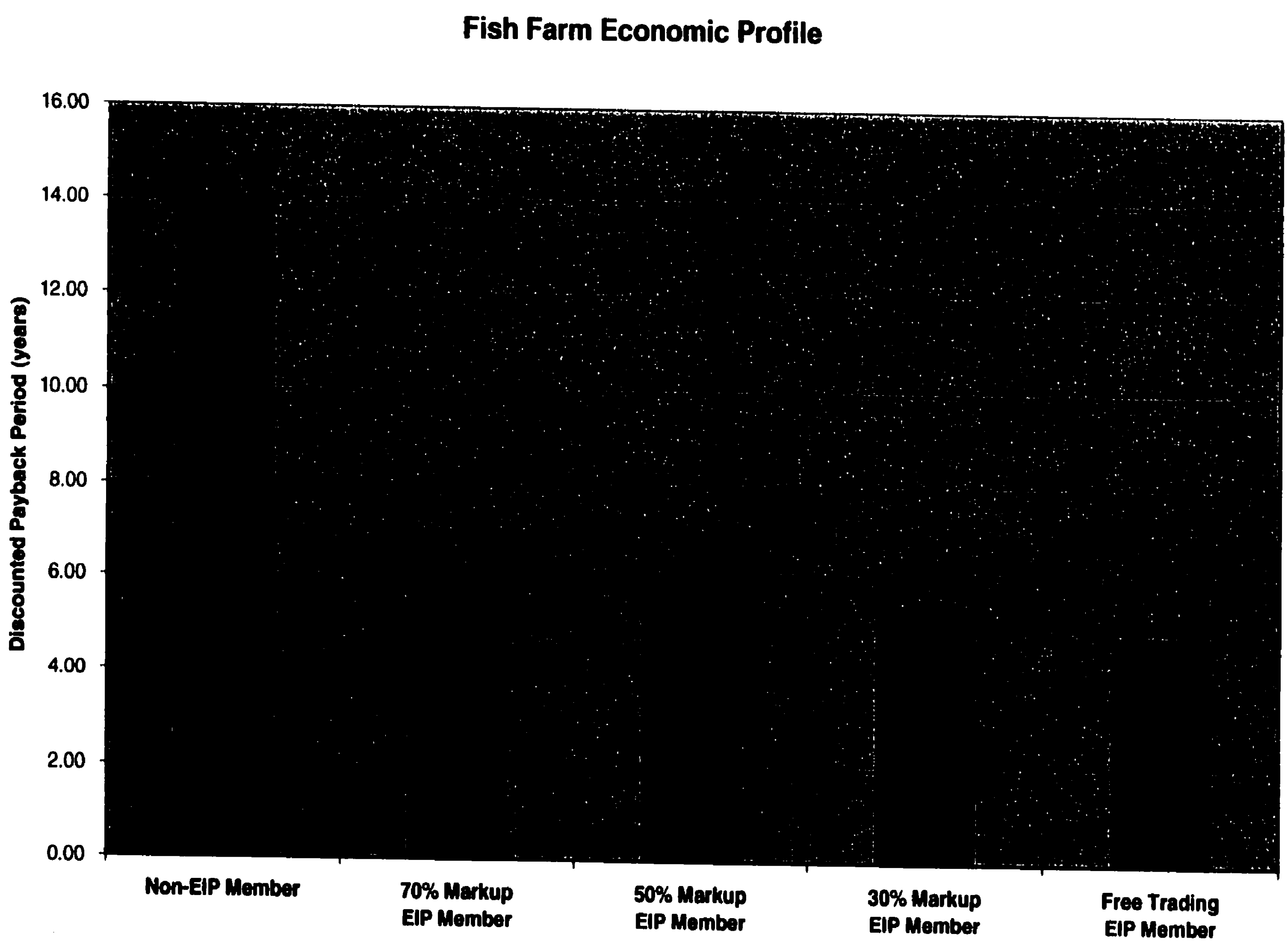


Figure 4.6(a). Discounted payback periods for Fish Farm.

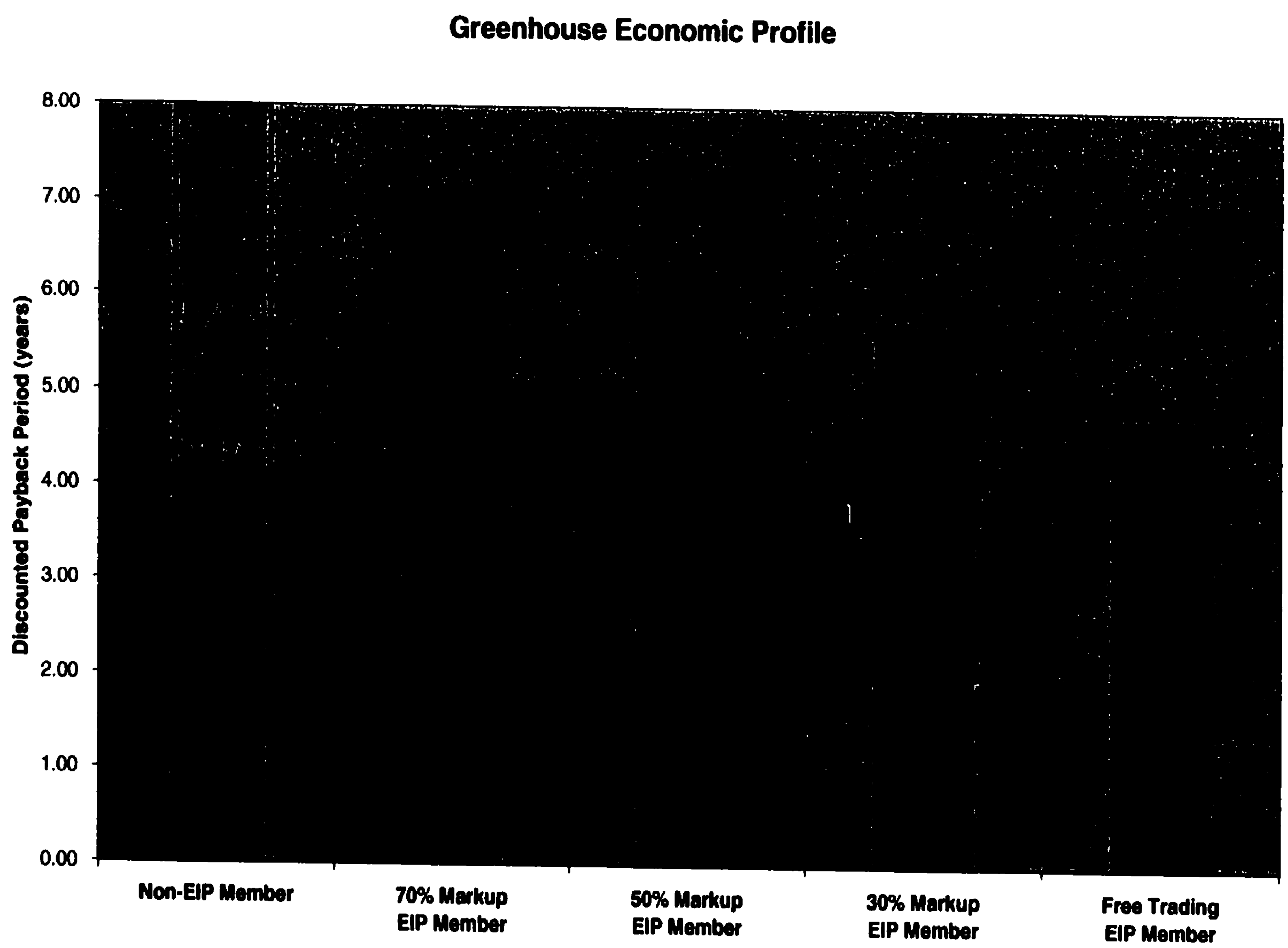


Figure 4.6(b). Discounted payback periods for Greenhouse.

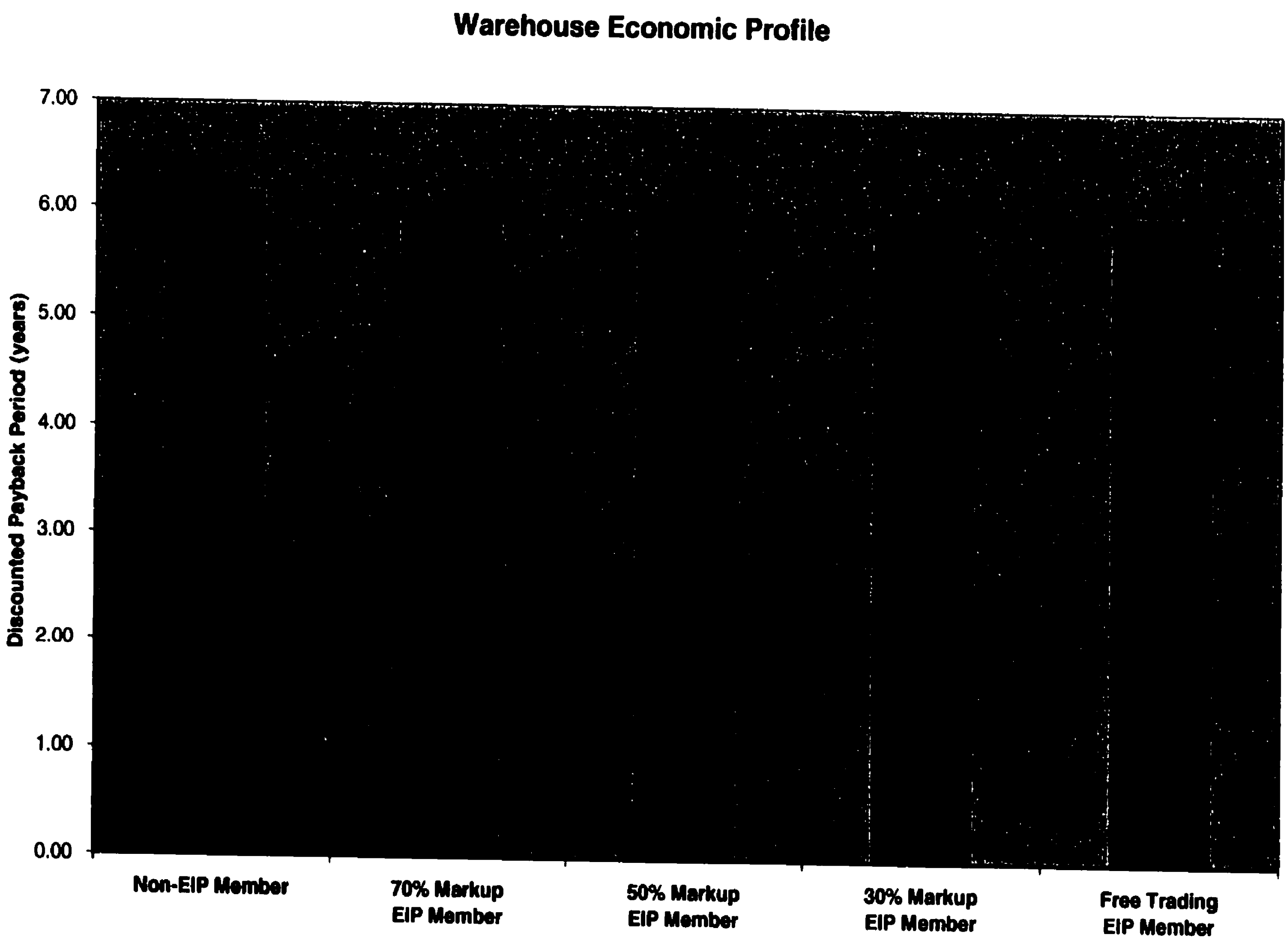


Figure 4.6(c). Discounted payback periods for Warehouse.

Five years is a reasonable payback period for a Fish Farm (Wendell James, Alberta Research Council, personal communication). Considering that discounted payback periods in this study ranged from just under 6 years for the 70%-EIP member down to about 5½ years for a 30%-EIP member, a Fish Farm company would be interested in setting up in the Lloydminster EIP. For a non-EIP member Fish Farm, the discounted payback period is approximately 14 years, and therefore does not warrant setting up.

Greenhouse

Figure 4.6(b) shows no discounted payback period for the non-EIP member Greenhouse. This is because the economic profile used for the Greenhouse resulted in no period of time when this project would payout. This is due to the large property cost associated with a non-EIP member's capital cost. Hence, it is not economically feasible for a Greenhouse to be established in the area outside the Lloydminster EIP.

For a Greenhouse a desirable payback period is about 10 years (Dr. Mirza, Crop Diversification Centre North, personal communication). The profit-EIP members have a discounted payback period of close to 7 years for a 70%-EIP member, just over 6 years for a 50%-EIP member, and just below 6 years for the 30%-EIP member. Therefore, a Greenhouse is an attractive investment.

Warehouse

The discounted payback periods for a Warehouse do not differ substantially whether or not they are part of the Lloydminster EIP. This is because of the large infrastructure cost (building cost, racks cost, etc.) involved in setting up a Warehouse and the low operating and maintenance costs. The discounted payback period for all cases is about 6 years. This is depicted in Figure 4.6(c). Nevertheless, an EIP member Warehouse has a smaller discounted payback period than a non-EIP member. Therefore, it is still more economical for a Warehouse company to locate within the Lloydminster EIP.

Flue Gas Injection

The cost of injecting flue gas into the underlying coalbeds is unknown at this time, as is the profit from the resulting methane that is produced. Detailed studies are required to determine the economics of such a project, including gas price forecasts, and evaluations of drilling and completion costs, water disposal costs, operating expenses and administrative expenses.

Percent Reduction

The percent reductions in discounted payback periods due to a facility being an EIP-member rather than a non-EIP member are provided in Table 4.7.

Table 4.7. Percent reductions in discounted payback periods due to co-location in the Lloydminster EIP.

[illegible]	[illegible]	[illegible]	[illegible]
Fish Farm	55.2	58.2	60.8
Greenhouse	N/A	N/A	N/A
Warehouse	2.3	2.4	2.4

Table 4.7 shows that a Fish Farm co-locating in the Lloydminster EIP instead of locating outside the EIP can result in substantial discounted payback period reductions of 60.8%, 58.2% and 55.2%, for the 30%-EIP member, 50%-EIP member and 70%-EIP member, respectively. Because the economic profile generated in Table 4.6(a) for the Greenhouse had no period of time in which this project would payout, reductions in discounted

payback periods cannot be calculated. For the Warehouse, there are nominal differences between the reductions in discounted payback periods for the different %markup EIP members.

Figure 4.7(a-b) graphically depicts the reductions in discounted payback periods for the Fish Farm and Warehouse.

4.4.3 Cost Savings of Eco-Industrial Park Member

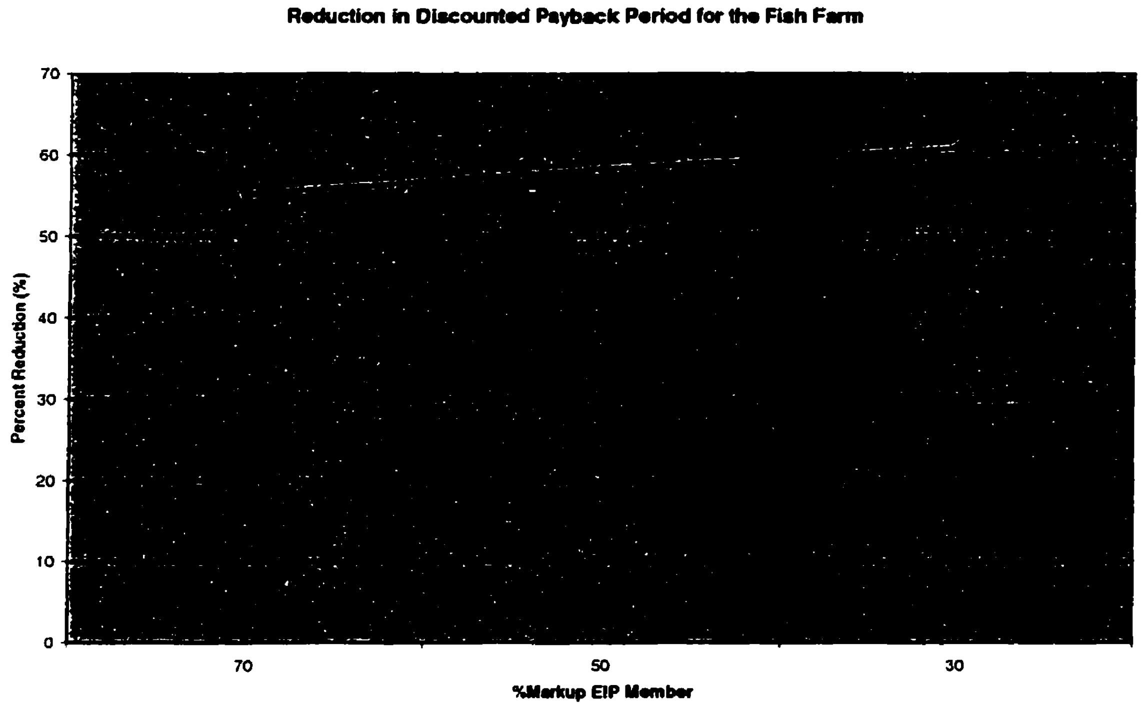
Capital Cost Savings

The capital cost savings associated with facilities setting up in the Lloydminster EIP in comparison with locating outside of the EIP are given in Table 4.8.

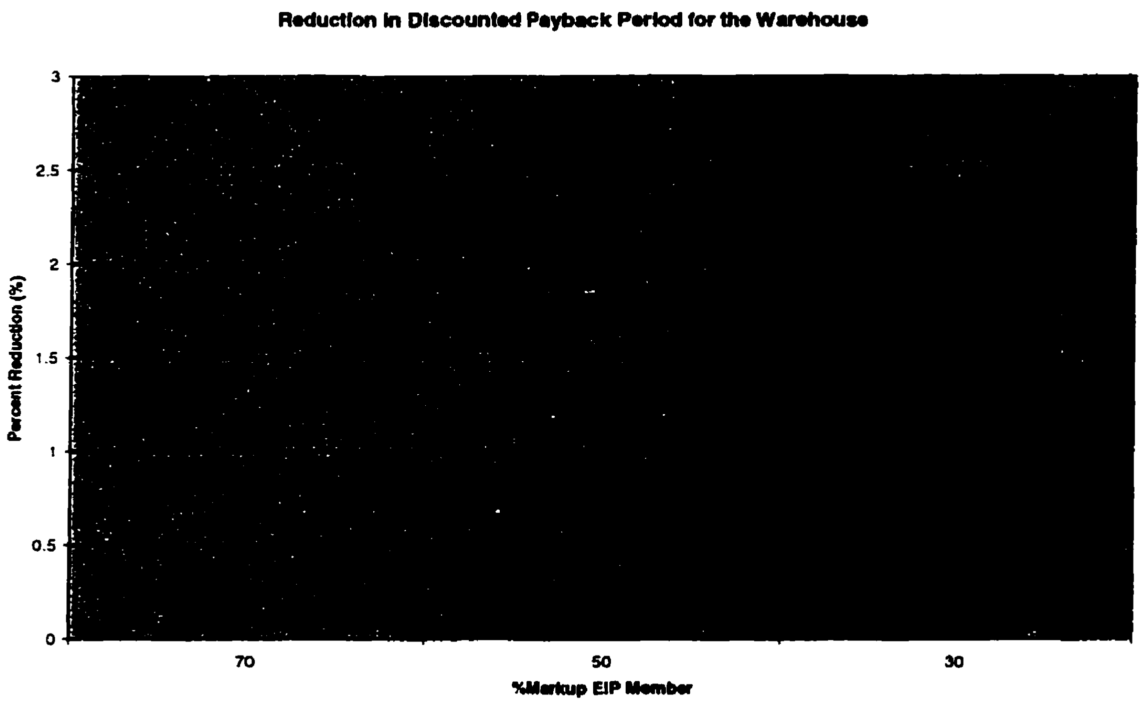
Table 4.8. Reduction in capital cost associated with co-locating in Lloydminster EIP.

[illegible]	[illegible]	[illegible]	[illegible]
Fish Farm	316,000	210,100	105,900
Greenhouse	854,900	440,900	414,000
Warehouse	6,150,000	6,047,300	102,700

Table 4.8 shows that there will be significant cost savings in the capital investment for the Fish Farm and Greenhouse to set up in the Lloydminster EIP. The reduction in capital cost associated with co-location of the Warehouse in the Lloydminster EIP is not as significant relative to its initial investment.



(a)



(b)

Figure 4.7. Reductions in discounted payback periods for (a) Fish Farm; and (b) Warehouse.

Annual Cost Savings

The annual economic benefit for a facility to set up in the Lloydminster EIP in comparison to locating outside of the EIP is given in Table 4.9.

Table 4.9. Annual cost savings for a facility to colocate in the Lloydminster EIP.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fish Farm	330,416	327,600	324,100	320,600	2,816	6,316	9,816
Greenhouse	343,700	338,300	328,000	317,900	5,400	15,700	25,800
Warehouse	190,200	190,900	189,800	188,700	-700	400	1,500

Table 4.9 shows that the 30%-EIP members have larger cost savings than the 50%-EIP members and 70%-EIP members, as expected. The Warehouse shows a loss of $700/yr when locating as a 70%-EIP member. This is largely due to the rental cost of land. The non-EIP member does not have to pay this annual rental cost because it purchases the land as part of its capital cost.

Annual Profit to COGEN

The economic benefit to COGEN from the development of the Lloydminster EIP is based on the profit from selling waste steam. The profit per year to COGEN is summarized in Table 4.10.

Table 4.10. Annual profit to COGEN with the development of the Lloydminster EIP.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fish Farm	1,026	$4.07/t	$2.91/t	$1.74/t	4,176	2,986	1,785
Greenhouse	7,008	$4.01/t	$2.86/t	$1.72/t	28,102	20,043	12,054
Warehouse	550	$4.28/t	$3.01/t	$1.83/t	2,354	1,656	1,007
				TOTAL	34,632	24,685	14,846

Table 4.10 shows that if COGEN sells waste steam at 70% markup, then it can profit by $34,632/yr. At a 50% markup COGEN profits by $24,685/yr, and at 30% by $14,846/yr. Therefore, there is a significant difference in profit values depending on the markup.

4.4.4 Profit to Anchor Facility

The development of an EIP in the Lloydminster area will provide significant economic benefits to the anchor facility. Table 4.11 shows the profit to the anchor facility in dollars per year for its part in the Lloydminster EIP.

The annual profit to the anchor facility is $34,777/yr if the co-locating facilities in the Lloydminster EIP are 70%-EIP members. The profit to the anchor facility for 50%-EIP members is $28,279/yr, and for 30%-EIP members is $21,777/yr.

4.4.5 Cost Savings for Eco-Industrial Park

Table 4.12 provides the cost savings in dollar value per year for each facility involved in the Lloydminster EIP and the overall cost savings for the EIP as a whole. The annual cost savings for each facility is comprised of the operating and maintenance cost savings as well as the interest saved from the lower capital cost.

Table 4.11. Annual profit to anchor facility in the Lloydminster EIP.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Water	Fish Farm	2,133 m3/yr	@$1.56/m3 $3327.48	@$1.19/m3 $2538.27	@$0.82/m3 $1749.06	@$.26/m3 $554.58	2,773	1,984	1,194
	Greenhouse	3,706 m3/yr	@$1.56/m3 $5781.36	@$1.19/m3 $4410.14	@$0.82/m3 $3038.92	@$.26/m3 $963.56	4,818	3,447	2,075
Natural Gas	Greenhouse	3,230 GJ/yr	@$2.945/GJ $9512.35	@$2.935/GJ $9480.05	@$2.925/GJ $9447.75	@$2.91/GJ $9399.3	113	81	48
Electricity	Fish Farm	186,880 kWh/yr	@$.06312/kWh $11795.87	@$.0552/kWh $10315.78	@$.04728/kWh $8835.69	@$.0354/kWh $6615.55	5,180	3,700	2,220
	Greenhouse	100,916 kWh/yr	@$.06312/kWh $6369.82	@$.0552/kWh $5570.56	@$.04728/kWh $4771.31	@$.0354/kWh $3572.43	2,797	1,998	1,199
	Warehouse	56,000 kWh/yr	@$.06312/kWh $3534.72	@$.0552/kWh $3091.2	@$.04728/kWh $2647.68	@$.0354/kWh $1982.4	1,552	1,109	665
	Feedmill	200,000 kWh/yr	@$.06312/kWh $12624	@$.0552/kWh $11040	@$.04728/kWh $9456	@$.0354/kWh $7080	5,544	3,960	2,376
Land	Fish Farm	1 ac	@$3000/ac $3000	@$3000/ac $3000	@$3000/ac $3000	@$1000/ac $1000	2,000	2,000	2,000
	Greenhouse	4 ac	@$3000/ac $12000	@$3000/ac $12000	@$3000/ac $12000	@$1000/ac $4000	8,000	8,000	8,000
	Warehouse	1 ac	@$3000/ac $3000	@$3000/ac $3000	@$3000/ac $3000	@$1000/ac $1000	2,000	2,000	2,000
						TOTAL	34,777	28,279	21,777

Table 4.12. Overall cost savings for Lloydminster EIP.

[illegible]	[illegible]	[illegible]	[illegible]
HLU (anchor facility)	34,777	28,279	21,777
COGEN	34,632	24,685	14,846
Feedmill	2,376	3,960	5,544
Fish Farm	15,524	19,024	22,524
Greenhouse	55,080	65,380	75,480
Warehouse	11,624	12,724	13,824
TOTAL	154,013	154,052	153,995

Table 4.12 shows that the overall cost savings for the Lloydminster EIP do not differ significantly if there are 70%-, 50%- or 30%-EIP members. This is because the more the co-locating facilities save, the less the HLU and COGEN profit. Of the 70%-, 50%- and 30%-EIP member scenarios, the 50%-EIP member scenario has the largest cost savings.

Not all cost savings for the Lloydminster EIP are quantifiable at this time because certain synergies require further research into their economic feasibility. For example, the profit from coalbed methane production due to flue gas injection.

4.4.6 Sensitivity Analysis

Due to lower confidence in the cost associated with the following items, they were altered by ±10% in the Fish Farm, Greenhouse and Warehouse economic profiles:

- Property (capital, rent & tax)
- Steam
- Electricity
- Payroll

Items with large costs were also evaluated in this sensitivity analysis because the large effect they could potentially have on the discounted payback period. For the Fish Farm this includes Building cost and Feed cost. For the Greenhouse, Miscellaneous costs were large from the generic profile. Building cost, Rack costs and Miscellaneous costs were large for the Warehouse.

Changing the cost of items results in alterations to the discounted payback periods for the Fish Farm, Greenhouse and Warehouse, as shown in Table 4.13, 4.14 and 4.15, respectively. Graphical depictions of the sensitivity analyses for the Fish Farm, Greenhouse and Warehouse are provided in Figures 4.8 (a-f), Figures 4.9 (a-e) and Figures 4.10 (a-g), respectively.

Fish Farm

The discounted payback period varied by over 1 year for the non-EIP member Fish Farm when the property cost was increased or decreased by 10%. The discounted payback period for the EIP members, on the other hand, showed only nominal fluctuations. This is because the property cost for the non-EIP member has a large initial capital cost, whereas the EIP members have a smaller annual property rental cost and tax.

Variations on the cost of steam resulted in nominal fluctuations in the discounted payback periods for the 70%-, 50%- and 30%-EIP members, and had no effect on the discounted payback period for the non-EIP member and for the free-trading EIP member. The reason why there was no effect to the discounted payback period for the non-EIP member is because it is located outside the Lloydminster EIP and does not receive waste steam from HLU and COGEN. The free-trading EIP member's discounted payback period was not effected because it receives waste steam at no cost.

Table 4.13. Sensitivity analysis on Fish Farm costs.

	[illegible]									
	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Property	15.17	12.90	6.28	6.21	5.86	5.80	5.50	5.44	4.86	4.85
Steam	13.96	13.96	6.30	6.19	5.86	5.80	5.48	5.45	4.86	4.86
Electricity	14.71	13.30	6.40	6.10	5.95	5.72	5.55	5.38	4.91	4.81
Payroll	25.97	10.17	8.09	5.10	7.39	4.83	6.81	4.58	5.87	4.14
Building	14.58	13.38	6.49	6.01	6.05	5.61	5.67	5.27	5.06	4.69
Feed	never pays out	9.02	9.52	4.69	8.54	4.45	7.76	4.24	6.56	3.87

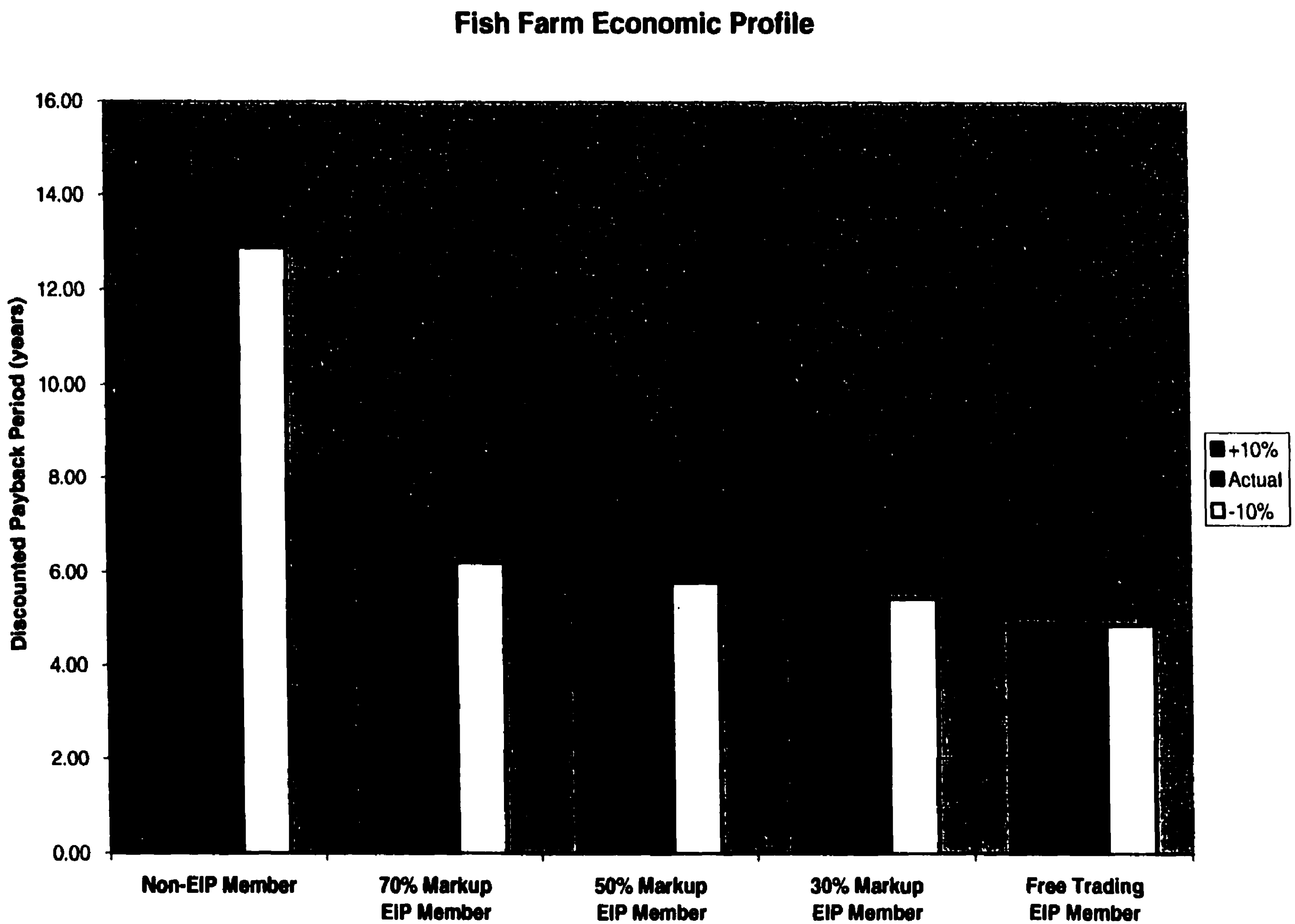


Figure 4.8(a). Sensitivity analysis on Fish Farm property cost.

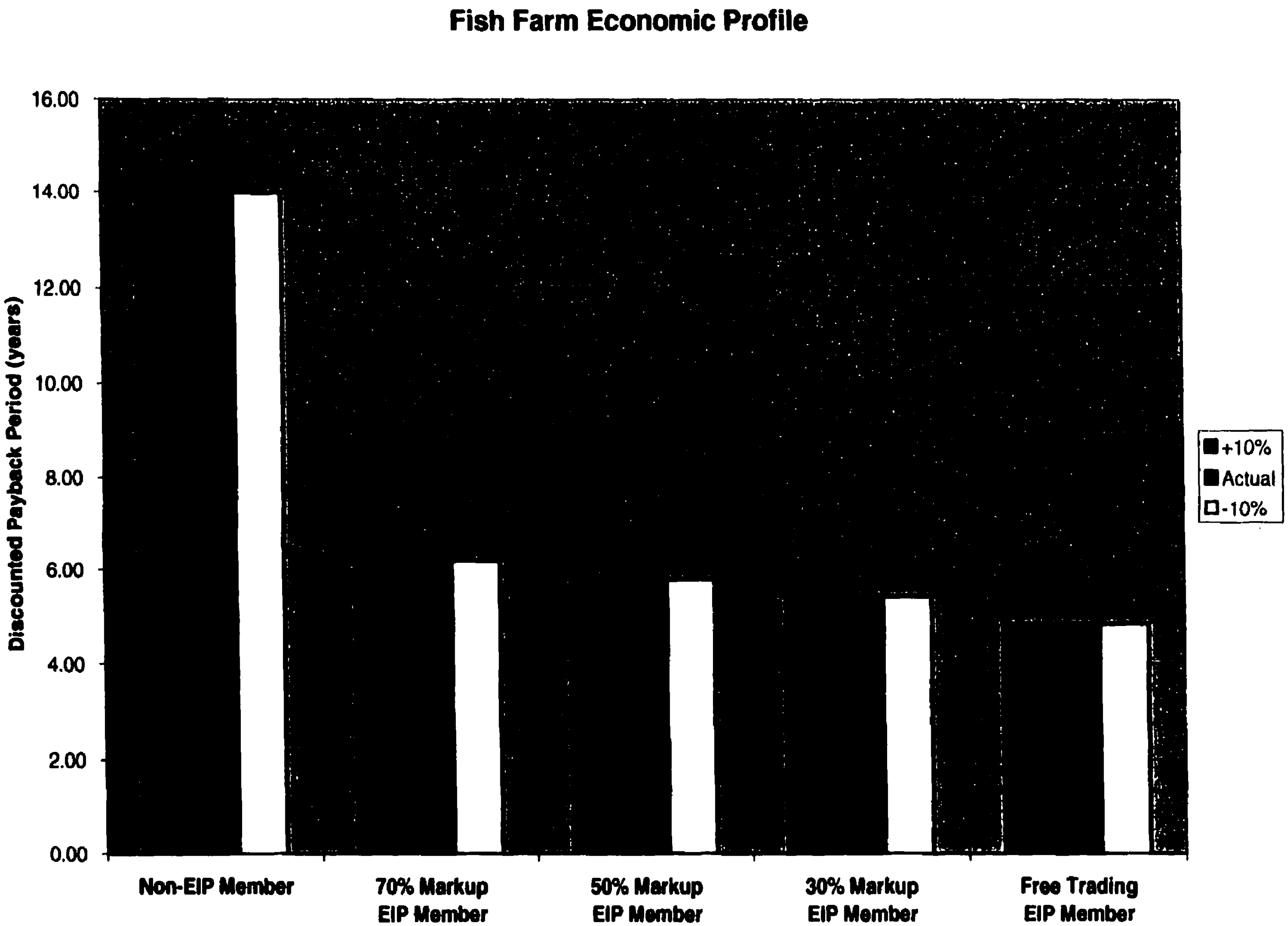


Figure 4.8(b). Sensitivity analysis on Fish Farm steam cost.

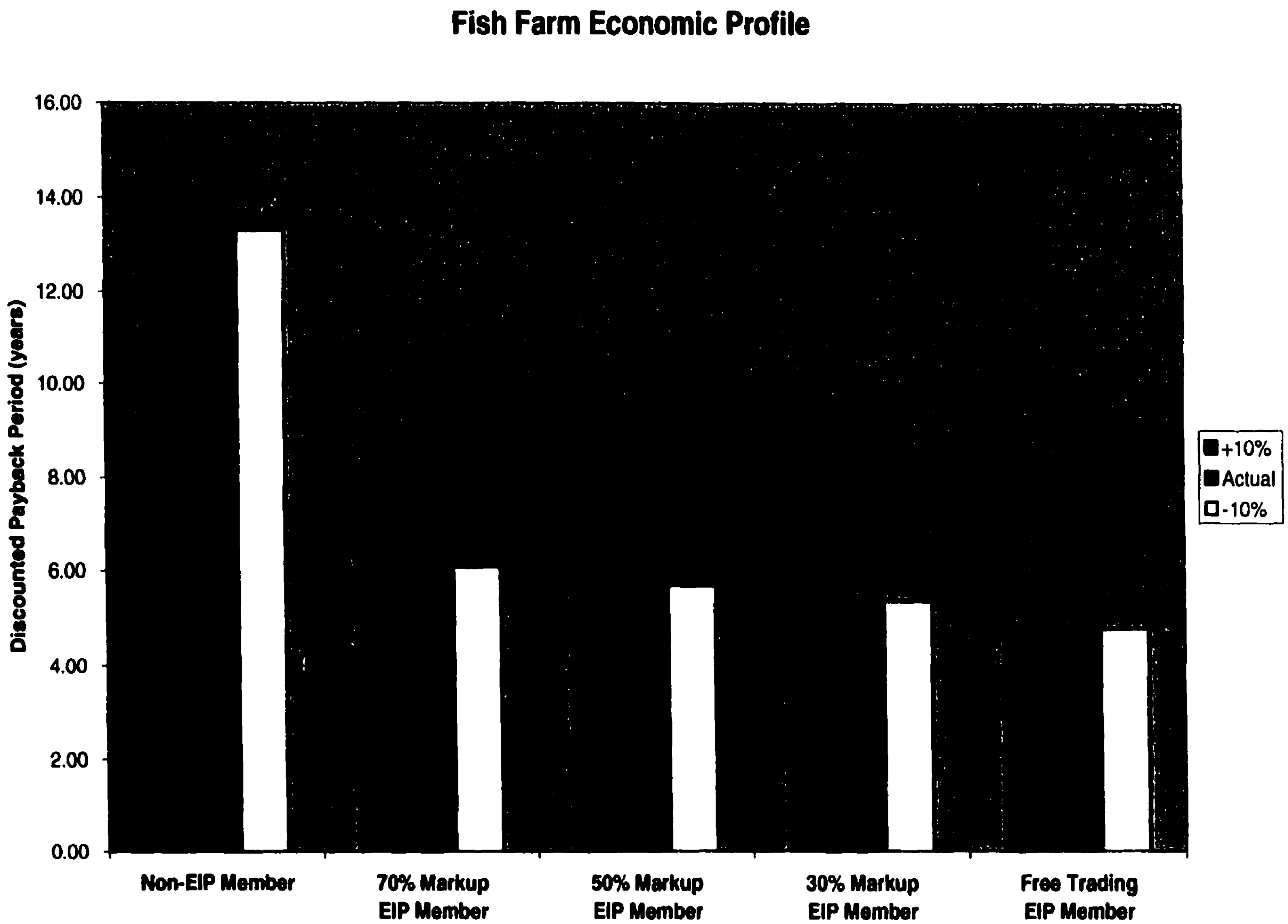


Figure 4.8(c). Sensitivity analysis on Fish Farm electricity cost.

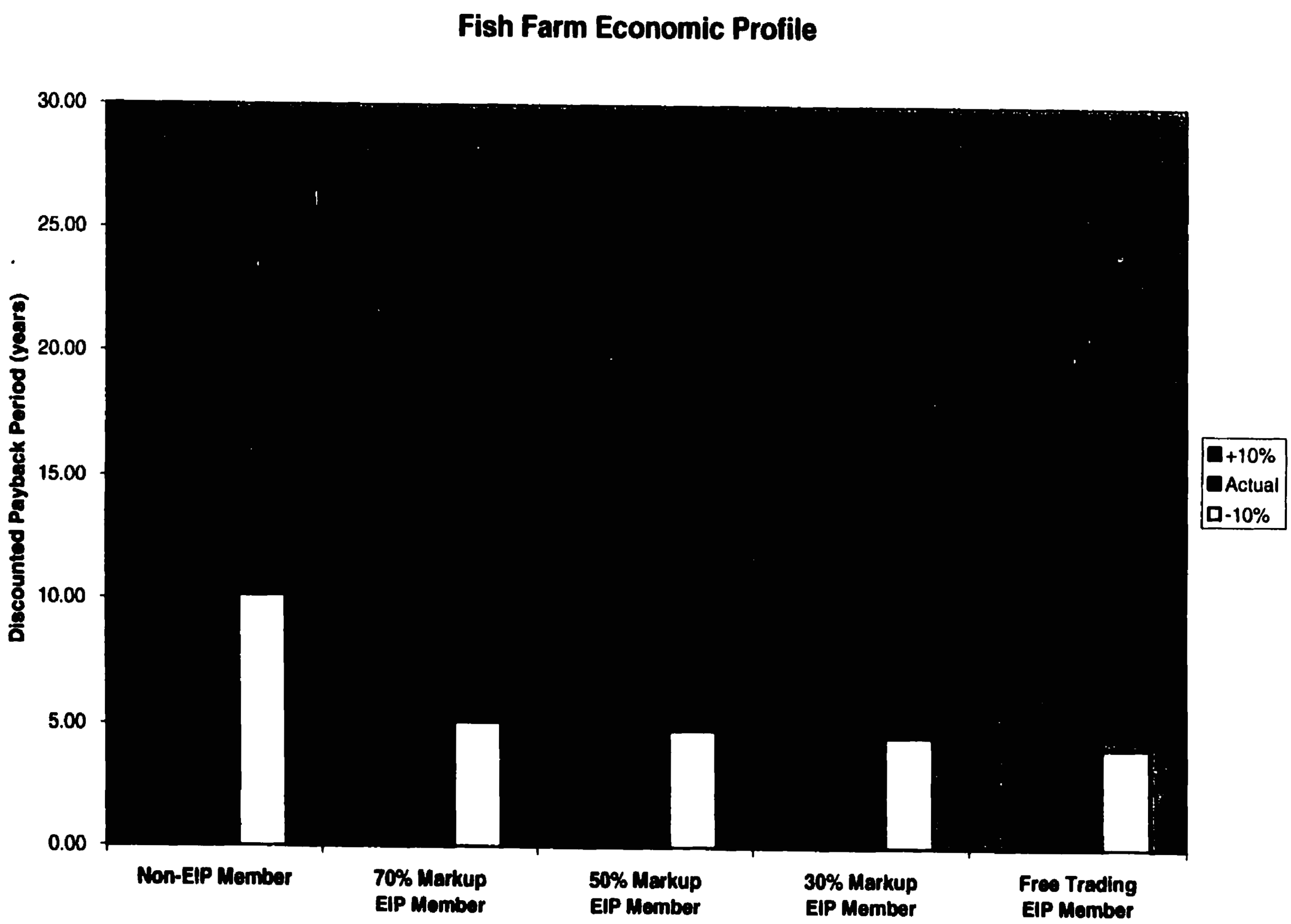


Figure 4.8(d). Sensitivity analysis on Fish Farm payroll cost.

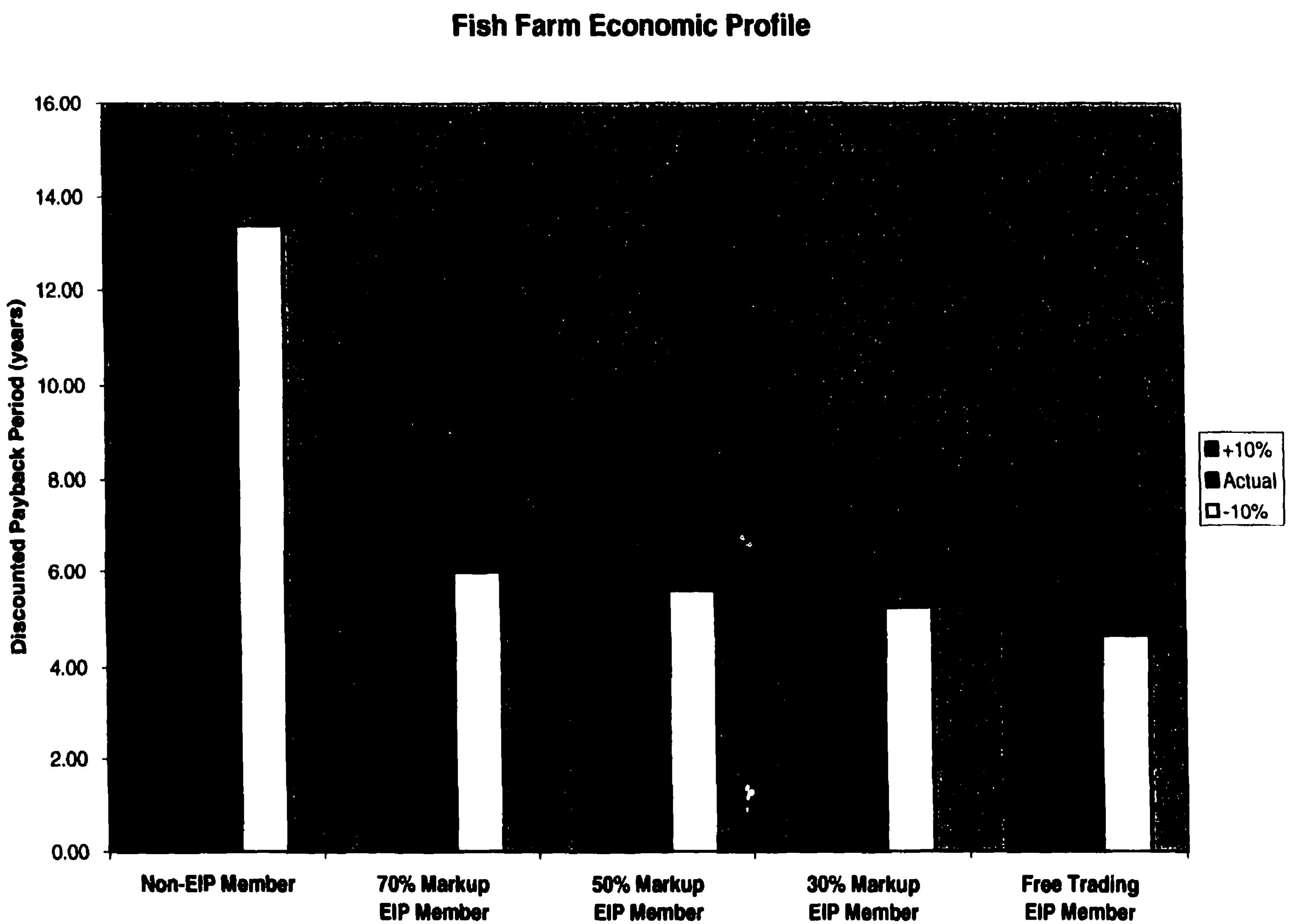


Figure 4.8(e). Sensitivity analysis on Fish Farm building cost.

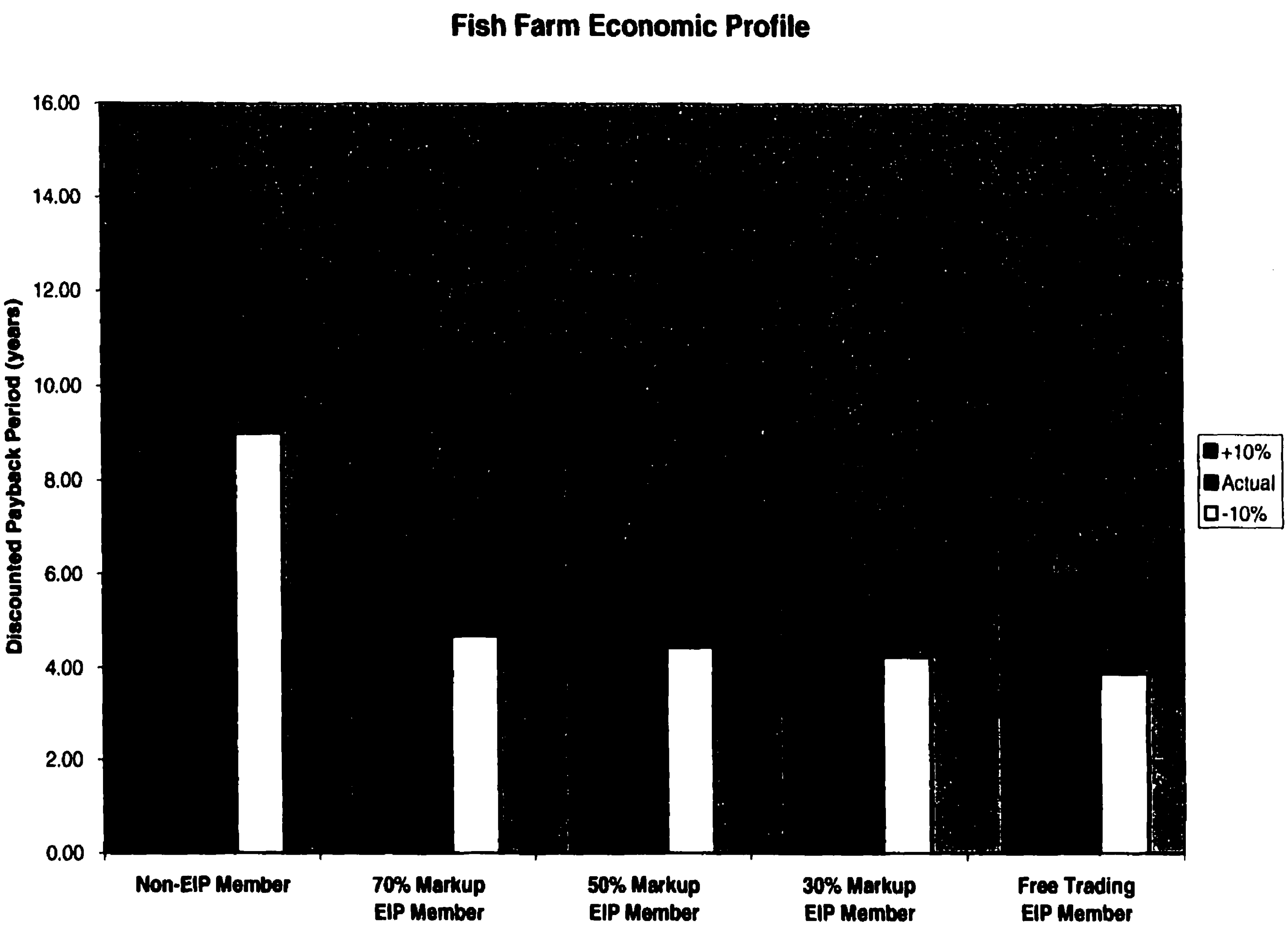


Figure 4.8(f). Sensitivity analysis on Fish Farm feed cost.

Table 4.14. Sensitivity analysis on Greenhouse costs.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Property	never pays out	never pays out	7.04	6.86	6.32	6.17	5.75	5.63	4.73	4.70
Steam	never pays out	never pays out	7.17	6.74	6.37	6.13	5.75	5.63	4.72	4.72
Electricity	never pays out	never pays out	7.00	6.90	6.28	6.21	5.71	5.66	4.73	4.71
Payroll	never pays out	39.20	8.33	5.97	7.33	5.45	6.56	5.02	5.30	4.26
Miscellaneous	never pays out	never pays out	7.36	6.58	6.58	5.95	5.96	5.44	4.90	4.55

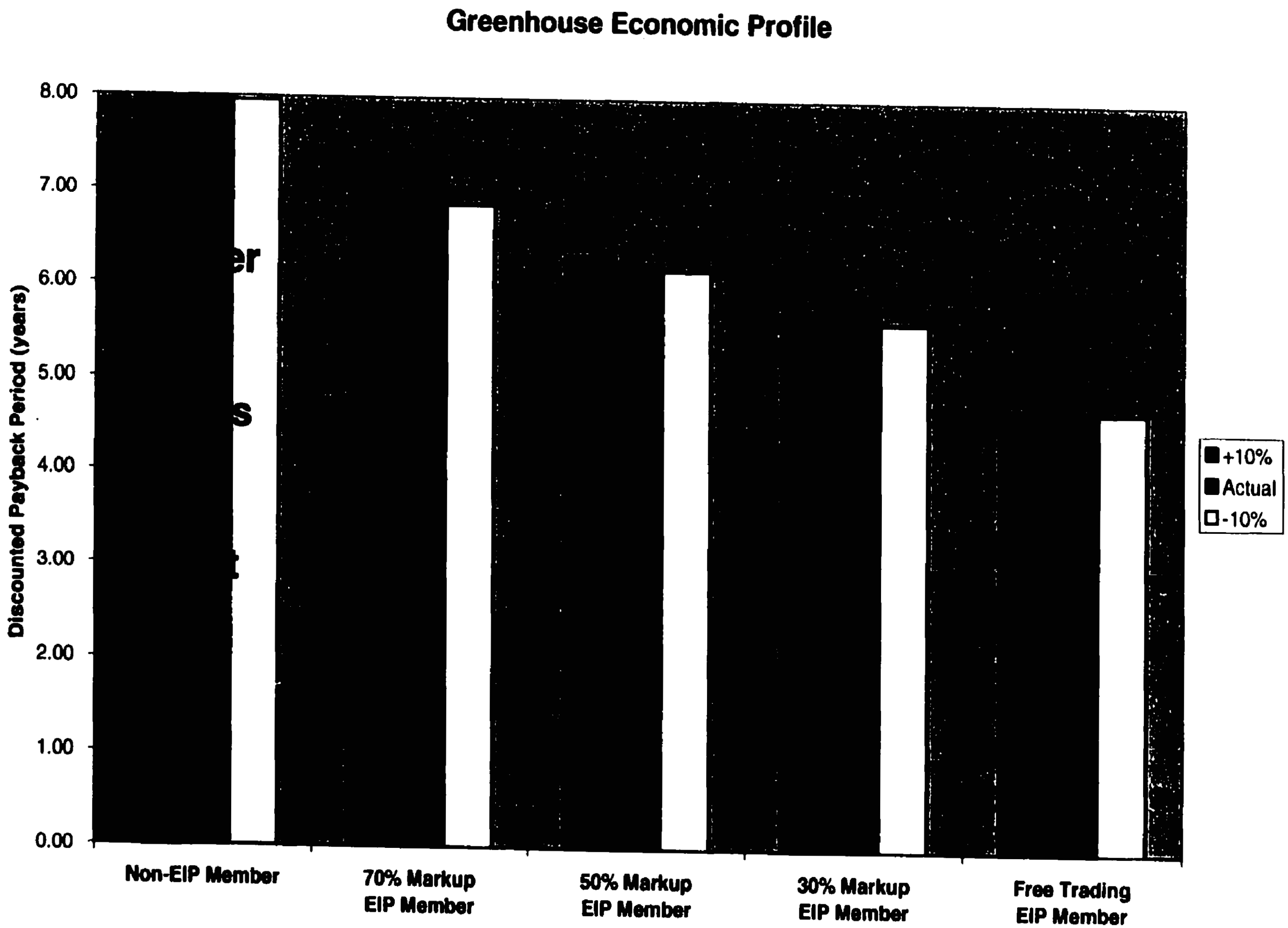


Figure 4.9(a). Sensitivity analysis on Greenhouse property cost.

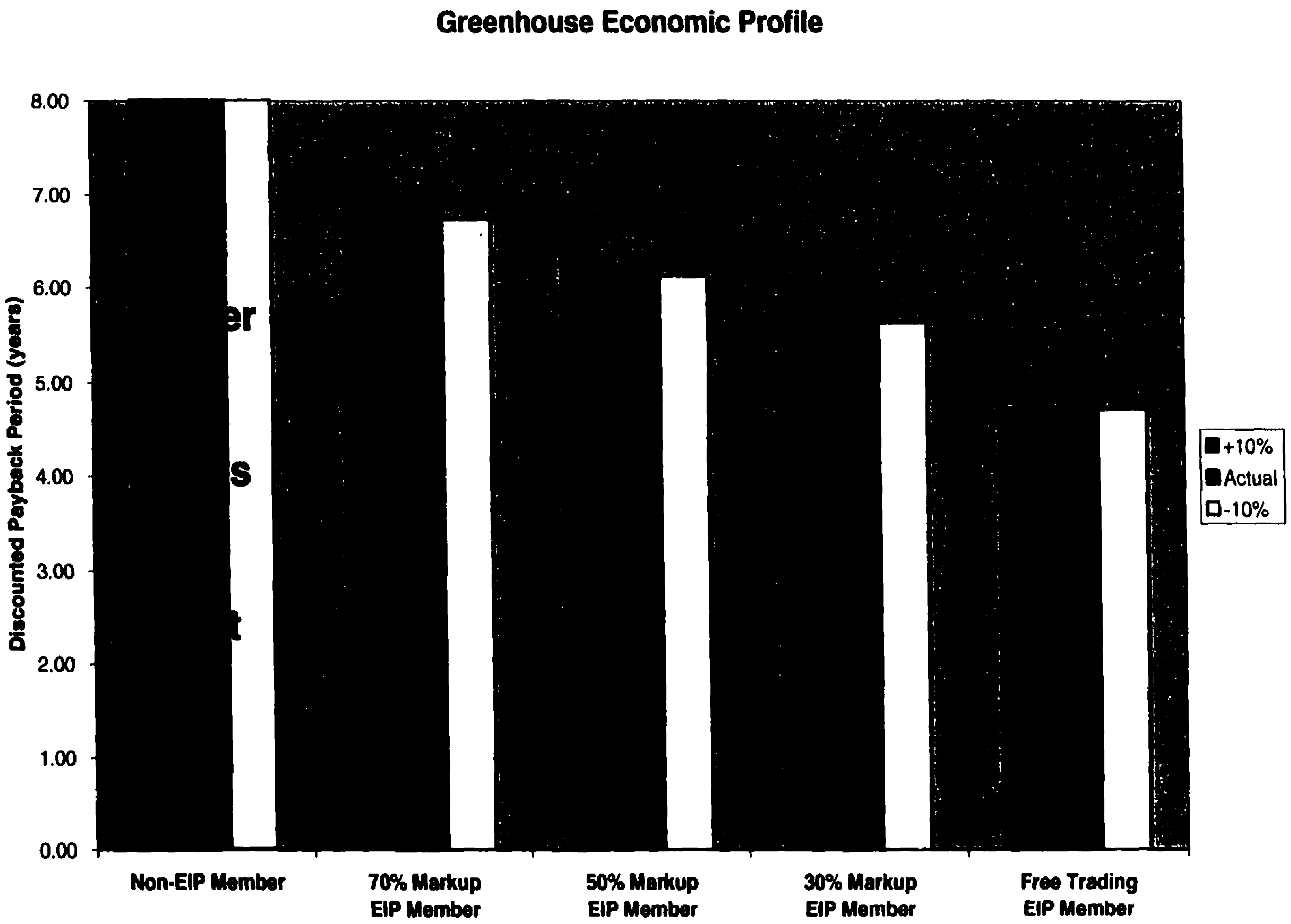


Figure 4.9(b). Sensitivity analysis on Greenhouse steam cost.

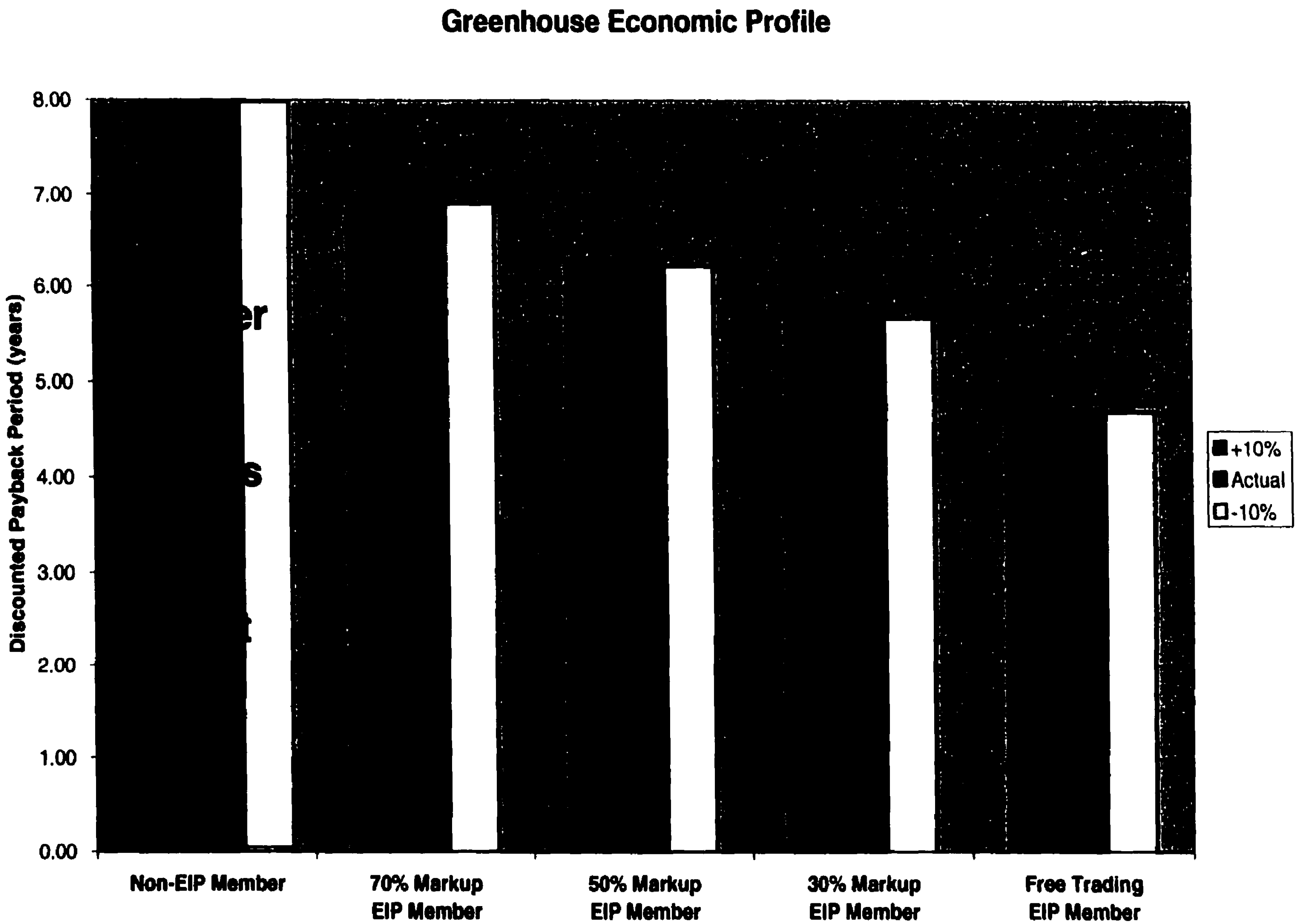


Figure 4.9(c). Sensitivity analysis on Greenhouse electricity cost.

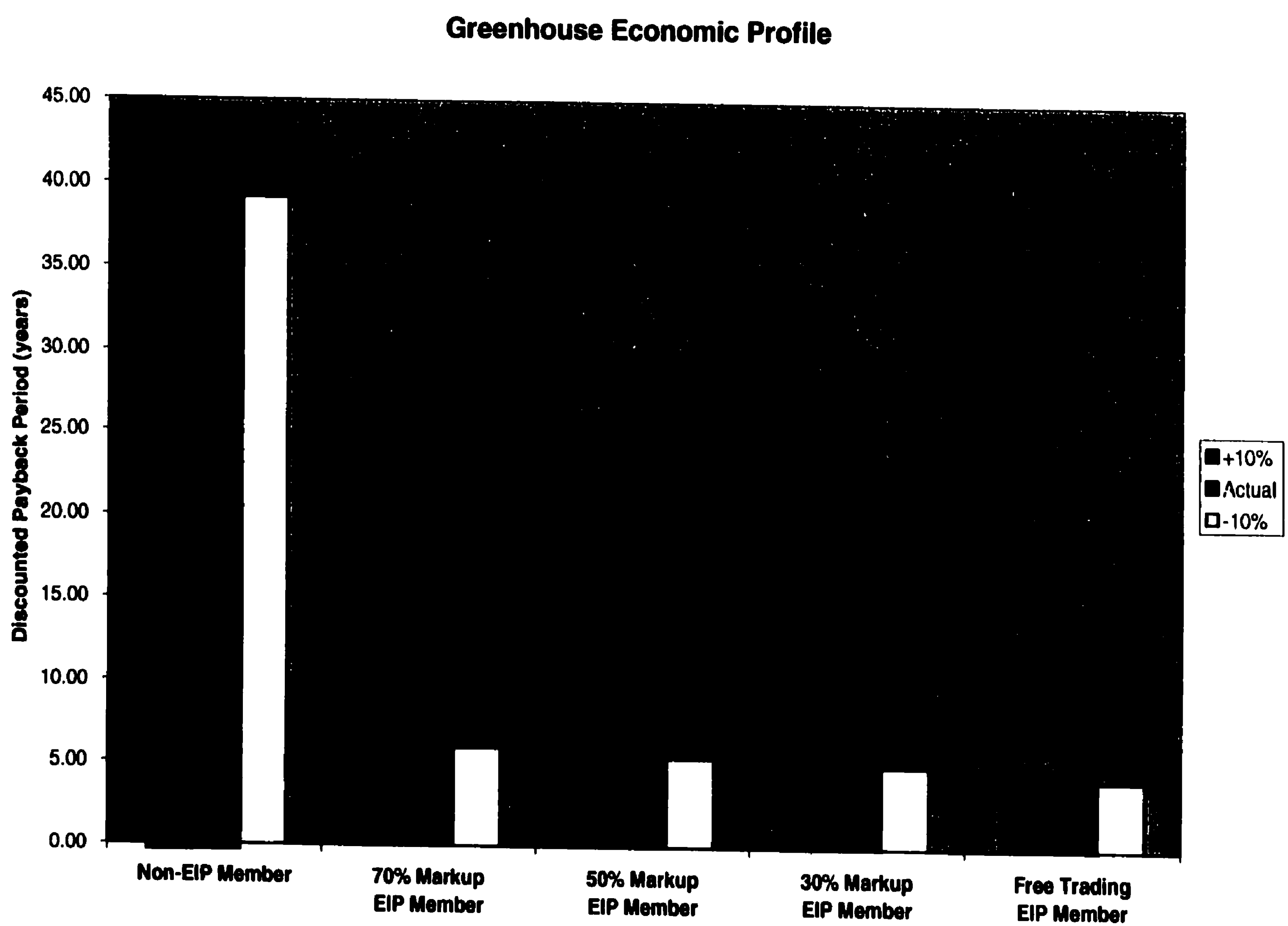


Figure 4.9(d). Sensitivity analysis on Greenhouse payroll cost.

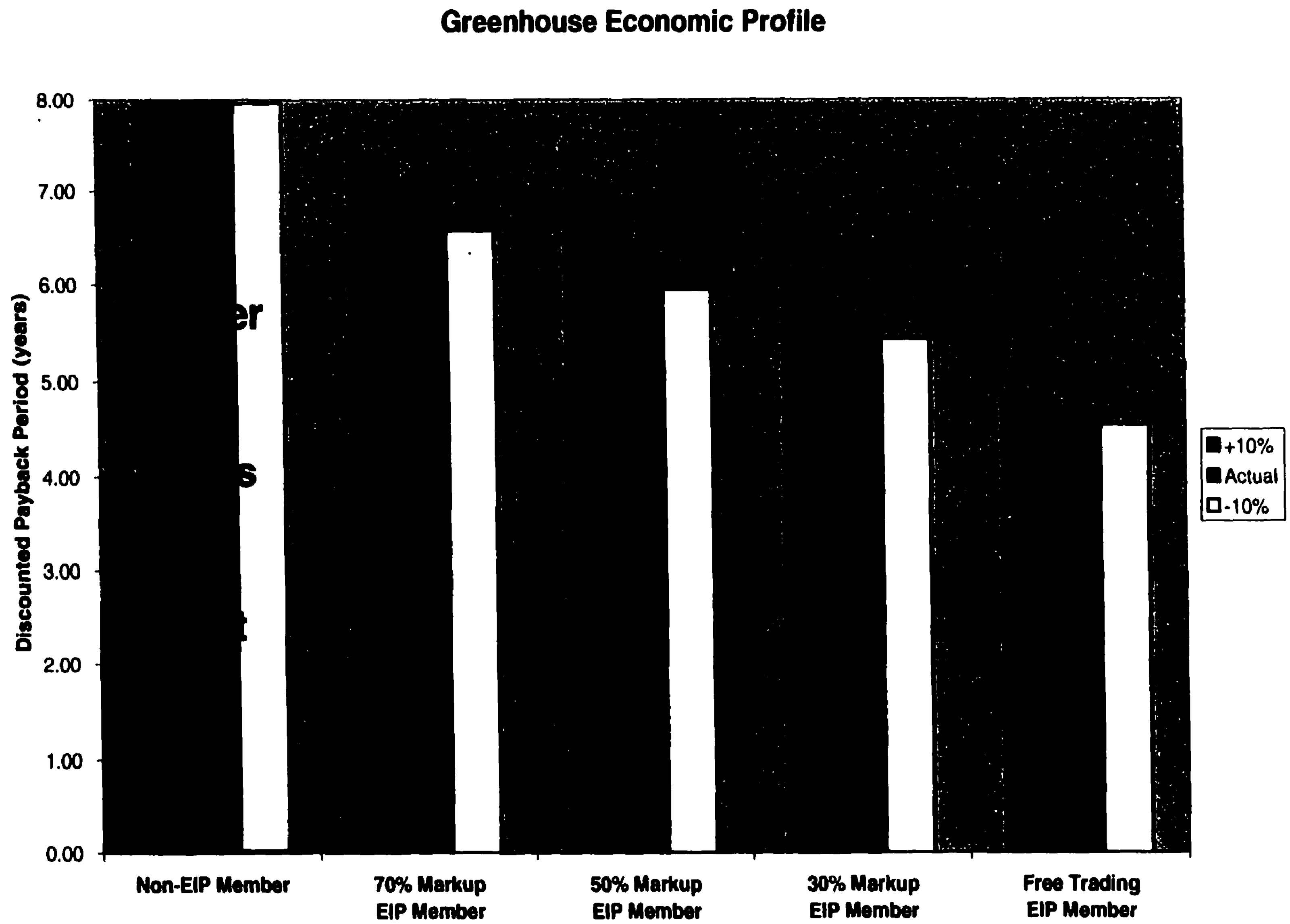


Figure 4.9(e). Sensitivity analysis on Greenhouse miscellaneous cost.

Table 4.15. Sensitivity analysis on Warehouse costs.

[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Property	6.16	6.13	6.00	6.00	5.99	5.99	5.99	5.99	5.97	5.97
Steam	6.14	6.14	6.00	6.00	5.99	5.99	5.99	5.99	5.97	5.97
Electricity	6.14	6.14	6.00	6.00	5.99	5.99	5.99	5.99	5.97	5.97
Payroll	6.19	6.09	6.04	5.95	6.04	5.95	6.03	5.94	6.02	5.93
Building	6.61	5.70	6.46	5.56	6.45	5.56	6.45	5.55	6.43	5.54
Racks	6.45	5.84	6.30	5.70	6.30	5.70	6.29	5.70	6.27	5.68
Miscellaneous	6.17	6.11	6.03	5.97	6.02	5.96	6.02	5.96	6.00	5.94

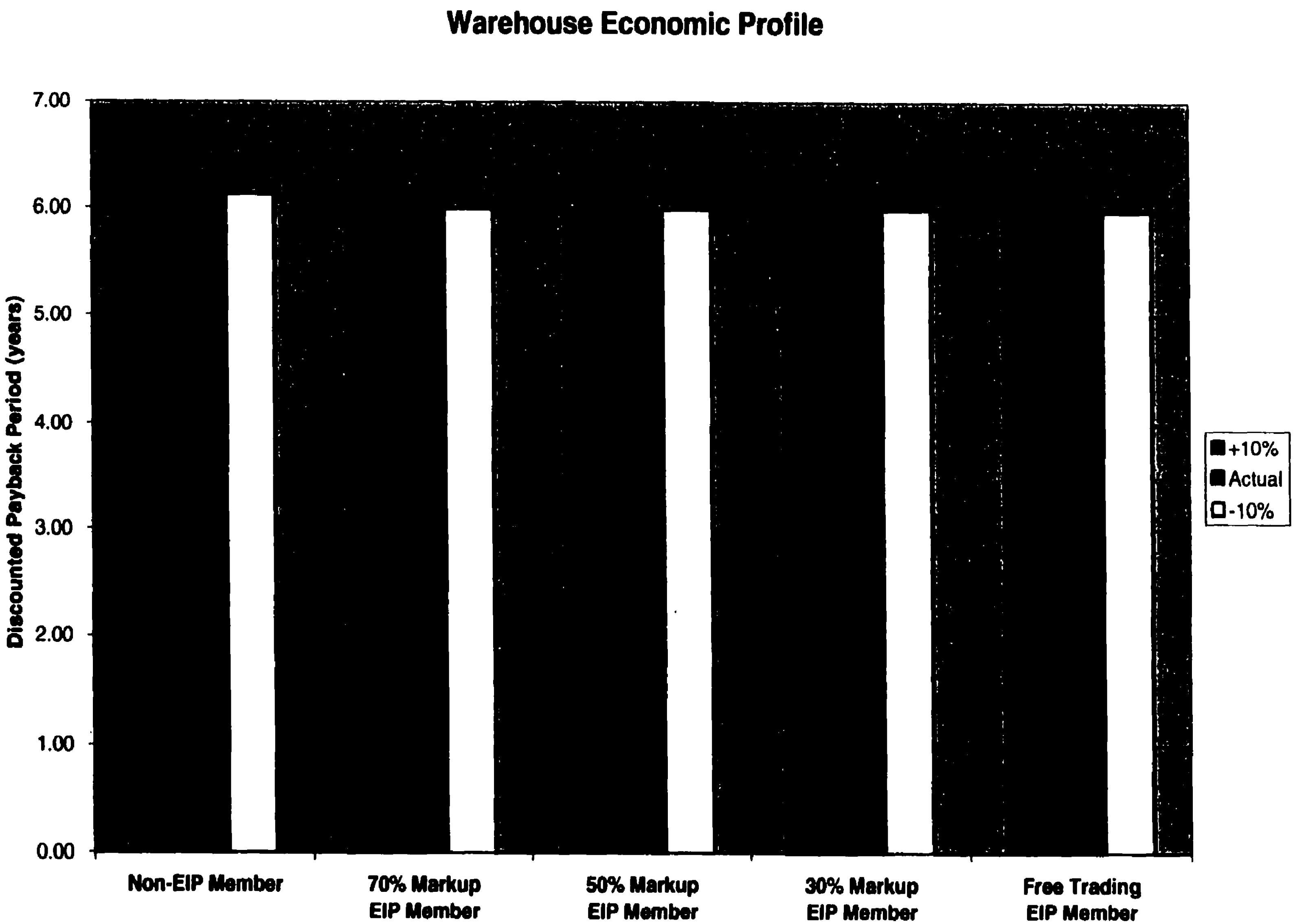


Figure 4.10(a). Sensitivity analysis on Warehouse property cost.

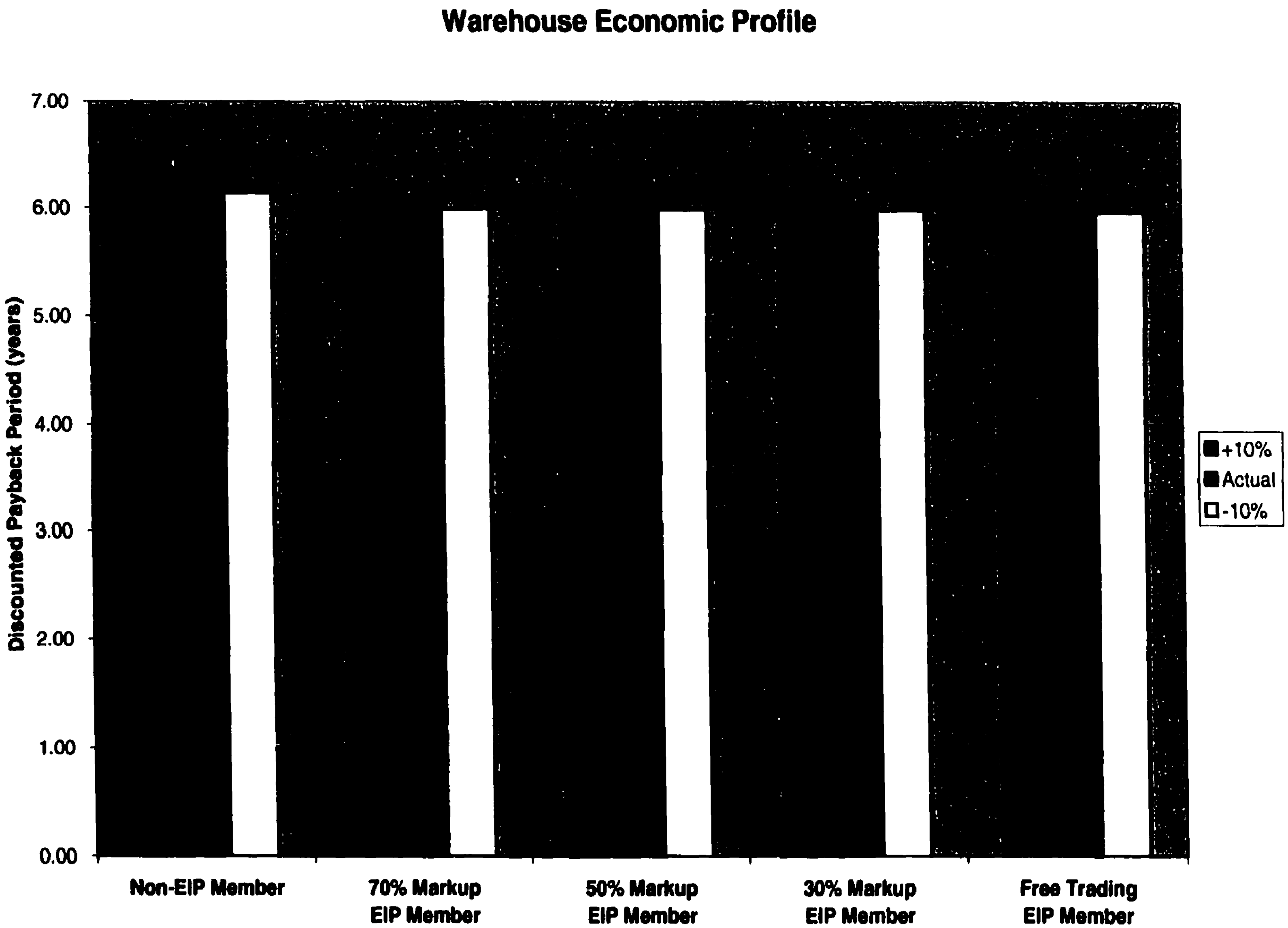


Figure 4.10(b). Sensitivity analysis on Warehouse steam cost.

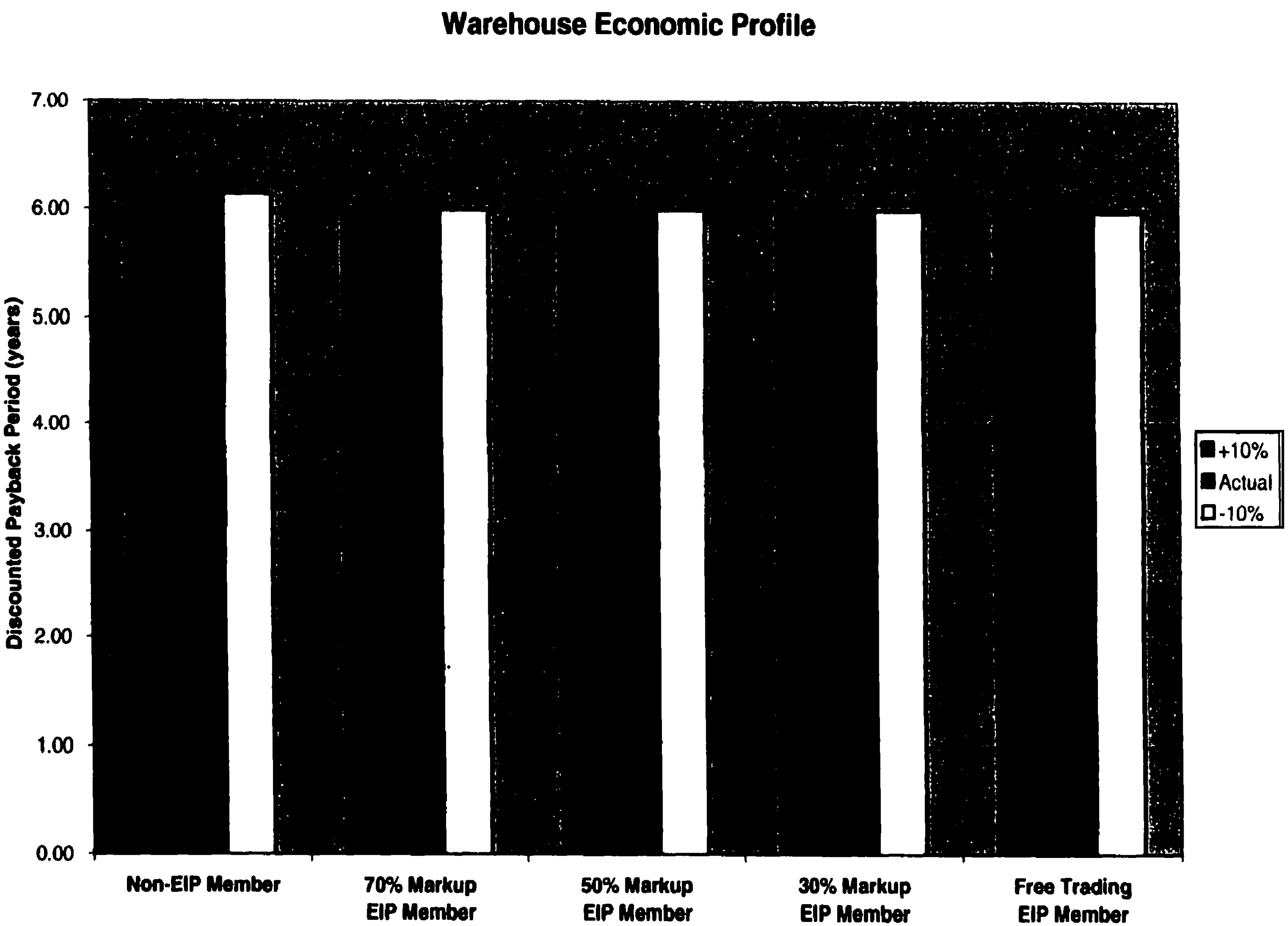


Figure 4.10(c). Sensitivity analysis on Warehouse electricity cost.

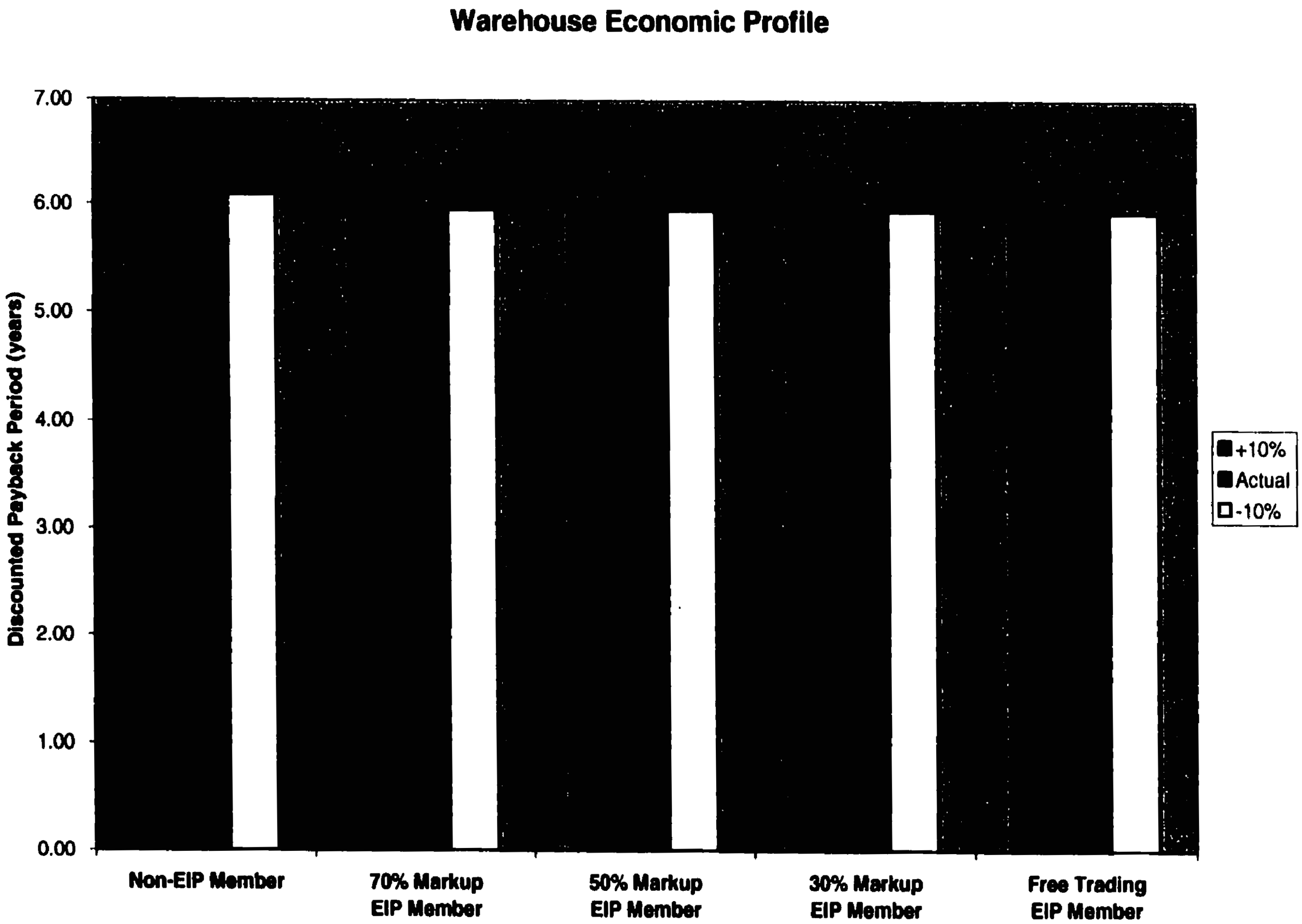


Figure 4.10(d). Sensitivity analysis on Warehouse payroll cost.

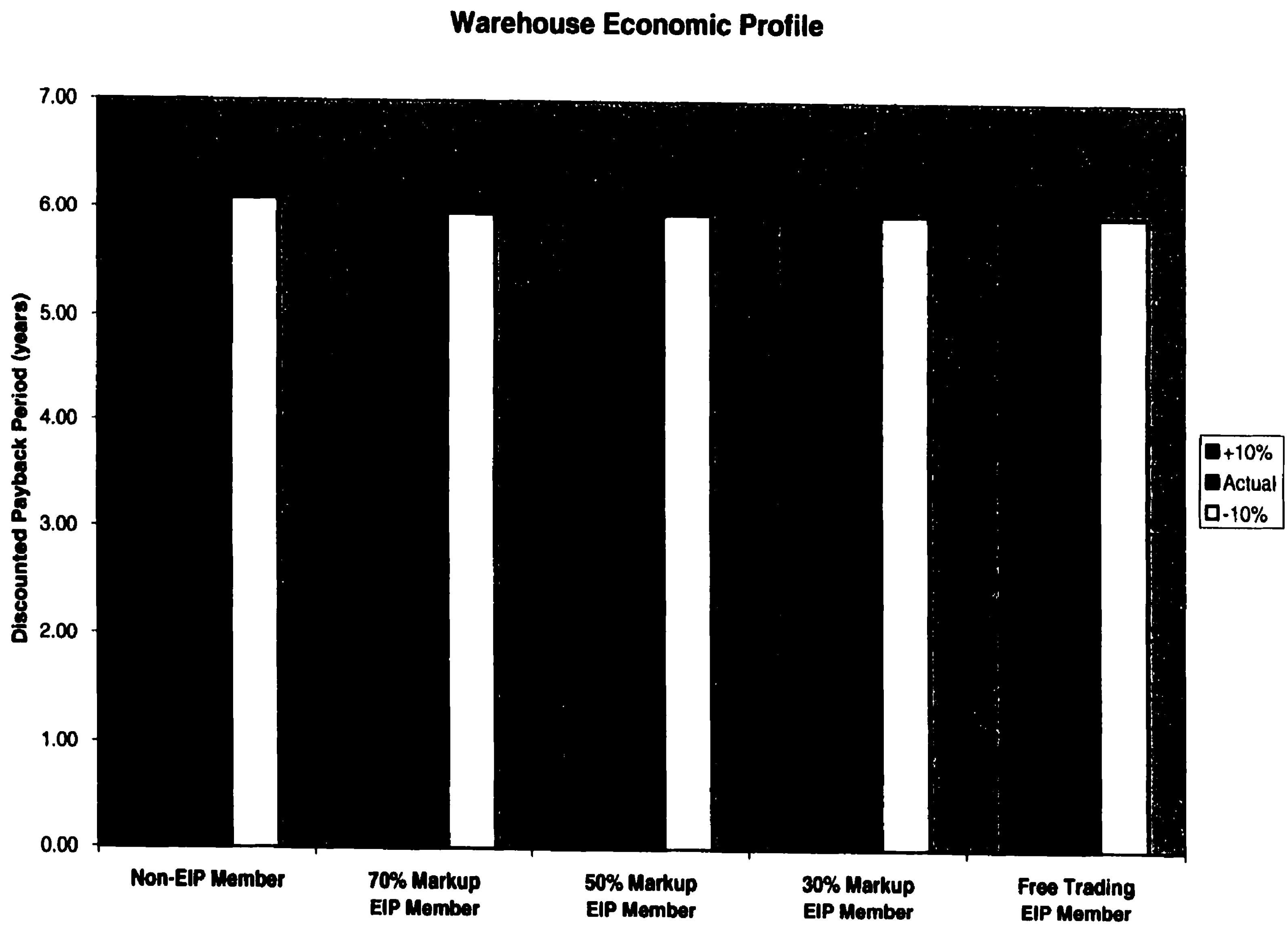


Figure 4.10(d). Sensitivity analysis on Warehouse payroll cost.

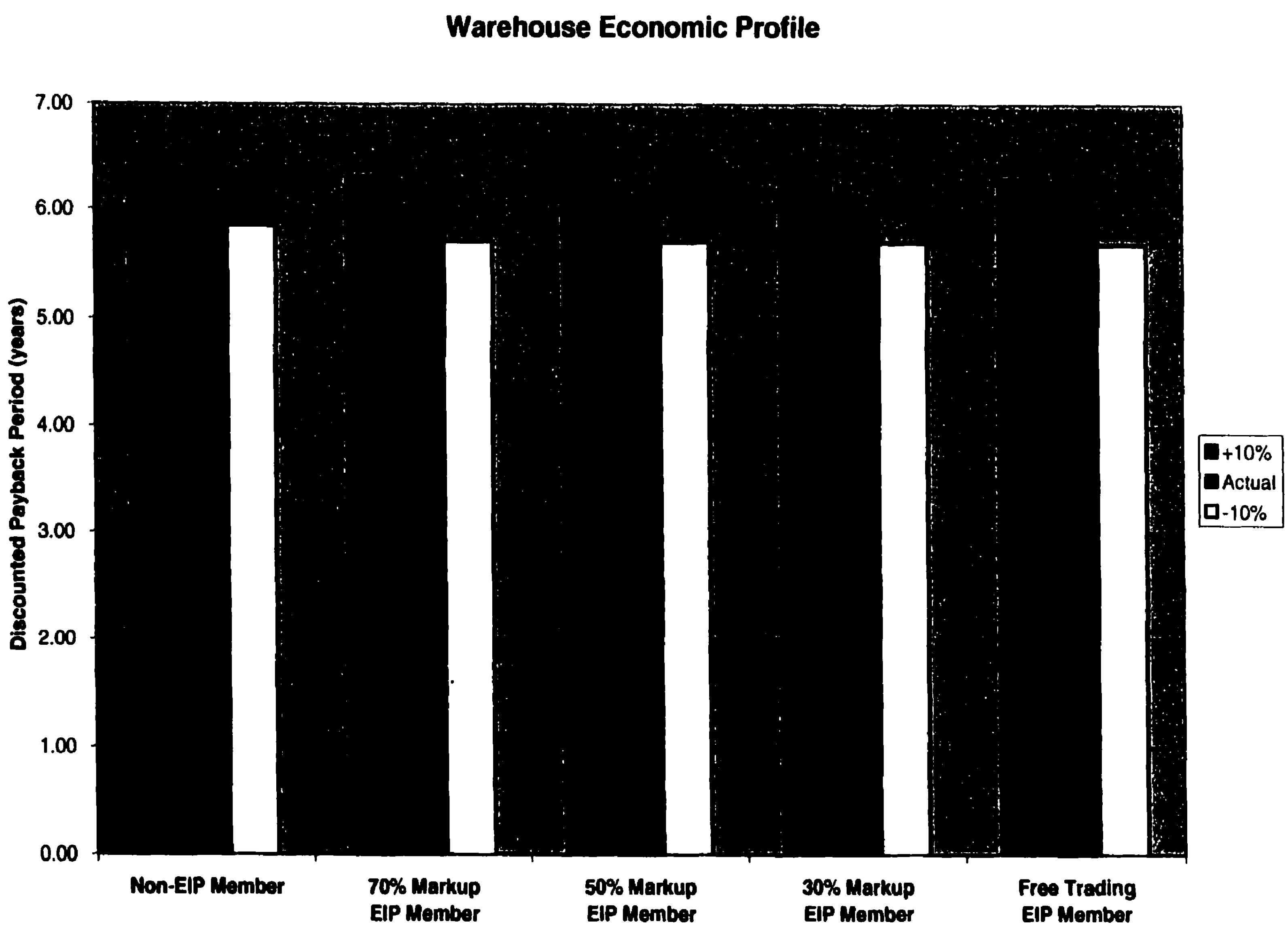


Figure 4.10(f). Sensitivity analysis on Warehouse racks cost.

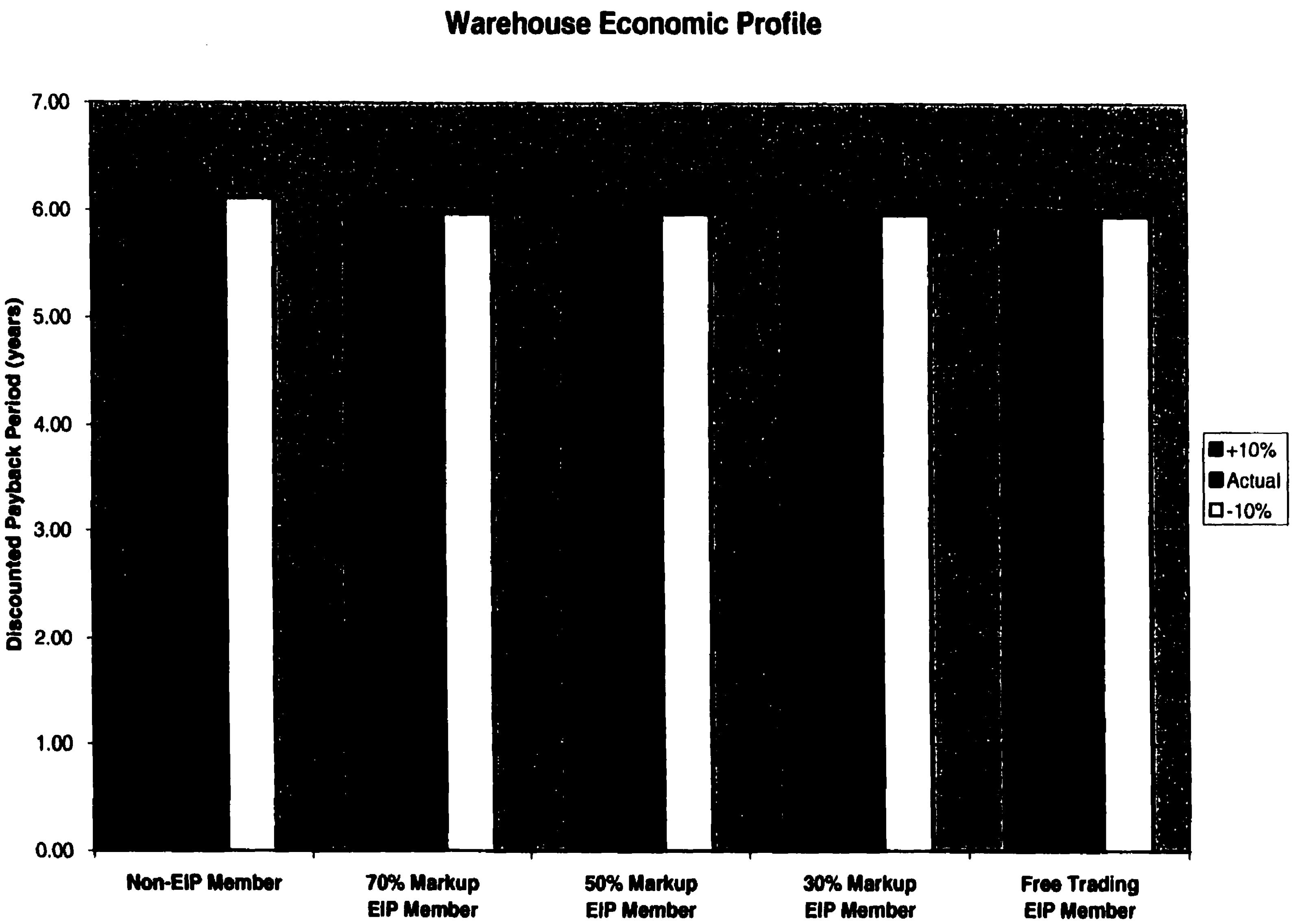


Figure 4.10(g). Sensitivity analysis on Warehouse miscellaneous cost.

With an increase or decrease of 10% of electricity cost, the non-EIP member Fish Farm's discounted payback period varied by just under 1 year. The variation was much less for the EIP members. This is because the cost of electricity is larger for the non-EIP member than for the EIP members. Therefore, fluctuating a larger cost by ±10% will have a greater effect than fluctuating a smaller cost by ±10%.

The discounted payback period is highly sensitive to changes in payroll cost. With a payroll cost increase of 10%, the discounted payback period for the non-EIP member Fish Farm increased by about 12 years. A payroll cost decrease of 10% resulted in a decrease in the discounted payback period for the non-EIP member of nearly 4 years. These changes were smaller for the EIP members because their initial capital costs were smaller.

The discounted payback period varied by about ½ year with changing the building cost by ±10% for the non-EIP member. The variation for the EIP members was less, as expected, due to their smaller overall capital investment.

The discounted payback period is quite sensitive to changes in feed cost. With an increase in feed cost by 10%, there is no period of time in which the non-EIP member Fish Farm will payout. The EIP members show an increase of about 2 to 3 years. A 10% decrease in feed cost resulted in a decline of approximately 5 years for the non-EIP member, and 1 to 2 years for the EIP members.

Greenhouse

The sensitivity analysis showed that the non-EIP member Greenhouse never pays out, except for when the payroll cost was decreased by 10% (discounted payback period was 39 years). This is due to the fact that the non-EIP member Greenhouse has a heavy initial capital cost.

Changes to the cost of steam resulted in minor fluctuations in the discounted payback periods for the 70%-, 50%- and 30%-EIP members, and had no effect on the discounted payback period for the free-trading EIP member. The discounted payback period for the free-trading EIP member was not effected because it receives waste steam at no cost.

The discounted payback period for the EIP members showed minor fluctuations with changes in property rental and tax costs, electricity cost and miscellaneous cost.

The discounted payback period is largely sensitive to changes in payroll cost. The discounted payback periods for the EIP members had significant differences with the variation of payroll cost.

Warehouse

Variations in the Warehouse's property, steam, electricity, payroll, building, racks and miscellaneous costs resulted in no/nominal changes in the discounted payback periods for the non-EIP, 70%-, 50%- and 30%-EIP members. This is due to the large capital cost and low operating and maintenance costs of a Warehouse.

4.5 ENVIRONMENTAL ANALYSIS

4.5.1 Greenhouse Gas Emission Reductions for Each Facility

Heating requirements for the co-locating EIP member facilities can be met by waste steam that is currently released from COGEN. The steam would replace the need for burning natural gas by boilers to generate heat. The resulting reduction in greenhouse gas emissions is given in Table 4.16.

Table 4.16. Reduction in greenhouse gas emissions for each facility.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fish Farm	60	1.907	72,275	138
Greenhouse	410	1.907	493,879	942
Warehouse	32	1.907	38,547	74
			TOTAL	1154

Replacing heat generated from natural gas driven boilers with waste steam from COGEN results in an annual greenhouse gas emission reduction of just over 1000 tonnes CO_2E.

Natural gas is used at COGEN in natural gas driven boilers to produce heat and power. Natural gas is used by the HLU for heating and in the process units. The combined total of flue gas from these two facilities, which is currently emitted to the atmosphere, is 816,514,100 m^3/yr. Table 4.17 provides the reduction in greenhouse gas emissions that would result, assuming that it is economically feasible to inject all the flue gas into the underlying coalbed in the study area.

The emission factor used for calculating the greenhouse gas emissions for COGEN and the HLU are not the same as that used for the co-locating EIP member facilities, as described in section 3.4.2. This is because these boilers are equipped with low NO_x burners. Therefore, the emission factor is (CAPP, 1999):

1.902 kg/m^3 if heat input $<$ 2900 kW
1.907 kg/m^3 if heat input = 2900 to 29,000 kW
1.906 kg/m^3 if heat input $>$ 29,000 kW

Table 4.17. Reduction in greenhouse gas emissions from flue gas injection.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HLU	258,390,000	1.906	333,283,770	635,239
COGEN	558,124,100	1.906	569,019,274	1,084,551
			TOTAL	1,719,790

4.5.2 Overall Greenhouse Gas Emission Reductions for Eco-Industrial Park

The reductions in greenhouse gas emissions for the entire Lloydminster EIP are provided in Table 4.18. This includes the tonnes of CO_2E reduced by eliminating the burning of natural gas for heat, which is given in Table 4.16. This also includes the tonnes of CO_2E that are not released to the atmosphere due to the injection of flue gas into the local coalbed formation (Table 4.17). The reduction in greenhouse gas emissions due to the reduction of transportation requirements cannot be given an actual quantitative number. Nevertheless, there will certainly be a decrease in shipping of materials due to the availability of many resources within the Lloydminster EIP, and therefore, reductions in vehicle emissions.

Table 4.18. Overall greenhouse gas emission reduction for the Lloydminster EIP.

[illegible]	[illegible]
Elimination of natural gas boilers	1,153
Flue gas injection into coalbeds	1,719,790
Reduction of transportation	unable to quantify
TOTAL	1,720,943

The Lloydminster EIP can reduce the current greenhouse gases that are emitted to the atmosphere by 1,720,943 tonnes CO_2E per year. This conservative estimate is a significant reduction in pollution.

The Kyoto Protocol identified mechanisms to reduce greenhouse gas emissions in order to minimize the risks posed by climate change (Carbon Trading Inc., 2000). One of these mechanisms is carbon trading. Carbon trading is the buying and selling of allowances to emit CO_2E (AMEEF, 1997). Carbon trading provides companies with flexibility in how they meet their carbon emission targets. This is economically beneficial because the cost of reducing greenhouse gases varies substantially from one location to another. The reductions of CO_2E/yr for each company in the Lloydminster EIP provides each of these companies with the potential to gain carbon credits that can be used (i.e. traded) elsewhere.

4.5.3 Reduction in Waste Disposal

The Lloydminster EIP can reduce the need for disposal of wastes. This is environmentally advantageous because most disposal techniques can be detrimental to the earth. For example, landfilling can cause groundwater problems due to leaching of contaminants and hamper plant growth on overlying soil due to methane migration. Reduction of waste disposal will also decrease associated transportation and thereby reduce vehicle emissions.

If further research finds it feasible, clarifier sludge, NORM, spent lime, and waste lube oil can be utilized within the study area instead of disposed of externally. NORM is currently collected by external companies, transported and injected deep in the ground. Injecting NORM into the salt caverns will decrease vehicle emissions that result from transportation of the waste to the disposal site. Land application of spent lime and clarifier sludge within the study area will eliminate the need to landfill these byproducts. Waste lube oil is currently collected and transported to recycling facilities. Utilizing waste lube oil within the study area will also decrease vehicle emissions due to transport.

In addition, if further research finds it feasible, petroleum coke and sulphur could be utilized within the study area. This would significantly reduce the large transportation requirements and associated vehicle emissions.

Effluent from the HLU, which is injected into the salt caverns, and extracted as contaminated brine water is currently disposed of through deep-hole injection. If research finds it feasible, this wastewater will no longer be disposed of into the earth, but utilized as salt water for the Fish Farm. In addition, wastewater generated within the Lloydminster EIP can be absorbed by the HLU's effluent stream to washout salt caverns.

4.5.4 Sensitivity Analysis

Table 4.19 (a) and (b) provides the tonnes of CO_2E/yr emitted to the atmosphere if the EIP member facilities required 10% more natural gas and 10% less natural gas, respectively, for heating.

Table 4.19. Greenhouse gas emission reduction for (a) 10% more heat; and (b) 10% less heat.

(a)

[illegible]	[illegible]	[illegible]
Fish Farm	79,503	152
Greenhouse	543,267	1036
Warehouse	42,402	81
		1269

(b)

[illegible]	[illegible]	[illegible]
Fish Farm	65,048	124
Greenhouse	493,879	848
Warehouse	34,692	66
		1038

Increasing/decreasing the heating requirement resulted in an insignificant difference to the overall reduction in greenhouse gas emissions for the Lloydminster EIP. There was only a 0.0067% difference to the overall reduction of 1,720,943 tonnes of CO_2E/yr.

The amount of flue gas to be injected into the underlying coalbed is adjusted by ±10%. Table 4.20 (a) and (b) provide the tonnes of CO_2E/yr due to increasing and decreasing the quantity of flue gas, respectively.

Table 4.20. Greenhouse gas emission reduction for (a) 10% more flue gas; and (b) 10% less flue gas.

(a)

[illegible]	[illegible]	[illegible]
HLU	284,229,000	698,763
COGEN	613,936,510	1,193,006
	TOTAL	1,891,769

(b)

[illegible]	[illegible]	[illegible]
HLU	232,551,000	571,715
COGEN	502,311,690	976,096
	TOTAL	1,547,811

Increasing and decreasing the quantity of flue gas resulted in substantial differences to the overall reduction in greenhouse gas emissions for the Lloydminster EIP. There was a 9.99% difference to the overall reduction of 1,720,943 tonnes of CO_2E/yr.

4.6 IMPACT ASSESSMENT

4.6.1 Conceptual Cognitive Map

The impacts of an EIP are depicted in the form of a conceptual CM in Figure 4.11. The following is a brief description of each cause-effect relationship in the CM:

- Increasing byproducts/wastes from facilities increases the amount of waste disposal. This is a positive correlation.
- An increase demand on materials and resources results in a decrease availability of those materials and resources. This is a negative correlation.
- Byproducts/wastes provided by existing facilities to be used as inputs to other facilities decreases pollution and waste disposal, but results in an increased number of secondary facilities co-locating in the area.
- The co-location of secondary facilities increases pollution, unutilized byproducts/wastes, employment and byproducts/wastes provided by these co-locating facilities. The co-location of secondary facilities decreases the amount of available land.
- An increased availability of materials and resources decreases the demand on these materials and resources.
- Increasing the number of vehicles increases construction of roads and pollution.
- Increased employment results in increased population size.

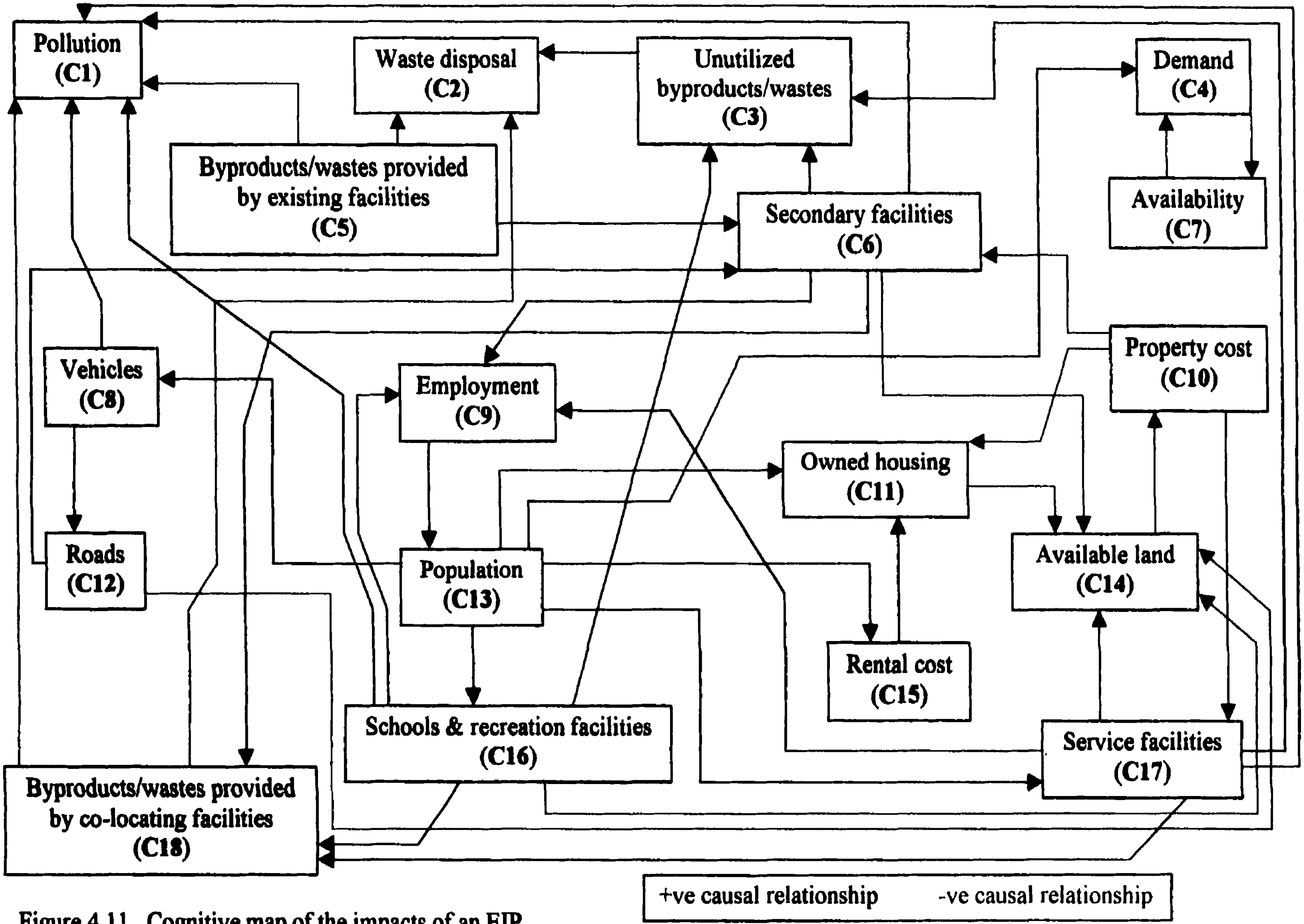


Figure 4.11. Cognitive map of the impacts of an EIP.

- Increasing property cost decreases the co-location of secondary facilities and service facilities, and owned housing.

- If owned housing is increased, the amount of available land is decreased.

- Increasing the development of roads increases the co-location of secondary facilities, but decreases the amount of land available.

- Increasing population results in increased demand on materials and resources, number of vehicles, owned housing, rental cost, schools & recreation facilities and service facilities.

- Decreasing the amount of available land increases property cost.

- Increasing rental cost increases owned housing.

- The co-location of schools & recreation facilities increases unutilized byproducts/wastes, byproducts/wastes provided by these facilities, pollution and employment. The co-location of these facilities decreases available land.

- Increasing the number of service facilities increases unutilized byproducts/wastes, byproducts/wastes provided by these co-locating facilities, pollution and employment. The co-location of these facilities decreases available land.

- Increasing byproducts/wastes provided by the co-locating facilities decreases pollution and waste disposal.

The cause-effect relationships we are most interested in evaluating are:

- the effect "byproducts/wastes provided by existing facilities" have on "pollution"; and
- the effect "byproducts/wastes provided by existing facilities" have on "waste disposal".

Table 4.21 is the adjacency matrix created using the information from Figure 4.11.

4.6.2 Fuzzy Cognitive Map

Figure 4.12 is a FCM of the impacts of an EIP with linguistic weights. The linguistic weights "somewhat" and "significantly" have been assigned to the causal relationships to better define these relationships, which have already been introduced in section 4.6.1. These causal relationships, in reality, are not fairly described in terms of "negative", "positive" and "no" effect. The linguistic variable chosen and their assignments to the causal relationships are largely based on my experience and understanding of the impacts. The adjacency matrix for this FCM is given in Table 4.22.

4.6.3 Vector Matrix Program

Vector matrix multiplication is the technique used to stabilize the adjacency matrix developed in section 4.6.2 (Table 4.21 and 4.22). Appendix E provides the code that was developed in MATLAB to determine when the matrix stabilizes. This code iteratively multiplies the previous state vector by the adjacency matrix using standard matrix multiplication.

Table 4.21. Adjacency matrix for the EIP.

Concepts	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
C1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C4	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0
C5	-1	-1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
C6	1	0	1	0	0	0	0	0	1	0	0	0	0	-1	0	0	0	1
C7	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C8	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
C9	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
C10	0	0	0	0	0	-1	0	0	0	0	-1	0	0	0	0	0	-1	0
C11	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0
C12	0	0	0	0	0	1	0	0	0	0	0	0	0	-1	0	0	0	0
C13	0	0	0	1	0	0	0	1	0	0	1	0	0	0	1	1	1	0
C14	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0
C15	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
C16	1	0	1	0	0	0	0	0	1	0	0	0	0	-1	0	0	0	1
C17	1	0	1	0	0	0	0	0	1	0	0	0	0	-1	0	0	0	1
C18	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

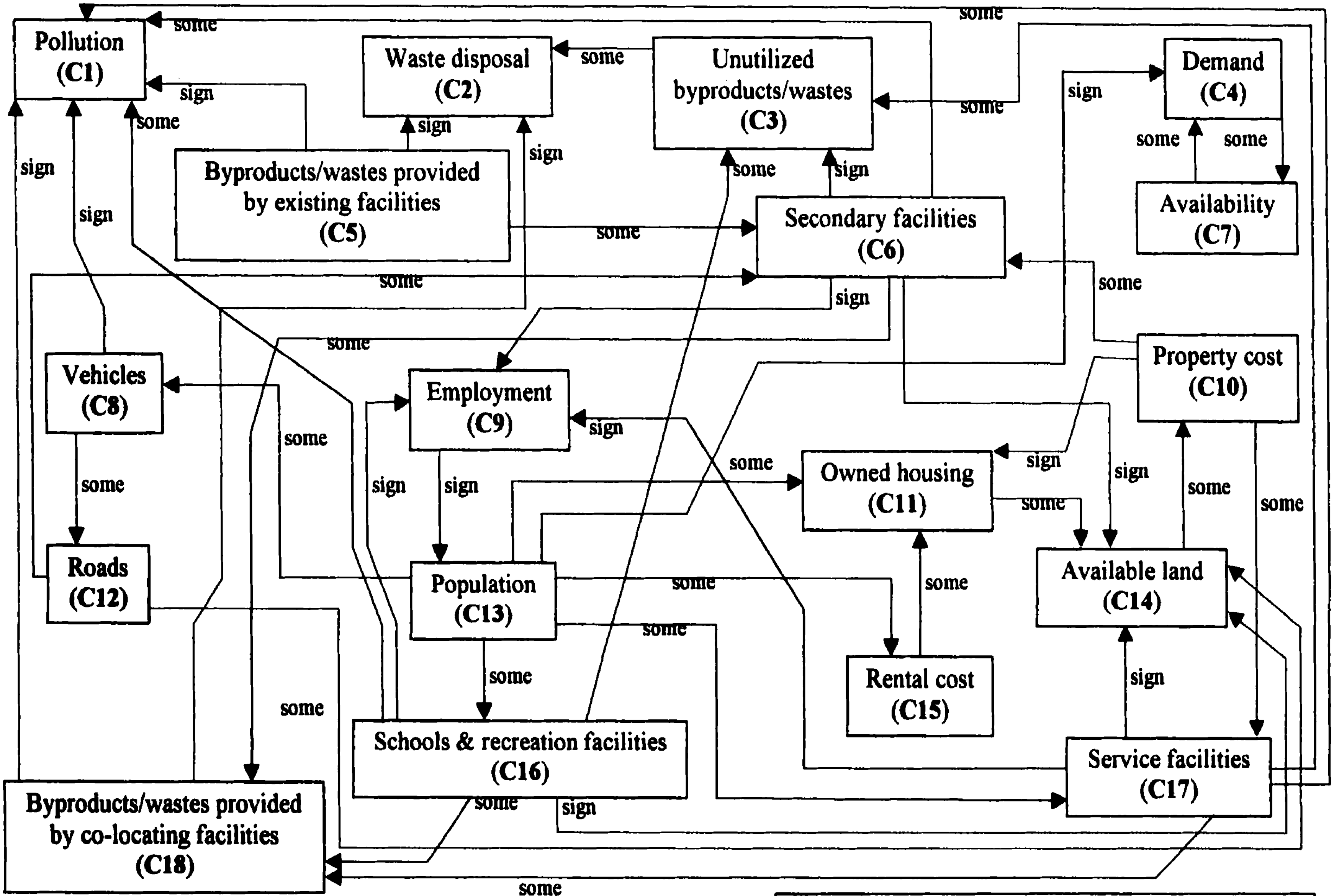


Figure 4.12. Fuzzy cognitive map of the impacts of an EIP.

+ve causal relationship   -ve causal relationship

Table 4.22. Adjacency matrix with linguistic strengths for the EIP.

Concepts	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
C1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C3	0	some (+)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C4	0	0	0	0	0	0	some (-)	0	0	0	0	0	0	0	0	0	0	0
C5	sign (-)	sign (-)	0	0	0	some (+)	0	0	0	0	0	0	0	0	0	0	0	0
C6	some (+)	0	sign (+)	0	0	0	0	0	sign (+)	0	0	0	0	sign (-)	0	0	0	some (+)
C7	0	0	0	some (-)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C8	sign (+)	0	0	0	0	0	0	0	0	0	0	some (+)	0	0	0	0	0	0
C9	0	0	0	0	0	0	0	0	0	0	0	0	sign (+)	0	0	0	0	0
C10	0	0	0	0	0	some (-)	0	0	0	0	sign (-)	0	0	0	0	0	some (-)	0
C11	0	0	0	0	0	0	0	0	0	0	0	0	0	some (-)	0	0	0	0
C12	0	0	0	0	0	some (+)	0	0	0	0	0	0	0	some (-)	0	0	0	0
C13	0	0	0	sign (+)	0	0	0	some (+)	0	0	some (+)	0	0	0	some (+)	some (+)	some (+)	0
C14	0	0	0	0	0	0	0	0	0	some (-)	0	0	0	0	0	0	0	0
C15	0	0	0	0	0	0	0	0	0	0	some (+)	0	0	0	0	0	0	0
C16	some (+)	0	some (+)	0	0	0	0	0	sign (+)	0	0	0	0	sign (-)	0	0	0	some (+)
C17	some (+)	0	some (+)	0	0	0	0	0	sign (+)	0	0	0	0	sign (-)	0	0	0	some (+)
C18	sign (-)	sign (-)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
some = somewhat																		
sign = significantly																		

The vector matrix program output, which can be observed in Appendix F, shows that the matrix stabilized after 7 iterations. Table 4.23 provides the state of each concept in the stabilized matrix. This is required in order to assess the indirect and total effects within the FCM, which will be discussed in section 4.6.4.

4.6.4 Indirect and Total Effects

After the matrix stabilized, the indirect effects and the total effects within the FCM were evaluated. As shown in Table 4.23, concept C_5 (Byproducts/wastes provided by existing facilities) activates all concepts except for C_{17} (Service facilities). The indirect and total effects of C_5 (Byproducts/wastes provided by existing facilities) on C_1 (Pollution) and C_2 (Waste disposal) are explained below.

Effect on Waste Disposal

There are a large number of paths that exist from the cause variable (C_5) to the effect variable (C_2) because of the numerous cycles that could result due to the loops that exist within the FCM. The indirect effects of C_5 on C_2 are provided in Table 4.24 excluding those paths that revisit a concept (i.e. excluding loops).

Table 4.23. Concept state values within stable matrix.

Concepts	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
State	1	-1	1	1	1	1	-1	1	1	1	1	1	1	-1	1	1	0	1

Table 4.24. Indirect effects of C_5 on C_2 (excluding loops).

[illegible]	[illegible]	[illegible]
I_1	5,2	Significantly
I_2	5,6,3,2	Somewhat
I_3	5,6,14,10,17,3,2	Somewhat
I_4	5,6,14,10,17,9,13,16,3,2	Somewhat
I_5	5,6,14,10,17,9,13,16,18,2	Somewhat
I_6	5,6,9,13,8,12,14,10,17,3,2	Somewhat
I_7	5,6,9,13,8,12,14,10,17,18,2	Somewhat
I_8	5,6,9,13,16,3,2	Somewhat
I_9	5,6,9,13,16,18,2	Somewhat
I_{10}	5,6,9,13,16,14,10,17,3,2	Somewhat
I_{11}	5,6,9,13,11,14,10,17,3,2	Somewhat
I_{12}	5,6,9,13,11,14,10,17,18,2	Somewhat
I_{13}	5,6,9,13,15,11,14,10,17,3,2	Somewhat
I_{14}	5,6,9,13,15,11,14,10,17,18,2	Somewhat
I_{15}	5,6,9,13,17,3,2	Somewhat
I_{16}	5,6,9,13,17,18,2	Somewhat
I_{17}	5,6,18,2	Somewhat

As an example of an indirect path, let us examine I_3. I_3 route is from C_5 to C_6, C_6 to C_{14}, C_{14} to C_{10}, C_{10} to C_{17}, C_{17} to C_3, and finally C_3 to C_2. This is depicted in Figure 4.13. The associated indirect effect is calculated as follows:

$$I_3(C_5,C_2) \tag{4.6}$$

$$= \min \{e_{5\,6}, e_{6\,14}, e_{14\,10}, e_{10\,17}, e_{17\,3}, e_{3\,2}\}$$

$$= \min \{\text{somewhat, somewhat, somewhat, somewhat, somewhat, somewhat}\}$$

$$= \text{somewhat}$$

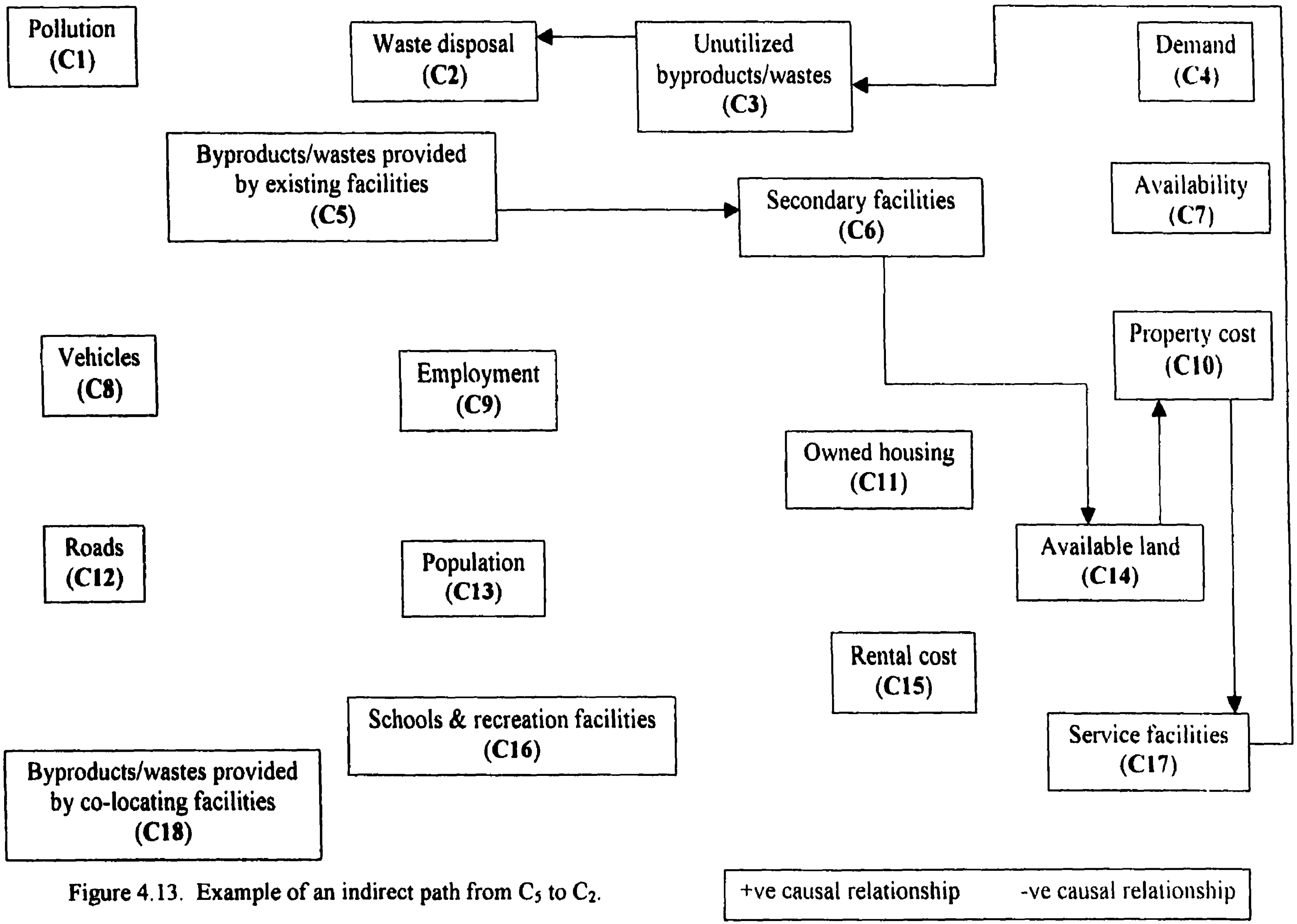


Figure 4.13. Example of an indirect path from C_5 to C_2.

The total effect of all the indirect paths from C_5 to C_2 is calculated as follows:

$$T(C_5, C_2) \tag{4.7}$$

$$= \max \{I_1(C_5,C_2),\ I_2(C_5,C_2),\ I_3(C_5,C_2),\ I_4(C_5,C_2),\ I_5(C_5,C_2),\ I_6(C_5,C_2),\ I_7(C_5,C_2),\ I_8(C_5,C_2),\ I_9(C_5,C_2),\ I_{10}(C_5,C_2),\ I_{11}(C_5,C_2),\ I_{12}(C_5,C_2),\ I_{13}(C_5,C_2),\ I_{14}(C_5,C_2),\ I_{15}(C_5,C_2),\ I_{16}(C_5,C_2),\ I_{17}(C_5,C_2)\}$$

= max {significantly, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat}

= significantly

All the indirect effects that includes loops (not listed in Table 4.24) will have an indirect effect of "somewhat". Therefore, they will not have any implication on the total effect.

The "-1" value in Table 4.23 for C_2 shows that there is a decrease. Therefore, C_5 significantly decreases C_2. In other words, byproducts/wastes provided by existing facilities to be used as inputs into other facilities results in an overall significant decrease in waste disposal. Therefore, even though the activity level within the area increases due to the co-location of secondary and tertiary facilities, the overall waste produced that needs to be disposed of decreases substantially.

Effect on Pollution

Infinite paths also exist from the cause variable (C_5) to the effect variable (C_1) because of the unlimited number of cycles that could result due to the loops that exist within the FCM. The indirect effects of C_5 on C_1 are provided in Table 4.25 excluding those paths that revisit a concept (i.e. excluding loops).

Table 4.25. Indirect effects of C_5 on C_1 (excluding loops).

Path	Concepts	Indirect Effect
I_1	5,1	Significantly
I_2	5,6,1	Somewhat
I_3	5,6,14,10,17,1	Somewhat
I_4	5,6,14,10,17,18,1	Somewhat
I_5	5,6,14,10,17,9,13,8,1	Somewhat
I_6	5,6,14,10,17,9,13,16,18,1	Somewhat
I_7	5,6,14,10,17,9,13,16,1	Somewhat
I_8	5,6,18,1	Somewhat
I_9	5,6,9,13,8,1	Somewhat
I_{10}	5,6,9,13,8,12,14,10,17,1	Somewhat
I_{11}	5,6,9,13,8,12,14,10,17,18,1	Somewhat
I_{12}	5,6,9,13,14,18,1	Somewhat
I_{13}	5,6,9,13,16,1	Somewhat
I_{14}	5,6,9,13,16,17,1	Somewhat
I_{15}	5,6,9,13,16,17,18,1	Somewhat
I_{16}	5,6,9,13,11,14,10,17,1	Somewhat
I_{17}	5,6,9,13,11,14,10,17,18,1	Somewhat
I_{18}	5,6,9,13,15,11,14,10,17,1	Somewhat
I_{19}	5,6,9,13,15,11,14,10,17,18,1	Somewhat
I_{20}	5,6,9,13,17,1	Somewhat
I_{21}	5,6,9,13,17,18,1	Somewhat

Therefore, the total effect is:

$T(C_5, C_1)$ (4.8)

$= \max \{I_1(C_5,C_1), I_2(C_5,C_1), I_3(C_5,C_1), I_4(C_5,C_1), I_5(C_5,C_1), I_6(C_5,C_1), I_7(C_5,C_1), I_8(C_5,C_1), I_9(C_5,C_1), I_{10}(C_5,C_1), I_{11}(C_5,C_1), I_{12}(C_5,C_1), I_{13}(C_5,C_1), I_{14}(C_5,C_1), I_{15}(C_5,C_1), I_{16}(C_5,C_1), I_{17}(C_5,C_1), I_{18}(C_5,C_1), I_{19}(C_5,C_1), I_{20}(C_5,C_1), I_{21}(C_5,C_1)\}$

= max {significantly, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat,

somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat, somewhat}

= significantly

All the indirect effects that includes loops (not listed in Table 4.25) will have an indirect effect of "somewhat". Therefore, they will not have any implication on the total effect.

The "1" value in Table 4.23 for C_1 shows that there is an increase. Therefore, C_5 significantly increases C_1. In other words, byproducts/wastes provided by existing facilities for use as inputs to other facilities results in an overall significant increase in pollution. This is likely due to the increased activity level in the area (i.e. co-location of secondary and tertiary facilities, roads, etc.).

One would expect that utilizing byproducts/wastes provided by exiting facilities would decrease pollution, especially since waste disposal decreases. FCM shows that this is not actually the case. This is one of the largest advantages of using FCM for impact assessment; it evaluates the real impacts of a project by taking into consideration all the effects.

4.6.5 Sensitivity Analysis

Linguistic weights were altered from significantly to somewhat, or vice versa, for the following causal relationships that had maximum uncertainty:

- C_3 (Unutilized byproducts/wastes) → C_2 (Waste disposal)
- C_5 (Byproducts/wastes provided by existing facilities) → C_1 (Pollution)
- C_5 (Byproducts/wastes provided by existing facilities) → C_2 (Waste disposal)
- C_6 (Secondary facilities) → C_1 (Pollution)

- C_6 (Secondary facilities) → C_3 (Unutilized byproducts/wastes)
- C_{18} (Byproducts/wastes provided by co-locating facilities) → C_1 (Pollution)
- C_{18} (Byproducts/wastes provided by co-locating facilities) → C_2 (Waste disposal)

The results of varying the linguistic variables of the chosen causal relationships are provided in Table 4.26.

Table 4.26. Sensitivity analysis on linguistic weights of causal relationships.

<table>
<tr><th>Relationship</th><th colspan="2">Linguistic Weight</th><th colspan="2">Total Effect</th></tr>
<tr><th></th><th>Actual</th><th>Changed To</th><th>Actual</th><th>Changed To</th></tr>
<tr><td>C3 → C2</td><td>somewhat</td><td>significantly</td><td rowspan="7">significantly</td><td>significantly</td></tr>
<tr><td>C5 → C1</td><td>significantly</td><td>somewhat</td><td>somewhat</td></tr>
<tr><td>C5 → C2</td><td>significantly</td><td>somewhat</td><td>somewhat</td></tr>
<tr><td>C6 → C1</td><td>somewhat</td><td>significantly</td><td>significantly</td></tr>
<tr><td>C6 → C3</td><td>significantly</td><td>somewhat</td><td>significantly</td></tr>
<tr><td>C18 → C1</td><td>significantly</td><td>somewhat</td><td>significantly</td></tr>
<tr><td>C18 → C2</td><td>significantly</td><td>somewhat</td><td>significantly</td></tr>
</table>

Table 4.26 shows that of the relationships analyzed, altering the linguistic weights for only C_5 (Byproducts/wastes provided by existing facilities) → C_1 (Pollution) and C_5 (Byproducts/wastes provided by existing facilities) → C_2 (Waste disposal) had an impact on the final solution (i.e. the total effect). Changing the linguistic weight of the relationship C_5 → C_1 from significantly to somewhat resulted in the total effect being changed from being significantly increasing to somewhat increasing. Altering the linguistic weight of the relationship C_5 → C_2 from significantly to somewhat resulted in the total effect being changed from being significantly decreasing to somewhat decreasing. Therefore, these two relationships were the only two relationships that made an overall difference to the impact due to variations in linguistic weights.

CHAPTER 5
CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

This study highlighted the potential byproduct synergy linkages and facilities that would fit well within the network of existing facilities in an EIP developed in the Lloydminster area. The following group of existing facilities were selected to be part of the Lloydminster EIP:

- Husky Lloydminster Upgrader
- Meridian Cogeneration Plant
- Asphalt Refinery
- Justamere Farms (Crop I, Feedmill, Feedlot)
- Dyjack Farms Ltd. (Crop II)
- A.D.M Agri-Industries

The following conclusions were arrived at from this study:

- Based on systemic ranking of the 15 potential new facilities that were analyzed, the facilities that were ranked the highest included the Fish Farm, Greenhouse and Warehouse. Therefore, these facilities would be easiest to justify setting up in the Lloydminster EIP.

- Based on the selected most feasible potential facilities and the chosen existing facilities, the following synergies were selected to be involved in the Lloydminster EIP:

  - steam
  - electricity

- natural gas
- water
- waste lube oil
- spent lime
- NORM
- sulphur
- flue gas
- straw
- oats & barley
- canola
- feed
- manure
- wastewater
- petroleum coke
- brine water
- clarifier sludge

- The supply of resources (including byproducts) meets the demand of resources within the Lloydminster EIP, with the exception of low-pressure steam and maybe water *(because supply information is not available)* from the Asphalt Refinery to the Canola Plant.

- The economic profile generated for the Fish Farm showed that this facility had attractive discounted payback periods if co-locating within the Lloydminster EIP (6.25 years, 5.83 years and 5.47 years for 70%-, 50%- and 30%-EIP members, respectively). The non-EIP member Fish Farm has an unattractive discounted payback period that is more than double of that of a 70%-EIP member (13.96 years). Thus, a Fish Farm co-locating in the Lloydminster EIP instead of locating outside the EIP can result in discounted payback period reductions of about 55%, 58% and 61% for the 70%-, 50%- and 30%-EIP members, respectively. The economic sensitivity analysis determined that the Fish Farm's discounted payback period is highly sensitive to changes in payroll and feed costs.

- The economic profile generated for the Greenhouse showed attractive discounted payback periods if setting up in the Lloydminster EIP (6.95 years, 6.25 years and 5.69 years for 70%-, 50%- and 30%-EIP members, respectively). The Greenhouse as a non-EIP member does not have a period in which the future net cash flows will be equivalent to the initial capital cost (i.e. never pays out). Therefore, it is not economically feasible for a Greenhouse to set up in the Lloydminster area, outside of the EIP. The economic sensitivity analysis determined that the Greenhouse's discounted payback period is quite sensitive to variations in payroll cost.

- The economic profile for the Warehouse showed attractive discounted payback periods (about 6 years) regardless of whether or not it was part of the Lloydminster EIP. This is due to the large infrastructure costs associated with establishing a Warehouse. A Warehouse co-locating in the Lloydminster EIP instead of locating outside the EIP results in discounted payback period reductions just above 2% for all EIP members. The economic sensitivity analysis determined that the Warehouse's discounted payback period was not very sensitive to alternations in the analyzed costs due to the large capital cost and low operating and maintenance costs.

- The economic sensitivity analysis showed that altering the cost of items resulted in larger variations in discounted payback periods for non-EIP members than EIP members. This is because non-EIP members have heavier initial capital investments.

- The reduction in capital cost associated with co-locating in the Lloydminster EIP is \$105,900 for the Fish Farm, \$414,000 for the Greenhouse, and \$102,700 for the Warehouse. The annual cost savings for the Fish Farm to colocate in the Lloydminster EIP is \$2,816, \$6,316 and \$9,816 for the 70%-, 50%- and 30%-EIP members, respectively. For the Greenhouse, the annual cost savings are \$5,400, \$15,700 and \$25,800 for the 70%-, 50%- and 30%-EIP members, respectively. The annual cost saving for the Warehouse is -\$700 for the 70%-EIP member, which is due to the rental cost of land that the non-EIP member does not pay. The annual cost saving for the 50%- and 30%-EIP members are \$400 and \$1,500, respectively.

- The annual profit to COGEN with the development of the Lloydminster EIP is about \$35,000 for the 70%-EIP member, \$25,000 for the 50%-EIP member, and \$15,000 for the 30%-EIP member. The annual profit to the anchor facility is approximately \$35,000 for the 70%-EIP member, \$28,000 for the 50%-EIP member, and \$25,000 for the 30%-EIP member.

- Development of an EIP in the Lloydminster area would result in $154,013/yr in overall cost saving if the EIP members are 70%-EIP members, $154,052/yr if 50%-EIP members, and $153,995/yr if 30%-EIP members. There is not much variance between these cost savings because the more a supplier profits in selling a material, the more the receiver has to pay for that material.

- The reduction in greenhouse gas emissions due to utilizing waste steam for heating the co-locating facilities instead of using natural gas driven boilers is about 1,150 tonnes CO_2E/yr. This is comprised of 140 tonnes CO_2E/yr for the Fish Farm, 940 tonnes CO_2E/yr for the Greenhouse and 70 tonnes CO_2E/yr for the Warehouse. The reductions in greenhouse gas emissions due to flue gas injection is 1,719,790 tonnes CO_2E/yr (635,239 tonnes CO_2E/yr for HLU and 1,084,551 tonnes CO_2E/yr for COGEN). However, a detailed study is required before the flue gas can be injected.

- The development of the Lloydminster EIP would result in greenhouse gas emission reductions just above 1,720,000 tonnes CO_2E/yr. This is a conservative estimate because there are many additional components that were not quantifiable. For example, reduction in greenhouse gases due to decreased transportation could not be quantified in this study. The environmental sensitivity analysis shows that changes in heating requirements for the co-locating facilities have a small effect on the overall greenhouse gas emission reduction, while changes in flue gas quantities that can be injected into the underlying coalbed have a significant effect.

- The impact assessment determined that utilizing byproducts/wastes provided by existing facilities as inputs for other facilities significantly increases pollution and significantly decreases waste disposal. Intuitively, one would expect that utilizing byproducts/wastes provided by exiting facilities would decrease pollution, especially since waste disposal decreases. FCM shows that this is not in fact the case. FCM evaluates the overall impacts of a project by taking into consideration all the effects. For example, establishment of secondary and tertiary facilities such as schools and colleges, newer and wider roads, etc. This is the prime advantage of using FCM for impact assessments; it provides a realistic evaluation of what will be the effects of a project. The impact assessment sensitivity analysis shows that of the seven relationships whose linguistic weights were altered, only two made an overall difference that changed the "significantly" to "somewhat".

The most significant overall contributions of this thesis project is the development of an EIP in the Lloydminster area, the analysis of environmental and economic benefits of this EIP, and the innovative use of fuzzy cognitive mapping for impact assessments.

5.2 Recommendations

The following recommendations were based on the findings of this study:

- The scope of this study focused on the Lloydminster area, and therefore, was limited to the Lloydminster market. A study should be conducted on a larger market. Many of the medium ranked facilities may be feasible to setup when considering a larger market. For example, the Salt Plant, the Concrete Admixture Plant, and the Sulphuric Acid Plant.

- This study focused on co-locating only the highest ranked facilities from the feasibility study. This does not mean that the logistics are not present to set up the medium ranked facilities, and maybe even the lowest ranked. Detailed studies on each are required to determine whether or not this is the case.

- For each of the selected facilities to set up in the Lloydminster EIP, an extensive detailed study needs to be completed for that facility.

- The following synergies require further research to determine if they are feasible:

    - flue gas (injection into underlying coalbed)

- spent lime (land application)
- sulphur (land application)
- petroleum coke (combustion)
- clarifier sludge (land application)
- NORM (injection into salt caverns)
- waste lube oil (HLU upgrading process)
- brine water (marine aquatic environment)

- In the FCM analysis, a large number of concepts were considered. However, this can still be expanded. A more detailed evaluation of the impact assessment should be conducted by expanding the FCM and assigning a greater number of linguistic weights.

- Technological advances are needed in order to make certain waste streams useable by other facilities. This will increase the number of synergies between facilities, which in turn will result in greater environmental and economic benefits.

An EIP is ever-growing and expanding. Therefore, the possible linkages are numerous and an increasing number of facilities could colocate. After this phase of the Lloydminster EIP is set up, the market for product outputs and availability of inputs will change. Due to this change in the dynamics of the system, another feasibility study needs to be conducted to determine the highest ranked facilities for the next phase of co-location.

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APPENDIX A:

DATA ON EXISTING FACILITIES

Husky Lloydminster Upgrader (anchor facility)

MATERIAL INPUTS	QUANTITY	DETAILS	CURRENT SOURCE	REF	
blended crude oil		heavy (density near 1.0)	Husky	(BW)	
gas oil		from oil recovery facilities	Husky NewAlta Enviro 800 m3/mo	(BW)	
diluent - condensate		sour pipeline condensate sour naphtha	Husky	(BW)	
slop oil			Husky	(BW)	
water		river water	City of Lloydminster	(DK)	
steam		4500 kPa (high P)	Husky/TransAlta	(DK)	
electricity			SaskPower	(DK)(GM)(AM)	
natural gas			ATCO & MIPL pipelines	(DK)	
PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**CURRENT RECEIVER**	**REF**	**POTENTIAL RECEIVER**
synthetic blended crude		light, sweet	Husky (transportation fuels)	(BW)	
light naphtha		diluent - condensate	Husky (pipelines)	(BW)	
sulphur			3 CDN (fertilizer) 3 US (fertilizer, 1 uranium) Ram River	(JB)	Agriculture (fertilizer/soil enhancement) Sulphuric Acid Plant (acid) Pharmaceuticals Plant (sulphur drugs)
petroleum coke		carbon black	4 CDN 1 Japanese	(JB)	COGEN/Metallurgical Smelters (energy) (ammonia or electrode manufacturing) (road material) (synthetic gas) Agriculture (control odors) Biofilters
NON-PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**CURRENT RECEIVER**	**REF**	**POTENTIAL RECEIVER**
steam	0 to 308,600 t/yr (180 C)	350 kPa (low P)	none (vented)	(DK)	Greenhouse/Fish Farm (heat water) (heating)
spent lime	675 m3/yr	estimate based on pond size ~37% moisture	stored on site option BFI (Calgary landfill)	(MM)	Agriculture (fertilizer/soil enhancement) Feedlot (buffer feed) Biogas Process
spent caustic	3,650 m3/yr		NewAlta in S Sask (disposal)	(MM)	Weyerhaeuser CH2M Gore & Storrie Ltd. (recycle) Marsulex
spent activated carbon	5 m3/yr	absorbed H2S - Amine Unit	stored on site Lafarge Cement Plant in BC	(MM)	Cement Plant Agriculture (absorb sterilant)
spent H-OIL catalyst	3,898 t/yr	contains Ni, V, Mo, Al	CS Metals in US (recycled)	(MM)(DK)	Cement Plant Metals Recovery Plant
effluent to disposal wells (brine water)	1,508,545 m3/yr	assume 100% salt cavern return	(deep well (4) disposal)	(KZ)	CH2M Gore & Storrie Ltd. (recycle) Salt Plant (salt) ARC & Fish Farm
flue gas	258,390,000 m3/yr	from burning NG and fuel gas	none (vented)	(DK)	Husky (coalbed methane recovery)
hydrocracking residue		pitch	HLU (coked)	(DK)	Concrete Admixture Plant
LABOUR REQUIREMENTS	**QUANTITY**			**REF**	
management	15			(DK)	
skilled labour	241			(DK)	
labour	30			(DK)	
PHYSICAL SIZE	**QUANTITY**			**REF**	
footprint	300 acres			site map (GK)	

Meridian Cogeneration (anchor facility)					
MATERIAL INPUTS	**QUANTITY**	**DETAILS**	**CURRENT SOURCE**	**REF**	
natural gas			ATCO & MIPL pipelines	(DK)	
water			City of Lloydminster	(DK)	
PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**CURRENT RECEIVER**	**REF**	**POTENTIAL RECEIVER**
electricity			SaskPower	(DK)	
NON-PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**CURRENT RECEIVER**	**REF**	**POTENTIAL RECEIVER**
steam	*876,000 t/yr (370 C-410 C)*	*4500 kPa (high P) pot:600 t/hr (max:500HLU&turbine) (waste= 100 t/hr)*	*none (vented)*	*(DK)*	*Greenhouse/Fish Farm (heat water) (heating)*
steam	262,800 t/yr (180 C)	350 kPa (low P)	none (vented)	(DK)	*Greenhouse/Fish Farm (heat water) (heating)*
flue gas	558,124,000 m3/yr	from burning NG	none (vented)	(DK)	Husky (coalbed methane)
LABOUR REQUIREMENTS				**REF**	
management	1			(DK)	
skilled labour	9			(DK)	
labour	0			(DK)	
PHYSICAL SIZE				**REF**	
footprint	12 acres			(DK)	

Asphalt Refinery

MATERIAL INPUTS	QUANTITY	DETAILS	CURRENT SOURCE	REF	
blended crude oil		heavy	pipeline	(LD)(DM)	
water			City of Lloyd (63,578 m3/yr) raw water wells (78,780 m3/yr)	(LD)(GD)	
electricity			ATCO	(DK)(AM)(BF)	
natural gas			ATCO pipeline	(LD)(RU)	
PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**CURRENT RECEIVER**	**REF**	**POTENTIAL RECEIVER**
asphalt			(mostly paving) (roofing)	(LD)(DM)	
tops			HLU	(LD)(RS)	
residuals			(dedusting/mining oils) (pentacarrier/pole treating oils) (fuel oils & emulsion oils) (drilling fluids)	(LD)(RS)	
straight run gas			Husky pipeline	(LD)(DM)	
NON-PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**CURRENT RECEIVER**	**REF**	**POTENTIAL RECEIVER**
spent lime	448 m3/yr		Lloyd landfill (conditioning agent)	(BF)	Agriculture (fertilizer/soil enhancement) Feedlot (buffer feed) Biogas Process
slop oil	2,428 m3/yr		Reclaimers Anadime Recycling Plant	(LD)	
steam	47 t/yr	350 kPa (low P)	none (vented)	(DK)	Canola Plant
waste lube oil	2,194 m3/yr		Little Dipper holdings Ltd. (recycled)	(AM)	Waste Lube Oil Recycling Plant HLU
LABOUR REQUIREMENTS	**QUANTITY**			**REF**	
management	9			(GD)	
skilled labour	63			(GD)	
labour	10			(GD)	
PHYSICAL SIZE	**QUANTITY**			**REF**	
footprint	272 acres			(BF)	

Crop I (oats & barley)

MATERIAL INPUTS	QUANTITY	DETAILS	CURRENT SOURCE	REF	UNIT COST	POTENTIAL SOURCE
fertilizer	4.5 t/yr			(JF)	$303/t	
oat seeds	10.8 t/yr			(JF)	$130/t	
barley seeds	15.2 t/yr			(JF)	$92/t	
manure	750 t/yr		Feedlot	(JF)	$0/t	
PRODUCT OUTPUTS	**QUANTITY**		**CURRENT RECEIVER**	**REF**	**UNIT COST**	**POTENTIAL RECEIVER**
oat grain	154 t/yr		Feedmill	(JF)	$77.81/t	Ethanol Plant
barley grain	218 t/yr		Feedmill	(JF)	$87.27/t	Ethanol Plant
straw	499 t/yr		Feedlot	(JF)	$37.48/t	Strawboard Plant
LABOUR REQUIREMENTS	**QUANTITY**			**REF**		
manager	1			(JF)		
skilled labour	1			(JF)		
labour	1			(JF)		
PHYSICAL SIZE	**QUANTITY**			**REF**		
footprint	617 acres			site map (GK)		

Feedmill

MATERIAL INPUTS	QUANTITY	DETAILS	CURRENT SOURCE	REF	UNIT COST	POTENTIAL SOURCE
oat grain	77 t/yr		Crop I	(JF)	$77.81/t	
barley grain	109 t/yr		Crop I	(JF)	$87.27/t	
electricity	200,000 kWh/yr		SaskPower	(JF)	$0.075/kWh	HLU ($0.06312/kWh)
alpha alpha pellets	120 t/yr			(JF)	$228/t	
PRODUCT OUTPUTS	**QUANTITY**		**CURRENT RECEIVER**	**REF**	**UNIT COST**	**POTENTIAL RECEIVER**
feed	313 t/yr		Feedlot	(JF)	$88/t	Fish Farm
LABOUR REQUIREMENTS	**QUANTITY**			**REF**		
manager	1			(JF)		
skilled labour	1			(JF)		
labour	1			(JF)		
PHYSICAL SIZE	**QUANTITY**			**REF**		
footprint	1 acre			(JF)		

Feedlot

MATERIAL INPUTS	**QUANTITY**	**DETAILS**	**CURRENT SOURCE**	**REF**	**UNIT COST**	**POTENTIAL SOURCE**
feed	156 t/yr	winter only	Feedmill	(JF)	$88/t	
straw	499 t/yr		Crop I	(JF)	$37.48/t	
PRODUCT OUTPUTS	**QUANTITY**		**CURRENT RECEIVER**	**REF**	**UNIT COST**	**POTENTIAL RECEIVER**
cattle	500 head/yr	for breeding		(JF)	$2,250/head	Meat Packer/Slaughterhouse
NON-PRODUCT OUTPUTS	**QUANTITY**		**CURRENT RECEIVER**	**REF**	**UNIT COST**	**POTENTIAL RECEIVER**
manure	750 t/yr		Crop I	(JF)	$0/t	
LABOUR REQUIREMENTS	**QUANTITY**			**REF**		
manager	1			(JF)		
skilled labour	1			(JF)		
labour	1			(JF)		
PHYSICAL SIZE	**QUANTITY**			**REF**		
footprint	380 acres			site map (GK)		

Crop II (wheat & canola)						
MATERIAL INPUTS	QUANTITY	DETAILS	CURRENT SOURCE	REF	UNIT COST	POTENTIAL SOURCE
fertilizer	5 t/yr			(JH)	$303/t	
canola seeds	952 kg/yr			(JH)	$0.7/kg	
wheat seeds	1429 kg/yr			(JH)	$0.2/kg	
PRODUCT OUTPUTS	QUANTITY		CURRENT RECEIVER	REF	UNIT COST	POTENTIAL RECEIVER
canola grain	20 t/yr		Canola Plant	(JH)	$260/t	
wheat grain	38 t/yr		SaskPool	(JH)	$90/t	Ethanol Plant
LABOUR REQUIREMENTS	QUANTITY			REF		
manager	1			(JH)		
skilled labour	0			(JH)		
labour	0			(JH)		
PHYSICAL SIZE	QUANTITY			REF		
actual	70 acres			(JH)		

Canola Plant

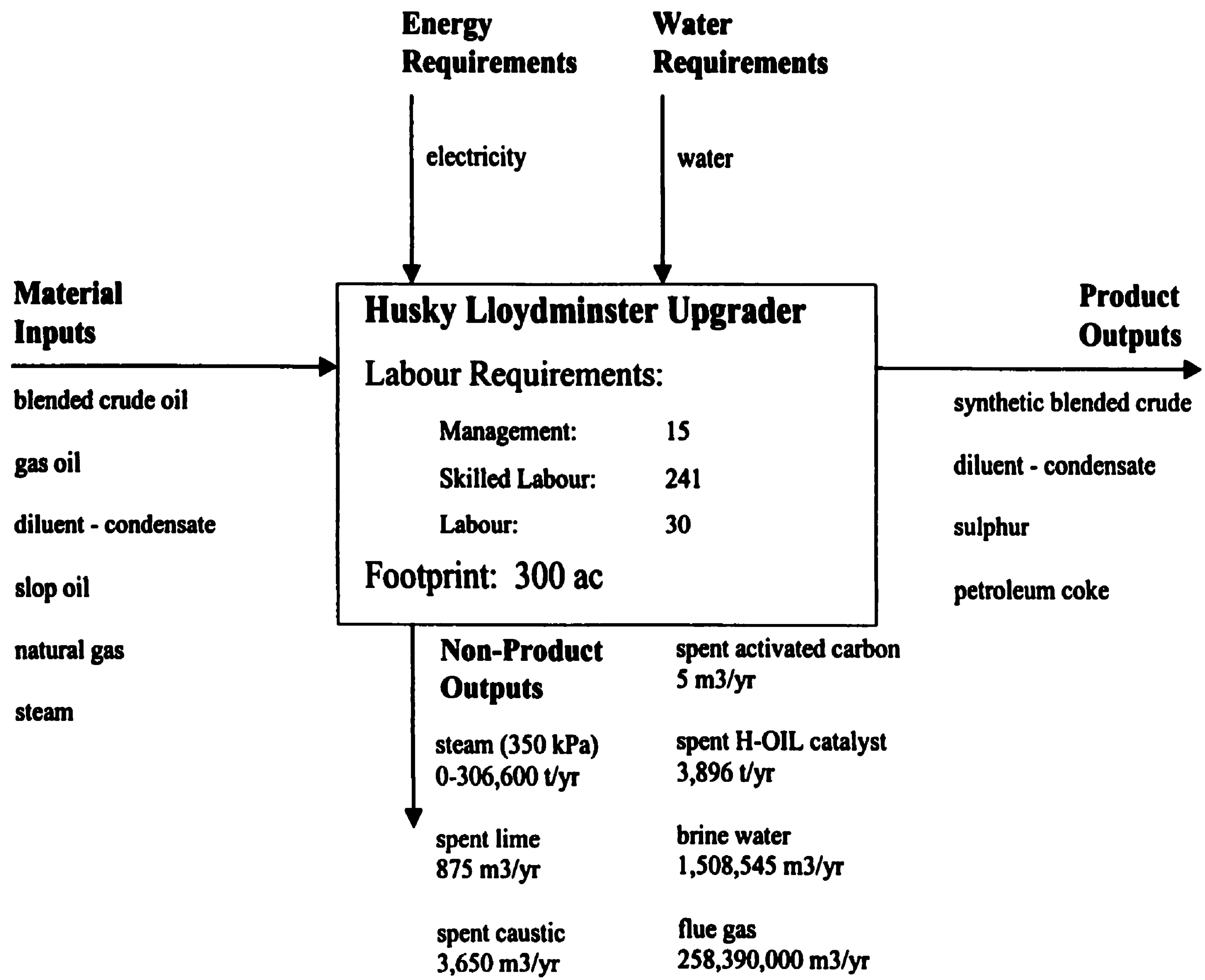
MATERIAL INPUTS	QUANTITY	DETAILS	CURRENT SOURCE	REF	UNIT COST	POTENTIAL SOURCE
canola grain	365,000 t/yr	usually $300/t (low this year)	Croplands	(TB)	$260/t	
electricity	1,825,000 kWh/yr		SaskPower	(TB)	$0.045/kWh	
water	250,000 m3/yr	172,709 m3/yr for steam	City of Lloyd	(TB)	$1.19/m3	HLU ($0.0985/m3)
natural gas	547,500 GJ/yr			(TB)	$2.80/GJ	HLU
steam	*244,940 t/yr*	*instead of H20 & NG 160 psi (med P)*		(TB)		
PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**CURRENT RECEIVER**	**REF**	**UNIT COST**	**POTENTIAL RECEIVER**
canola oil	146,000 t/yr			(TB)	$838/t	
meal	219,000 t/yr			(TB)	$120/t	
deodorizer distillate	365 t/yr	Vitamin E		(TB)	$1764/t	
LABOUR REQUIREMENTS	**QUANTITY**			**REF**		
management	3			(TB)		
skilled labour	7			(TB)		
labour	20			(TB)		
PHYSICAL SIZE	**QUANTITY**			**REF**		
footprint	10 acres			(TB)		

Name	Abbreviation	Company
Angela Mah	AM	Husky Energy Inc.
Bert Faber	BF	Husky Energy Inc.
Brenda Wilm	BW	Husky Energy Inc.
Dave Kay	DK	Husky Energy Inc.
Daryl Macleod	DM	Husky Energy Inc.
David McCoy	DMc	Husky Energy Inc.
Dr. Mirza	Dr.M	Crop Diversification Centre North
Gerold Danoluk	GD	Husky Energy Inc.
Garnet Keuhn	GK	Husky Energy Inc.
Geoff Martin	GM	Husky Energy Inc.
Jan Binden	JB	Husky Energy Inc.
John Fox	JF	Justamere Farms Ltd.
Jack Hill	JH	Dyjack Farms Ltd.
Kevin Zern	KZ	Husky Energy Inc.
Laureen Dimmel	LD	Husky Energy Inc.
Monty Moore	MM	Husky Energy Inc.
Ron Schmitz	RS	Husky Energy Inc.
Ron Smith	RS	Husky Energy Inc.
Ron Umbsaar	RU	Husky Energy Inc.
Tim Benkel	TB	A.D.M Agri-Industries
Wendel James	WJ	Alberta Research Council
Husky quantities:1998 values except water, electricity (1999) & natural gas (2000)		
italics: potential to use that material		

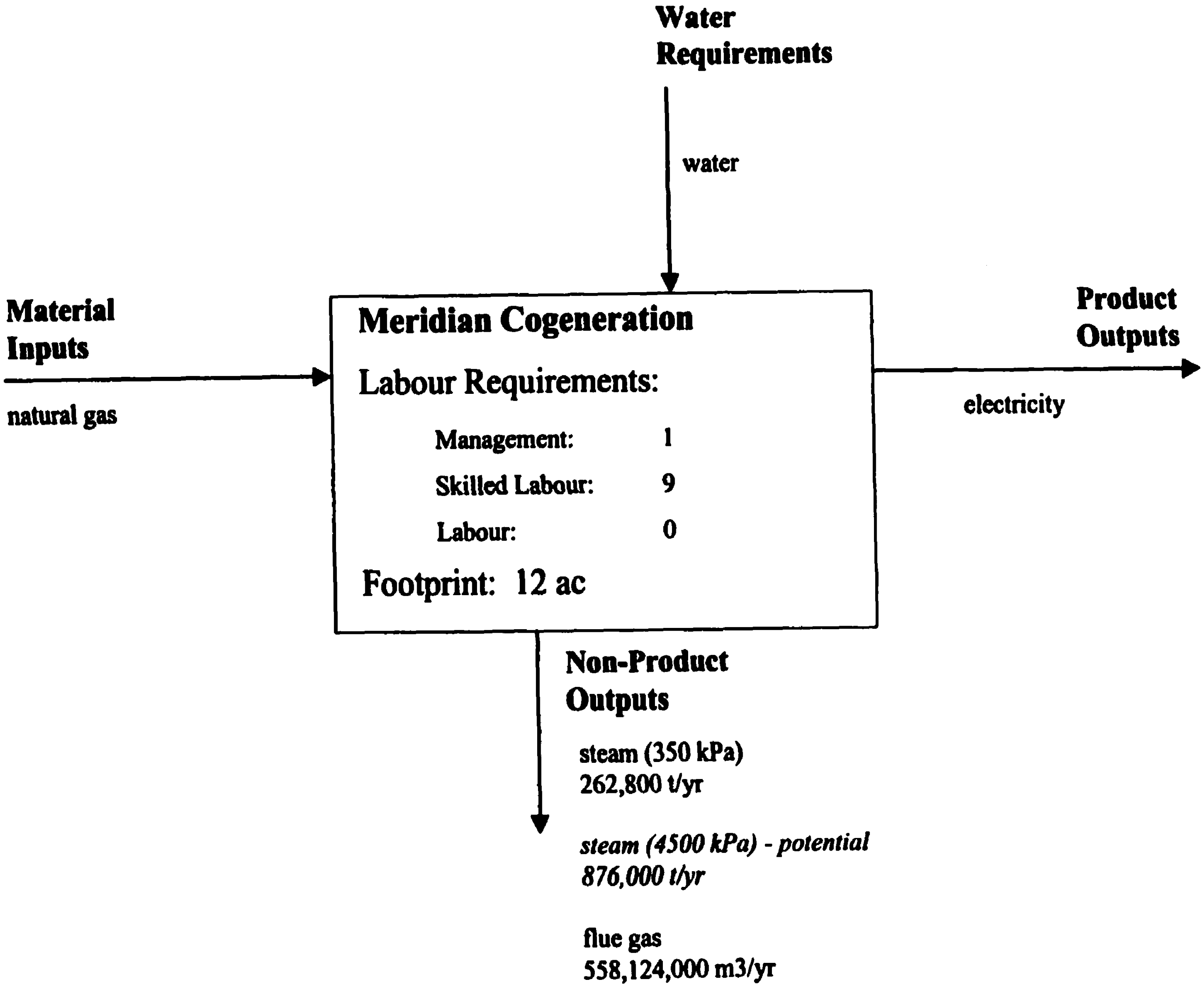
APPENDIX B:

MATERIAL AND RESOURCE FLOW DIAGRAMS FOR EXISTING FACILITIES

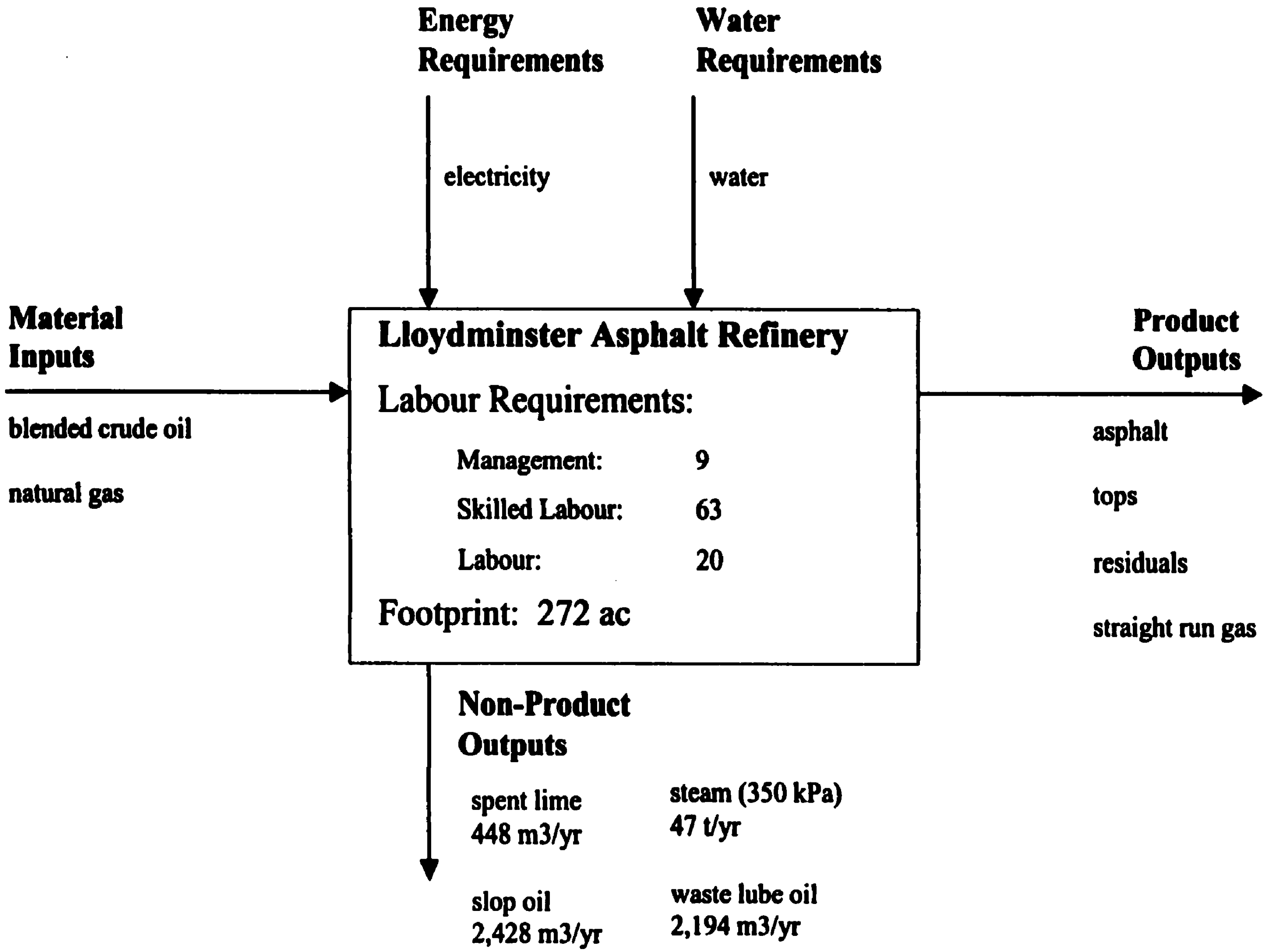
Material and Resource Flow Diagram



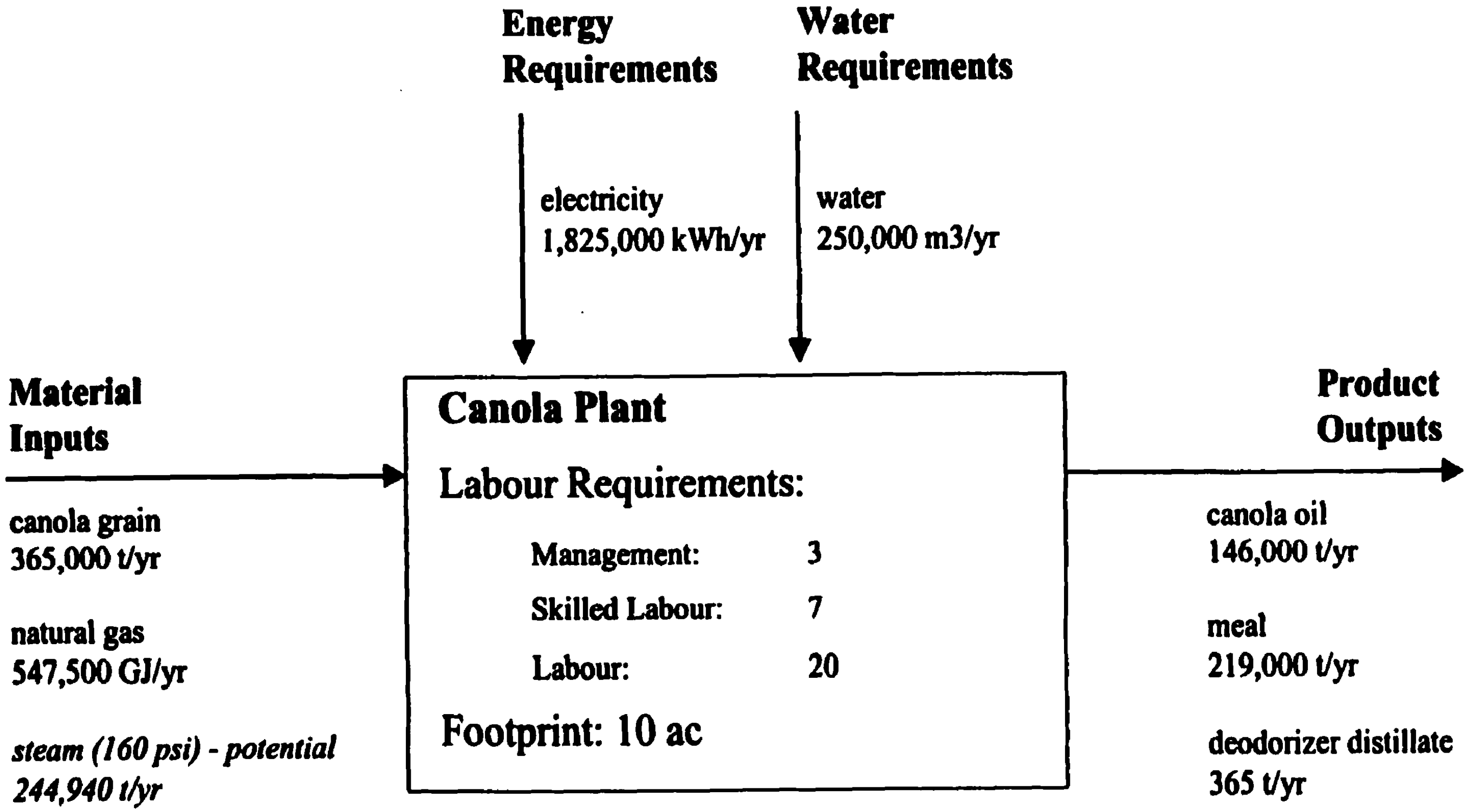
Material and Resource Flow Diagram



Material and Resource Flow Diagram



Material and Resource Flow Diagram



Material and Resource Flow Diagram

Material Inputs

oat seeds
10.8 t/yr

barley seeds
15.2 t/yr

fertilizer
4.5 t/yr

manure
750 t/yr

Crop I (oats & barley)

Labour Requirements:

Management:	1
Skilled Labour:	1
Labour:	1

Footprint: 617 ac

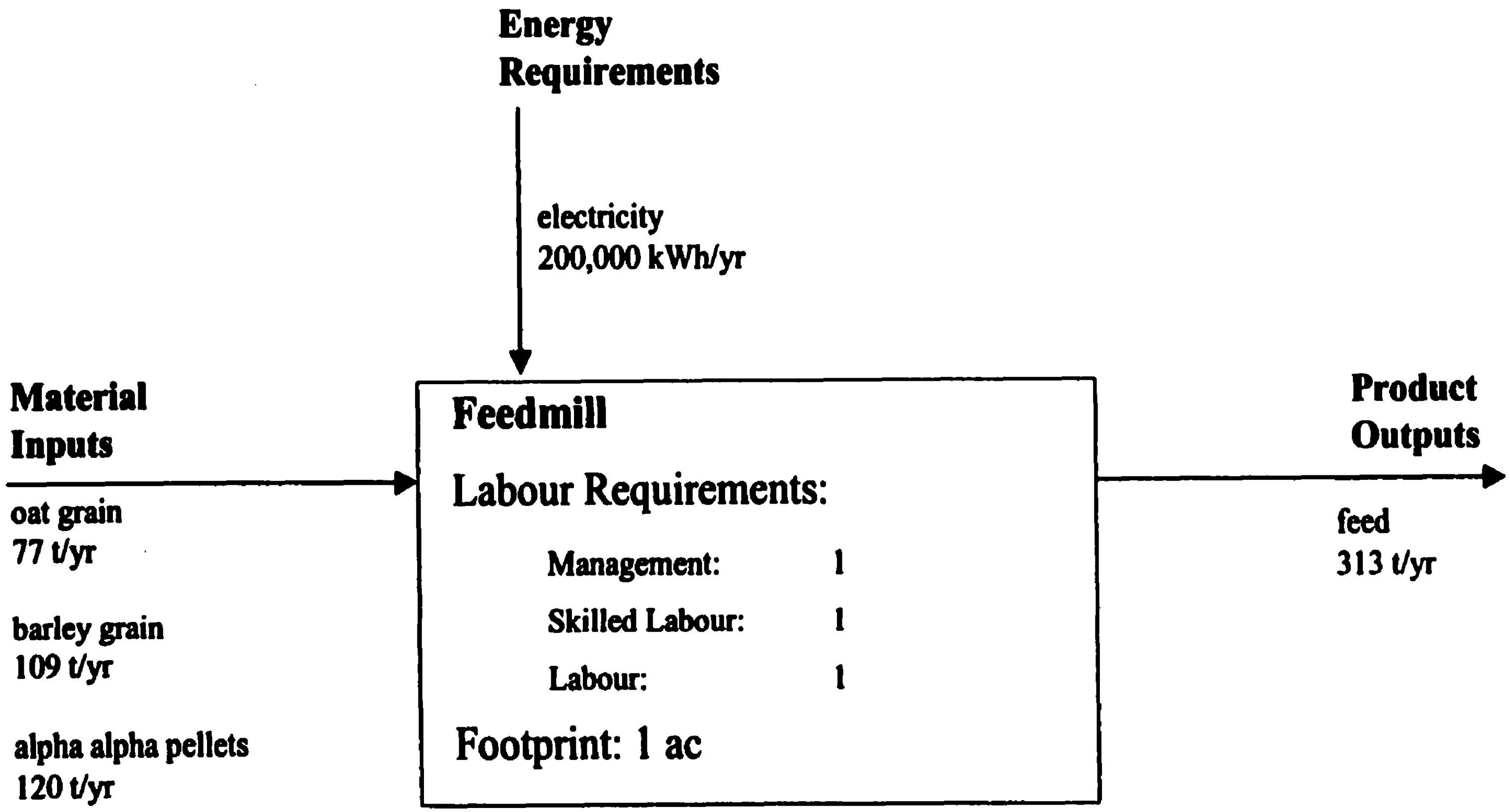
Product Outputs

oat grain
154 t/yr

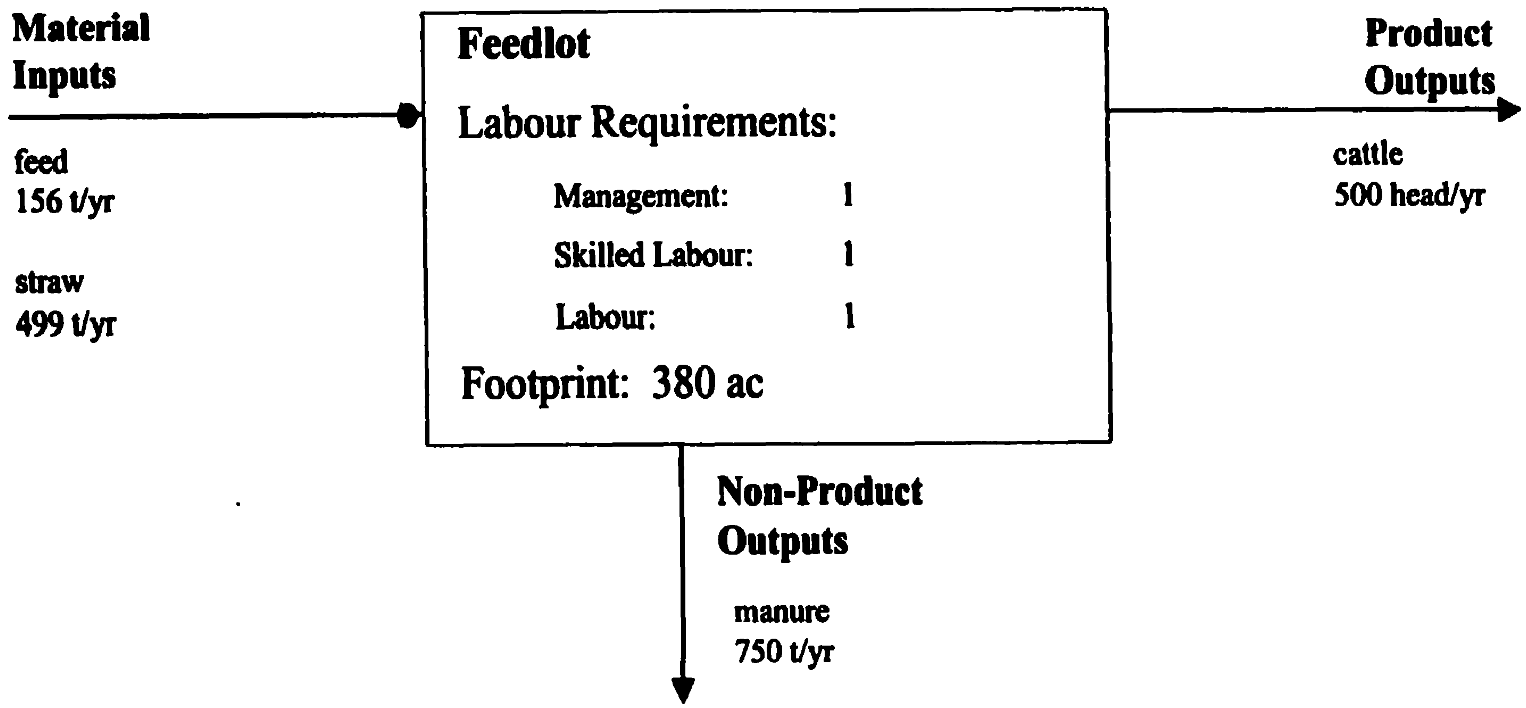
barley grain
218 t/yr

straw
499 t/yr

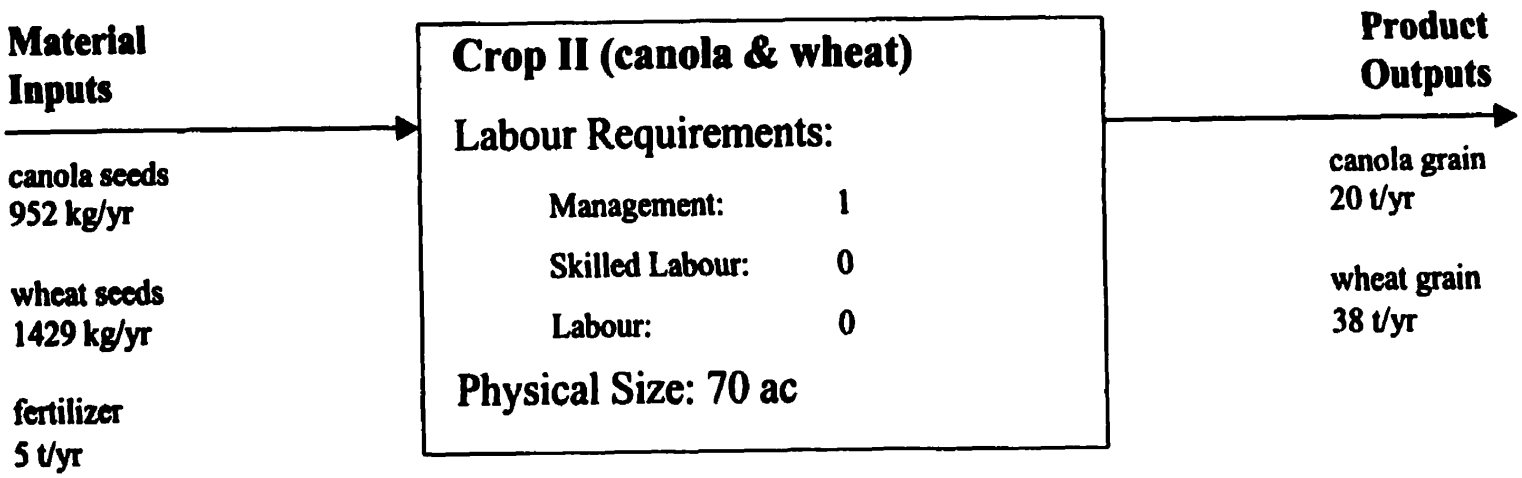
Material and Resource Flow Diagram



Material and Resource Flow Diagram



Material and Resource Flow Diagram



APPENDIX C:

DATA ON FEASIBLE FACILITIES

Fish Farm

MATERIAL INPUTS	QUANTITY	DETAILS	UNIT COST	POTENTIAL SOURCE
water	2,133 m3/yr		$2.11/m3	HLU
feed	63 t/yr		$1213/t	
electricity	186,880 kWh/yr		$0.075/kWh	HLU
natural gas	1,893 GJ/yr		$2.96/GJ	
steam	*1,026 t/yr*	*low P*		*HLU*
PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**UNIT COST**	
fish	52 t/yr	30cm trout (0.3kg ea)	$7665/t	
NON-PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**UNIT COST**	**POTENTIAL RECEIVER**
clarifier sludge	520 m3/yr	5% solids	$0/m3	Cropland I & II
LABOUR REQUIREMENTS	**QUANTITY**			
management	1			
skilled labour	0			
labour	2			
PHYSICAL SIZE	**QUANTITY**			
actual	0.11 acre			
footprint	1 acre			

Quantities adopted from: Proceeding of the In-Land Aquaculture: Issues and Opportunities Workshop, 1997

Greenhouse

MATERIAL INPUTS	QUANTITY	DETAILS	UNIT COST	POTENTIAL SOURCE
electricity	100,916 kWh/yr		$0.075/kWh	HLU
water	3,706 m3/yr	needed to be heated to 20 C	$2.11/m3	HLU
seedlings	10,700/yr	includes growing media	$1.60/seedling	
natural gas	16,149 GJ/yr		$2.96/GJ	HLU
fertilizer	85 t/yr		$303/t	
steam	*7,008 t/yr*	*instead of 80% NG*		*HLU*
PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**UNIT COST**	
tomatoes	318 t/yr		$1500/t	
LABOUR REQUIREMENTS	**QUANTITY**			
management	1			
skilled labour	1			
labour	2			
PHYSICAL SIZE	**QUANTITY**			
actual	1.3 acre			
footprint	4 acres			

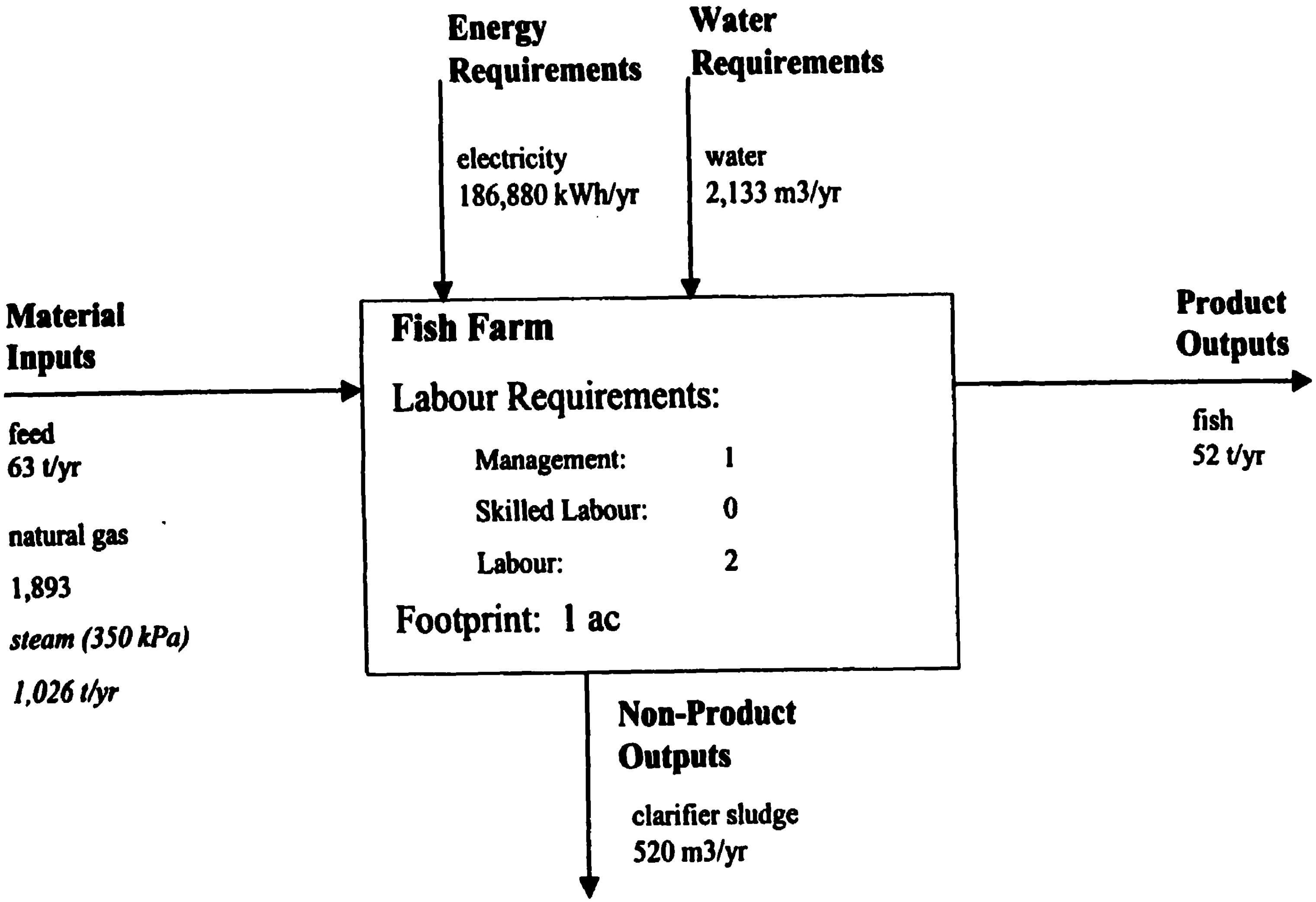
Quantities adopted from: Dr. Mirza, Greenhouse Production Costs and Returns for Tomatoes (Conference Handout), 1998

Warehouse				
MATERIAL INPUTS	**QUANTITY**	**DETAILS**	**UNIT COST**	**POTENTIAL SOURCE**
electricity	56,000 kWh/yr		$0.075/kWh	HLU
natural gas	1,014 GJ/yr		$2.96/GJ	HLU
steam	*550 t/yr*			*HLU*
PRODUCT OUTPUTS	**QUANTITY**	**DETAILS**	**UNIT COST**	
storage service	12,000 m3/yr		$191/m3	
LABOUR REQUIREMENTS	**QUANTITY**			
management	1			
skilled labour	0			
labour	2			
PHYSICAL SIZE	**QUANTITY**			
actual	0.30 acre			
footprint	1 acre			
Quantities adopted from: Heather Anderson, Husky Energy Inc., personal communication				

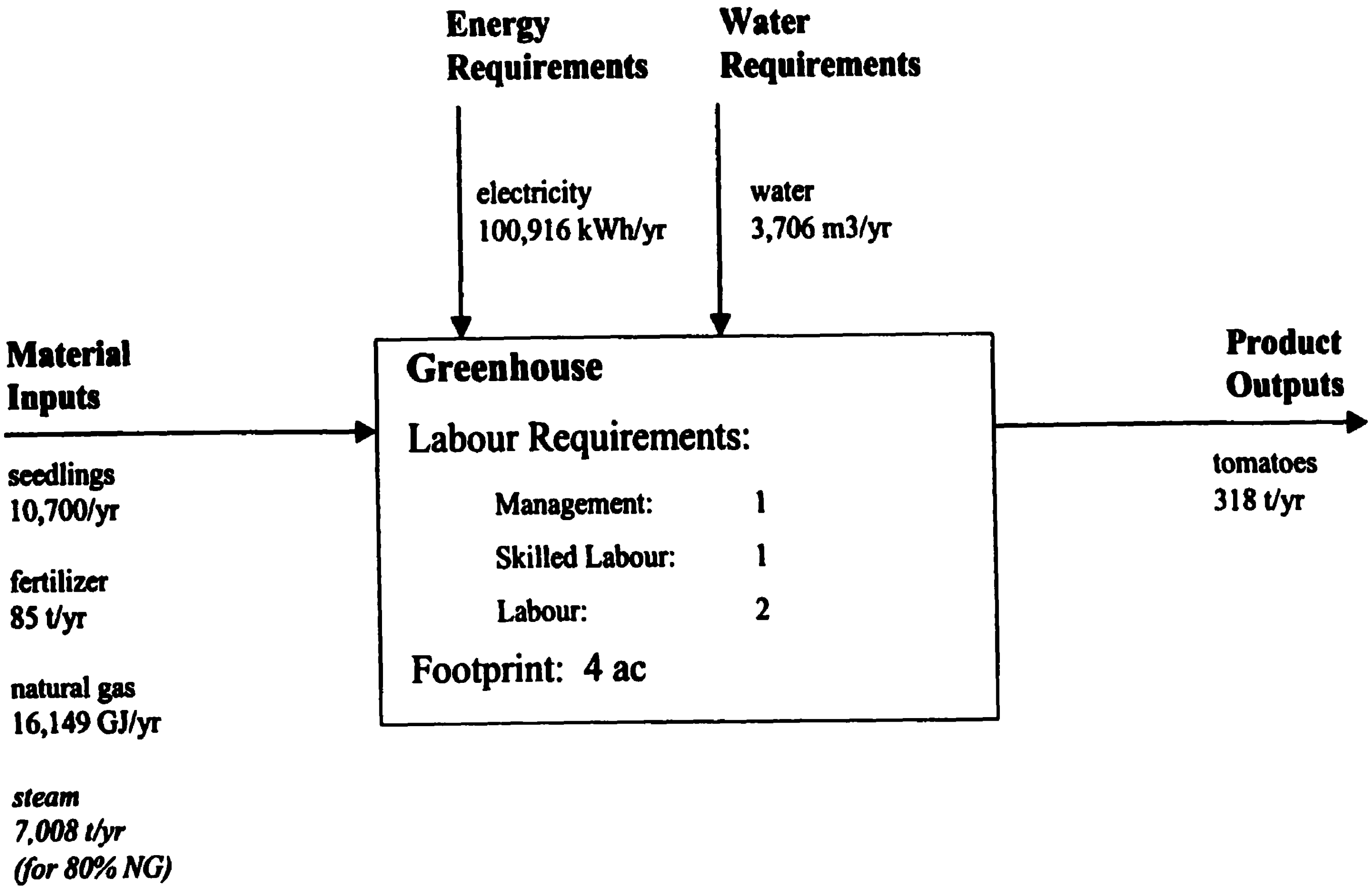
APPENDIX D:

MATERIAL AND RESOURCE FLOW DIAGRAMS
FOR FEAIBLE FACILITIES

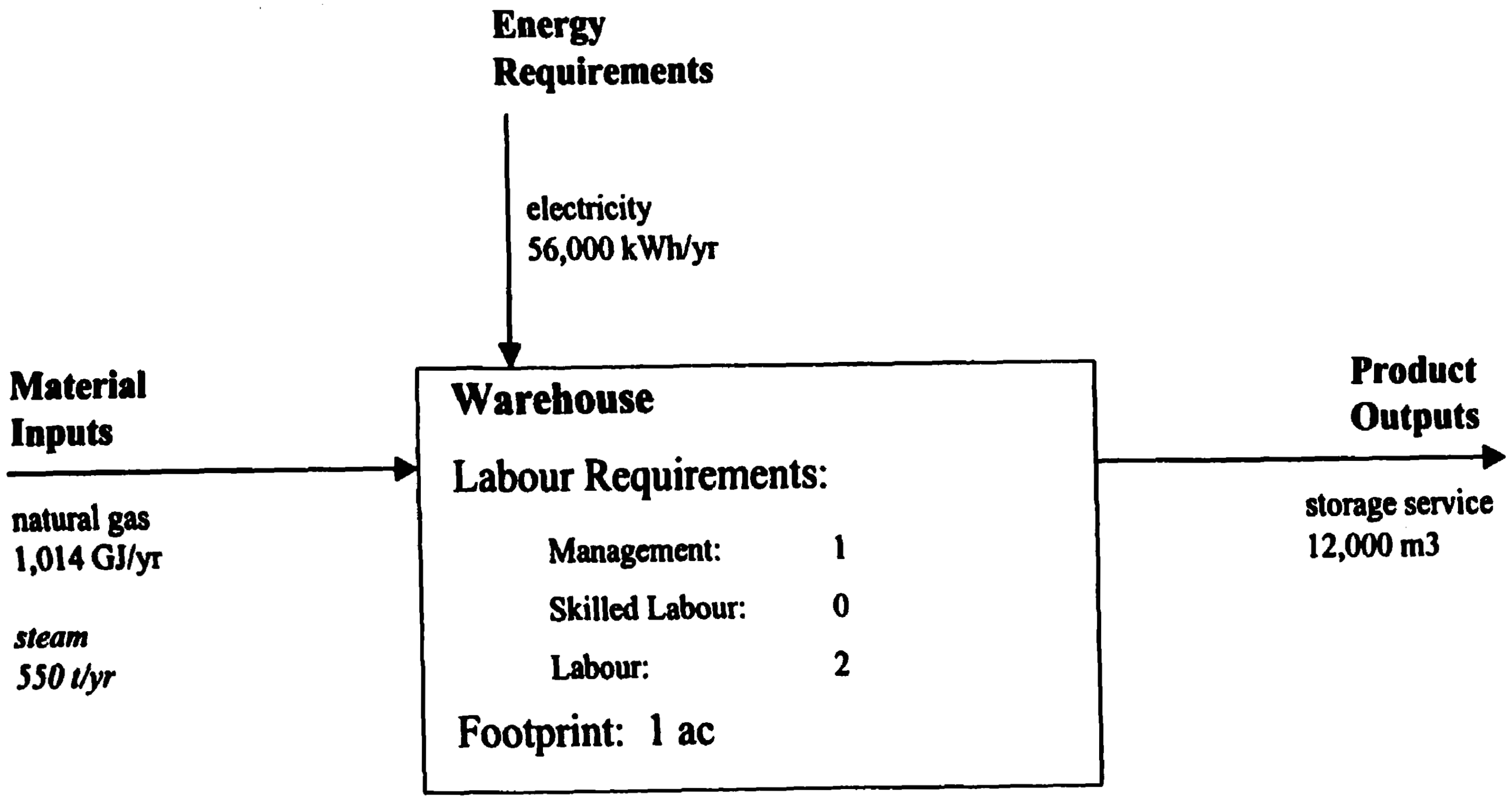
Material and Resource Flow Diagram



Material and Resource Flow Diagram



Material and Resource Flow Diagram



APPENDIX E:

VECTOR MATRIX PROGRAM CODE

```
% declare the first matrix A
Aold = [0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0];
% declare the first matrix B
B = [0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
    0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
    0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
    0.0 0.0 0.0 0.0 0.0 0.0 -1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
    -1.0 -1.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
    1.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 -1.0 0.0 0.0 0.0 1.0
    0.0 0.0 0.0 -1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
    1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0
    0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0
    0.0 0.0 0.0 0.0 0.0 -1.0 0.0 0.0 0.0 0.0 -1.0 0.0 0.0 0.0 0.0 0.0 -1.0 0.0
    0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 -1.0 0.0 0.0 0.0 0.0
    0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 -1.0 0.0 0.0 0.0 0.0
    0.0 0.0 0.0 1.0 0.0 0.0 0.0 1.0 0.0 0.0 1.0 0.0 0.0 0.0 1.0 1.0 1.0 0.0
    0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 -1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
    0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
    1.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 -1.0 0.0 0.0 0.0 1.0
    1.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 -1.0 0.0 0.0 0.0 1.0
    -1.0 -1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0];
k = 1.0;
% matrix dimensions
m=18;
%
disp (['The starting matrix Aold']);
for j = 1:m
   fprintf ('%6.2f ',Aold(j));
end
fprintf ('%c\n', ' ');
% print the relationship matrix
```

```
disp (['The relationship matrix B']);
for i = 1:m
  fprintf ('%c\n', ' ');
    for j = 1:m
        fprintf ('%6.2f ',B(i,j));
    end
end
fprintf ('%c\n', ' ');

while k >= 1.0

Anew = Aold*B;
for j = 1:m
  if Anew(j) >= 0.5
    Anew(j) = 1.0;
  elseif Anew(j) <= -0.5
    Anew(j) = -1.0;
    else Anew(j) = 0.0;
   end
  end
% compare between Aold and Anew
  for j=1:m
    if abs(Aold (j)- Anew (j))>0.01
      k = 1.0;
      break;
    else
      k = 0.0;
    end
    end
% thresholding
Anew (5) = 1.0;
```

```
%
     fprintf ('%c \n ', ' ');
   disp (['The new matrix Anew']);


     for j=1:m
     Aold(j) = Anew(j);
     fprintf (' %6.2f  ', Anew(j));
     end
end
fprintf ('%c\n', ' ');
```

APPENDIX F:

VECTOR MATRIX PROGRAM OUTPUT

The relationship matrix B

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-1.00	-1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	1.00
0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	1.00
1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	1.00
-1.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The new matrix Anew

-1.00 -1.00 0.00 0.00 1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

The new matrix Anew

0.00 -1.00 1.00 0.00 1.00 1.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 -1.00 0.00 0.00 0.00 1.00

The new matrix Anew

-1.00 -1.00 1.00 0.00 1.00 1.00 0.00 0.00 1.00 1.00 0.00 0.00 1.00 -1.00 0.00 0.00 0.00 1.00

The new matrix Anew

-1.00 -1.00 1.00 1.00 1.00 0.00 0.00 1.00 1.00 1.00 0.00 0.00 1.00 -1.00 1.00 1.00 0.00 1.00

The new matrix Anew

0.00 -1.00 1.00 1.00 1.00 0.00 -1.00 1.00 1.00 1.00 1.00 1.00 1.00 -1.00 1.00 1.00 0.00 1.00

The new matrix Anew

0.00 -1.00 1.00 1.00 1.00 1.00 -1.00 1.00 1.00 1.00 1.00 1.00 1.00 -1.00 1.00 1.00 0.00 1.00

The new matrix Anew

1.00 -1.00 1.00 1.00 1.00 1.00 -1.00 1.00 1.00 1.00 1.00 1.00 1.00 -1.00 1.00 1.00 0.00 1.00

The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

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The new matrix Anew

1.00 -1.00 1.00 1.00 1.00 1.00 -1.00 1.00 1.00 1.00 1.00 1.00 1.00 -1.00 1.00 1.00 0.00 1.00