Life–Cycle Value Assessment of Greenhouse Gas Mitigating Technologies

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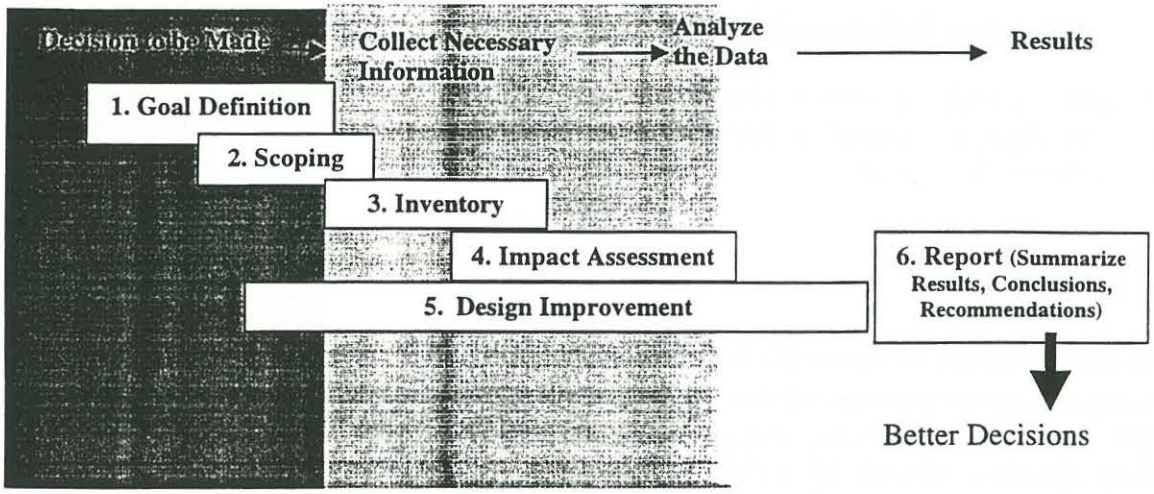
ABSTRACT

In order to fully understand the complete benefits and costs of alternative energy sources compared to conventional energy sources, one must consider the entire life-cycle from raw material extraction, through production and delivery to final energy use. This paper describes the advantages of applying Life-cycle Value Assessment (LCVA) as a tool for technology assessment and greenhouse gas reduction measurement and analysis.

The LCVA tool has been used extensively to evaluate existing and emerging technologies in Canada. LCVA has been developed by the Pembina Institute in cooperation with several of Canada's leading energy companies who are seeking a practical method for better understanding and integrating environmental impact information with financial analysis for better business decision making. Life-cycle Value Assessment is:

- a business analysis tool providing more complete information for making better project decisions on the basis of environmental, financial and socio-economic considerations,
- a design improvement tool that identifies and analyzes full costs and benefits of various options for reducing environmental impacts and improving total project economics,
- a pragmatic merger of environmental life-cycle analysis, business financial value assessment, and systems (process) engineering design improvement.

LCVA uses a systematic methodology to identify, quantify and analyze the environmental, financial, and social implications of each of the activities involved in producing and consuming a product or service. Using this tool can identify opportunities to improve the technical design, upgrade operating procedures, or substitute processes and materials in order to reduce costs, reduce environmental impacts, and help ensure employee and community satisfaction. LCVA also extends this systematic analysis beyond the normal "corporate boundaries" of direct company activities, to include all life-cycle stages of a technology, process, or product. These life cycle stages typically flow from extraction of raw materials, through manufacturing, transportation and customer use, to final disposal or recycling. This "cradle-to-cradle" analysis ensures that decision-makers are aware of the total system impacts of a decision, and do not unknowingly shift costs or environmental burdens onto others at "upstream" or "downstream" stages of the life-cycle. The following diagram depicts an overview of LCVA:



Some examples of the technologies LCVA has been applied to include:

- Hydrogen supply options for fuel cell vehicles,
- Wind turbines: life cycle air emissions compared to traditional Alberta energy sources,
- Sulphur Extraction: environmental and financial implications of a soil/sulphur separation technology,
- Coal Bed Methane: life cycle comparison to traditional gas production operations,
- Landfill Gas Energy Application: compared to conventional landfill practices,
- Microturbine: solution gas management option comparison,
- MSW Co-composting: comparison of traditional landfilling/spreading to soil amendment production.

LCVA can also be applied as a rigorous method to quantify greenhouse gas reductions through technology application. Using this approach not only results in a higher degree of certainty in the reduction amount, but provides a better understanding of the associated project boundaries and risks of "double-counting". A life-cycle approach, such as LCVA, is essential to credible verification of greenhouse gas reduction projects.

Life-cycle Value Assessment provides a decision making framework to meet corporate, government and public's needs of integrating economic, social, and environmental factors into business decision making, technology selection, and project design.

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1.0 An Introduction to LCVA

1.1 An Analysis Tool for Integrating Environmental and Economic Considerations

Life-cycle Value Assessment (LCVA) has been developed by the Pembina Institute as an analysis tool for integrating environmental and economic considerations into corporate activities such as purchasing decisions, design option selection, and process technology choices. This unique and effective methodology ensures that the major environmental and economic impacts are fully considered across the entire life cycle of a product or production system.

The Pembina Institute created and refined the LCVA methodology in cooperation with several of Canada's leading energy companies. These progressive companies were seeking a practical method to better understand and integrate environmental considerations with financial analysis across a wide range of corporate decisions.

The unique business value of LCVA comes from its ability to compile and blend better financial information and better environmental and social information for the benefit of designers and decision makers. LCVA is thus an analysis methodology, a design improvement tool, and a decision-making tool. It serves as one of the most practical business tools available to operationalize the concept of sustainable development – a laudable but somewhat complex goal of achieving environmental protection and economic development along with social justice and equity. Central to the development of the LCVA methodology is the use of techniques that allow the systematic pursuit of eco-efficiency. In its simplest terms, eco-efficiency is about providing more value to society with less impact on the environment.

1.2 What is LCVA?

LCVA is:

- a *business analysis methodology* that provides more complete information for making better project decisions on the basis of environmental, financial and socio-economic considerations;
- a *design improvement tool* that identifies and analyzes full costs and benefits of various options for reducing environmental impacts and improving total project economics; and
- a *decision-making tool* that offers an opportunity to assess potential risks, provided through a pragmatic blend of environmental and social life-cycle analysis, business financial value assessment, and systems (process) engineering design improvement.

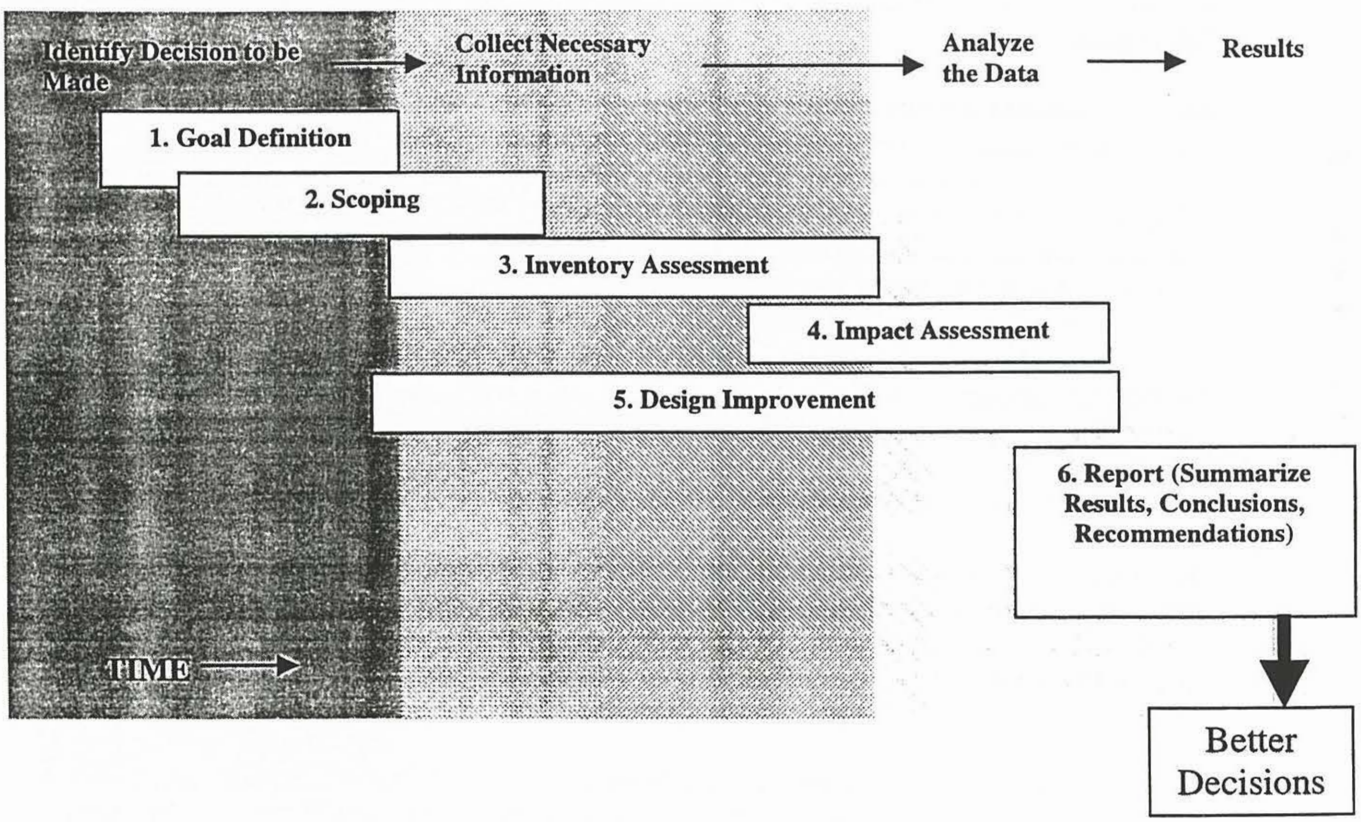
LCVA uses a systematic methodology to identify, quantify and analyze the environmental, financial and social implications of each activity involved in producing or consuming a product or service. Along the way, LCVA can unearth opportunities to improve the technical design, upgrade operating procedures, and substitute processes and materials in order to reduce costs and environmental pollutants as well as other impacts.

LCVA extends this systematic analysis beyond the normal corporate boundaries of direct company activities to include all life-cycle stages of a process, product, or technology. These life cycle stages typically flow from conceptualization through design, extraction of raw materials, manufacture, transportation, customer use or operations to final disposal or recycling. This "cradle-to-grave", or "cradle-to-cradle", analysis ensures that decision-makers are aware of the total system impacts of a decision and do not unknowingly shift costs or environmental burdens onto others at upstream or downstream stages of the life cycle.

1.3 What Is Involved in Using Life-cycle Value Assessment?

The LCVA methodology has six main steps, illustrated in Figure 1.1.

Figure 1.1 The LCVA Process



Step 1 – **Goal Definition** – clearly defines the decisions to be made, the questions to be answered and the actual processes, products, technologies, or production systems to be analyzed and compared on the basis of equivalent provision of service.

Step 2 – **Scoping** – consists of clearly mapping out the life-cycle flow of activities involved in production, use and end-of-life, and organizing these activities into discrete and convenient units of analysis, which are referred to as unit processes.

Step 3 – **Inventory Assessment** – involves collecting and validating data to quantify the inputs and outputs within the life-cycle stages selected for analysis. The data are compiled and modeled to provide aggregated results for various scenarios and systems to answer the key questions outlined in the LCVA goal definition.

Step 4 – **Impact Assessment** – involves assessing the results identified in step 3 in terms of their environmental and financial impacts and significance. This step considers the relative change in total environmental loadings and the sensitivity of exposed areas, along with capital and operational costs and relative risks.

Step 5 – **Design Improvement** – is not a single stage but a series of steps conducted in tandem with the four main analysis stages. Done fully, it ensures that a systematic and serious effort is made to find opportunities to reduce the financial and environmental impacts of various technologies, process activities and material supply choices across the full life cycle.

Step 6 – **Report Preparation** – involves synthesizing and summarizing results, along with development of conclusions and recommendations. These are compiled in a report or presentation to the decision makers who are responsible for project approval, selecting options, or making any other decisions that originally triggered the LCVA. This stage also provides an opportunity to synthesize potential design improvement options for later consideration by design staff.

The level of effort and resources allocated to improving the decision-making process through LCVA should be determined by the nature and extent of potential environmental and financial implications.

1.4 LCVA, Eco-efficiency and Environmental Impacts

Eco-efficiency means continuous improvement in providing desirable outputs (such as goods and services, jobs, profits) for less resource use and lower output of undesirable waste. Like any other measure of efficiency, the goal is to maximize the ratio of benefits to costs; however, broad eco-efficiency analysis casts a much wider net and includes both ECO-nomic and ECO-logical costs and benefits.

LCVA is designed to advance eco-efficiency by systematically examining and, where possible, quantifying the financial, material, energy, labour and other inputs and outputs of each activity stage in the life cycle of a product or process. This allows for accurate aggregation of the total costs and environmental loadings of a full production-consumption system, and allows for a comparison of the relative eco-efficiencies of various choices under consideration.

The World Business Council for Sustainable Development notes, "A key feature of eco-efficiency is that it harnesses the business concept of creating value and links it with environmental concerns. The goal is to create value for society, and for the company, by doing more with less over the product life cycle."

In LCVA, the more significant environmental outputs are identified and quantified. Environmental loadings with common impacts are grouped into stressor categories that help characterize potential stresses on the environment – categories such as greenhouse gases, acid deposition precursors, ground level ozone precursors, hazardous air pollutants, water eutrophication nutrients, or loss of productive land to other uses. The total loadings for a production-consumption system can be assessed in each of these categories against existing background loadings. Equally important, the relative loadings per unit of product for various options can be compared to select the most eco-efficient choices.

1.5 Applications of LCVA

LCVA can be applied to improve decision making in many corporate arenas – these include:

- High level project feasibility assessment;
- Corporate and project risk assessment;
- Detailed engineering design;
- Process optimization;
- Technology selection;
- Product, process or route selection;
- Environmental impact assessment or application for approval; and
- Social impact information.

For project feasibility assessment, LCVA can be applied in varying amounts of detail to provide better information for assessing the feasibility of options to meet a business need – such as growth in the business, expansion of current facilities, or meeting regulations.

To obtain the greatest benefit from applying a life-cycle approach to decision making, LCVA should begin before detailed engineering, including technology selection, on any particular option is completed. The earlier LCVA is applied, the more opportunity for identifying the optimal option before spending significant time and resources in detailed engineering. This can require additional time and resources earlier in a project, i.e., before detailed engineering. However, this investment has potentially very large returns later in the project by identifying and avoiding potential economic, technical, and environmental risks and liabilities.

2.0 LCVA of GHG Mitigating Technologies

By considering new and existing technologies or applications as systems having life cycle environmental and social implications, one can ensure that all potential impacts are addressed and any potential improvements can be identified.

The life cycle approach captures total potential emission through addressing the boundaries of each system being assessed. Upon establishing boundaries for a system, any potential for 'burden shifting' or 'leakage' can be identified.

2.1 Burden Shifting

The act of reducing environmental impact from a single activity may actually shift the environmental burden to another stage in the life cycle of that or a competing system. An everyday example of this would be switching bathroom paper hand towels for air dryers. The greenhouse gas implication may be worse or better, depending on such activities as landfill applications for the hand towels and electricity supply options for the air dryer.

2.2 Leakage

The IPCC defines leakage "as the unanticipated decrease or increase in GHG benefits outside of the project's accounting boundary as a result of project activities". Common leakage examples occur in the forestry sector, where areas that are protected as a result of sequestration initiatives result in other areas being harvested. This concept can extend to greenhouse gas mitigation technologies. An example of this could be replacing an older cogeneration unit for a high efficiency combined cycle gas turbine with no waste heat capture. Here, it is essential to account for the fuel that would now be required to make up for the heat or electricity no longer supplied through the cogen application. In such a scenario GHG emissions may be generated and not accounted for, should a life cycle approach not be applied.

Another form of leakage is the effects of price signals. For example, a drop in the demand for a particular fuel as a result of fuel switching will likely reduce the price for that fuel, based on contemporary economic theory. This reduction in price may lead to an increase in consumption in other locations, resulting in no net reduction of greenhouse gases. This type of leakage would likely be more apparent on a cumulative basis, and thus would be more difficult to identify and account for at the project level.

Some other significant benefits can be gained when using LCVA to select a technology, such as:

- Influencing purchase options based on supplier location. Buying 'local' can help to reduce transportation-related impacts as well as contribute to local or national economies.
- Reducing life cycle impact of technologies through exercising green procurement from upstream material suppliers.
- Awareness of potential non-GHG risks associated with the technology through broader environmental life cycle analysis.
- Providing a more complete picture of the impacts and benefits of competing technologies.
- Providing a framework to enhance or improve the technology or system being considered.

The Pembina Institute has applied LCVA to an array of technologies and applications to better portray their full life cycle aspects. Specific examples of this include[1]:

- Hydrogen supply options for fuel cell vehicles,
- Wind turbines: life cycle air emissions compared to traditional Alberta energy sources,
- Sulphur Extraction: environmental and financial implications of a soil/sulphur separation technology,
- Coal Bed Methane: life cycle comparison to traditional gas production operations,
- Landfill Gas: comparing methane capture for electricity production to conventional landfill practices,
- Microturbine: solution gas management option comparison,
- MSW Co-composting: comparison of traditional landfilling/spreading to soil amendment production.

The assessment of each of these technologies or applications was compared to the life cycle impacts of their conventional options. As an example of how a life cycle approach can help reveal critical information about a technology, an overview of the hydrogen supply LCVA is provided in Section 2.3.

2.3 Case Study – A Comparison of the Life-Cycle Greenhouse Gas Emissions for Various Fuel-Cell Vehicle Systems [2]

The objective of this LCVA was to quantify the relative life-cycle emissions of GHGs from various options available for producing hydrogen gas for automotive fuel cell application. The five systems analyzed were: 1) On board reformulated gasoline fuel processing, 2) On board methanol fuel processing, 3) Centralized Natural Gas Reforming, 4) Decentralized Natural Gas Reforming, and 5) Decentralized Electrolysis. Each system is based on travelling 1000 km, with all five options compared to the Mercedes-Benz A-Class vehicle powered by a gasoline internal combustion engine. Other options exist for producing hydrogen, including electrolysis using electricity from renewable resources or nuclear power, or on-board reforming of ethanol. These options were prescreened and considered to be insufficient in scale to meet anticipated demand, too costly, or too environmentally impractical to warrant a full assessment in this study.

The results indicate that when compared to the gasoline powered baseline vehicle:

The decentralized steam methane system poses the fewest technical challenges and is expected to result in the most cost-effective hydrogen production system. This process has the potential to reduce emissions by up to 70%.

Decentralized electrolysis systems result in little reduction in GHGs if the electricity is produced from a non-renewable resource.

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[1] All studies, except for Hydrogen and Wind LCVAs, were performed through client confidential services.

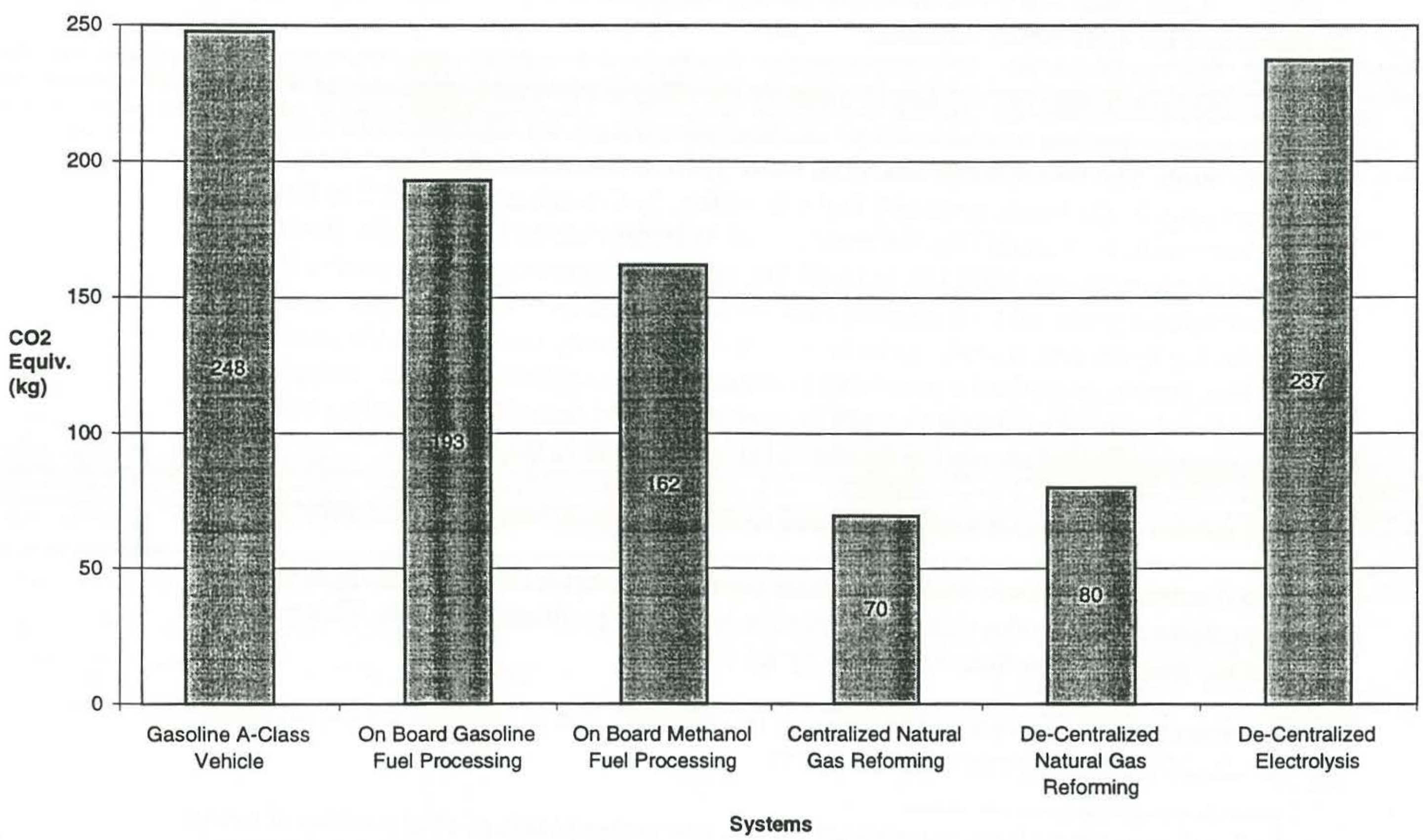
[2] "A Comparison of the Life-Cycle Greenhouse Gas Emissions for Various Vehicle Fuel-Cell Systems – Strategic Options for Canada", Pembina Institute, August 1999.

On-board fuel processing of gasoline or methanol result in a potential 20 to 30% reduction in GHG emissions.

The decentralized steam methane and electrolysis systems present the most feasible options with respect to infrastructure needs since they can be expanded as fuel cell vehicles increase in numbers. These options can also utili ze existing natural gas and electrical grids, unlike the methanol option or centralized hydrogen production option.

The results from this paper clearly demonstrated that there are various options to consider in the commercialization stages of the hydrogen fuel cell powered vehicle, and that each option can have significantly different greenhouse gas emissions implications. The results also clearly indicated that there are strategic liaisons that can be considered in trying to enhance the optimum options, such as with the natural gas, or renewable electricity industries. The following figure demonstrates the potential range of life cycle greenhouse gas emissions generated by each of the options assessed.

Figure 2.1 Total Greenhouse Gas Emissions for Each System



All five hydrogen fuel production options present challenges with respect to technology, infrastructure, and cost. Each has certain advantages and disadvantages. By applying a life cycle approach to the assessment of the fuel cell technology, it is apparent that significant and varying issues are raised with each option.

3.0 LCVA for GHG Reduction Emission Verification

LCVA can also be applied as a rigorous method to quantify greenhouse gas reductions through technology application. Using this approach not only results in a higher degree of certainty in the reduction amount, but provides a better understanding of the associated project boundaries and risks of "double-counting". A life-cycle approach, such as LCVA, is essential to credible verification of greenhouse gas reduction projects.

3.1 Real, Measurable & Verifiable Reductions

Programs such as the western Canada-based Greenhouse Gas Emission Reduction Trading (GERT) pilot that register emission reductions require that these reductions are real, measurable, and verifiable. Taking a life-cycle approach helps to ensure that each of these criteria is met.

Through assessing all activities associated with a project, both upstream and downstream, there is a much greater certainty that any shift in emissions to other stages of the life cycle are incorporated. This ensures that the chances of burden shifting are minimized.

This approach also provides a structure for which all emissions, including greenhouse gases, can be systematically quantified in a robust manner. By providing a breakdown of emissions and their sources through applying a rigorous, complete, and transparent method, any registration or verification bodies can approve reductions with higher certainty and greater ease.

3.2 Credit Eligibility

Through applying a life-cycle approach, emission reductions can be categorized and quantified according to their potential eligibility towards being considered a 'credit'. Depending on the stage of the life cycle for either the project or reference (business as usual) case, these 'credits' may have varying levels of eligibility as determined by the emerging rules of credit trading systems. Direct emissions from on-site activities for both project and reference cases, such as burner-tip emissions, would typically be considered more eligible due to greater certainty around measurability and actual reductions. Indirect emissions from upstream activities in a reference case will likely be less eligible as the occurrence of real reductions, or emission displacement, is less certain. Emissions occurring from activities upstream of the project case, however, will likely have a greater potential to be an eligible *debit* against any reduction as the certainty of their occurrence is high. Upstream emissions are generally associated with extraction, processing or manufacturing, and transportation related activities.

4.0 Conclusion

Life-cycle Value Assessment provides a decision making framework to meet corporate, government and public needs of integrating economic, social, and environmental factors into business decision making, technology selection, and project design.

This approach can be applied as a strict assessment of a particular technology, or as a tool to better assess competing technology options. The outcomes desired from applying an LCVA, such as a streamlined analysis of greenhouse gases to a broader environmental analysis with potential design improvements, determines the level of depth that is required for the analysis.

When considering claiming greenhouse gas reduction 'credits' from the implementation of a technology, an LCVA approach will account for all potential and significant GHG sources. Any GHG reductions will be easier to register and any potential saleable credit will carry a higher value based on a more complete analysis.