NJ-IES Guide

Corporate sustainability is an extremely important, yet complex issue, especially with consideration of other business priorities and shareholder expectations. Now, imagine having a quantitative, absolute measure of sustainability and a well-defined decision-making process that clearly identifies business strategies that are not only eco-efficient, but also economically sound and operationally effective.

I.1 Overview. New Jersey Institute of Technology (NJIT) received a two-year Energy Technology Demonstration Grant to develop and demonstrate The New Jersey Industry Eco-efficiency and Sustainability (NJ-IES) Guide. NJ-IES is an advanced management and engineering tool providing New Jersey industry with the ability to assess eco-efficiency and create sound business strategies toward sustainability. NJ-IES is web-based with an available *iBook*® mobile app running on the Apple *iPad*® to provide NJ industry with a powerful, yet easy-to-use guide to sustainability. The home page for the NJ-IES website is located at http://njies.njit.edu and is shown below in Fig. I.1.1.

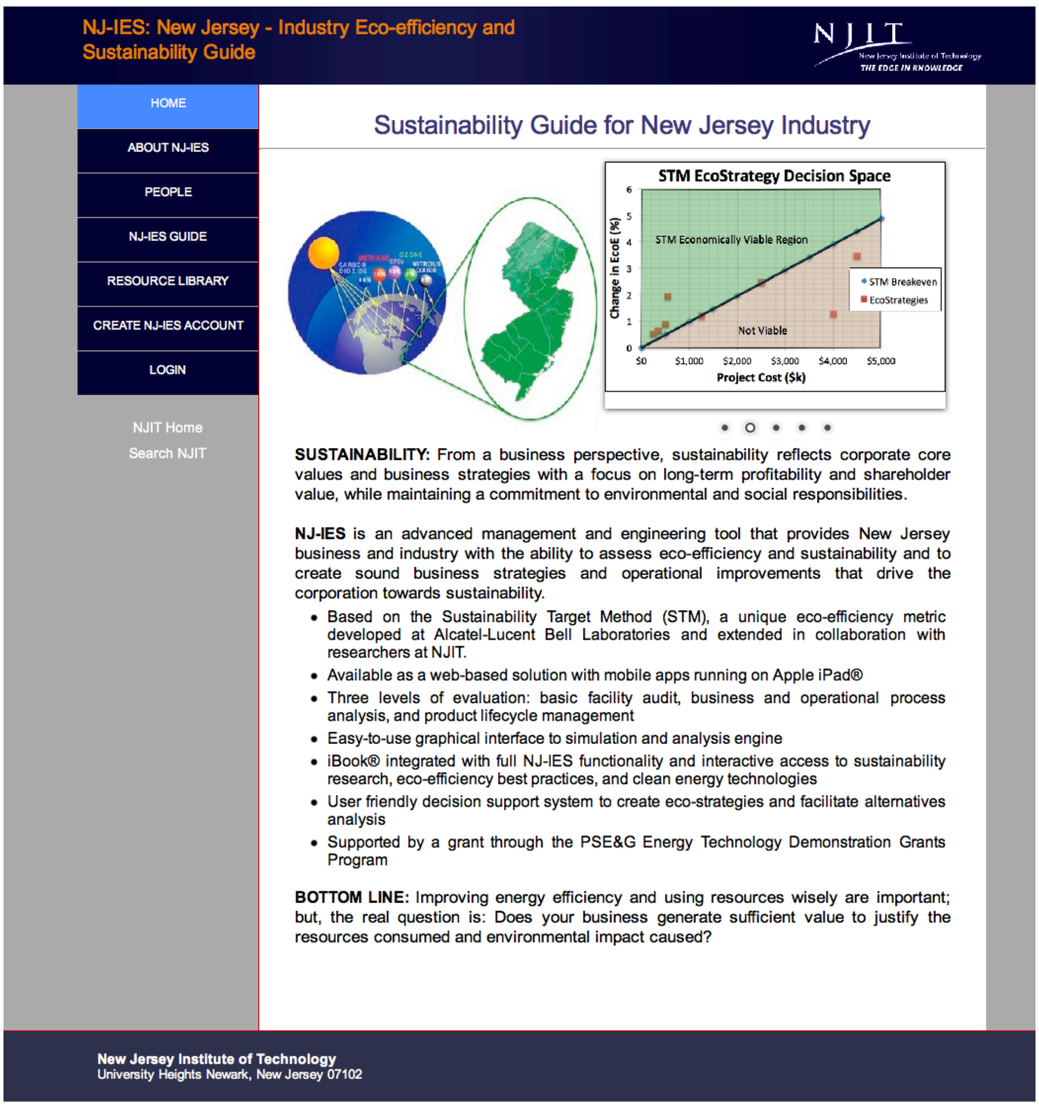


Fig. I.1.1 - Screen capture of NJ-IES home page at http://njies.njit.edu

Specifically, the NJ-IES Guide provides a better understanding of current energy consumption patterns with the ability to assess eco-efficiency, to identify improvement strategies, and to capture and share best practices. Today challenges for industry go beyond energy consumption for buildings and office space into special requirements for plant equipment and extended responsibility for supply chain partners and lifecycle product performance.

In addition to state-of-the-art software engineering, the underlying technologies and advances embedded in the NJ-IES project are the following:

Sustainability Target Method: Efficiency measures can be very misleading and do not provide absolute targets that relate directly to sustainability. In fact, you may be using energy wisely and efficiently and still be generating greenhouse gas emissions that are not sustainable. Consequently, a novel approach to measuring energy consumption and efficiency based on a technique developed by Bell Labs and extended by researchers at NJIT has been implemented. This approach, referred to as the Sustainability Target Method (STM), has been used in a variety of applications to calculate the eco-efficiency (EcoE) of entire businesses, plant operations and individual products. The STM methodology establishes linkages between the Earth's carrying capacity, economic value, and environmental impact to provide an absolute or "target" criteria for sustainability that is practical for use by managers and plant engineers.

Simulation and Decision Support System: By simulating the operational and energy flows throughout the facility, engineering analyses of consumption patterns and process inefficiencies can be performed and alternative strategies for improvement can be evaluated. The decision support system module analyzes each "what-if" scenario and eco-strategy and provides companies with the ability to explore a variety of alternatives and implement projects with lower risk and less uncertainty.

Interactive Multimedia Technologies: This innovative technology is based on training and educational techniques and implemented in Management Best Practices module within the NJ-IES website and the integrated iBook® available for the iPad®.

Eco-efficiency analysis is performed by NJ-IES at three levels of evaluation: basic facility audit, business and operational process analysis, and product lifecycle management. The powerful analytic and simulation engine generates a range of reports for each level with tabular and graphic output, and, useful industry benchmarks are extracted from well-established databases and other sources.

To validate NJ-IES, two pilot test cases were conducted to evaluate prototype versions of NJ-IES with the objective of demonstrating both the capabilities and exploring the value of NJ-IES in improving eco-efficiency in very distinct industry sectors and business operations. These two pilot studies are discussed later in the report. A description of the STM technique is provided in the next section in order to provide a clear understanding of the underlying approach used in NJ-IES to assess eco-efficiency and create sound business strategies. The following sections of project final report are organized with respect to the six primary modules incorporated into NJ-IES: Corporate Profile, Facility Assessment, Process Assessment, Product Assessment, Management Best Practices, and EcoStrategies and Sustainability, as shown in Fig. I.1.2.

Fig. I.1.2 – Screen capture of NJ-IES audit, assessment, best practices and strategy planning modules

I.2 Sustainability Target Method (STM). The Sustainability Target Method (STM) was developed originally by Dickinson, Mosovsky and Morabito at Bell Laboratories [1-2] and extended by Dr. Caudill and his research team at NJIT [3-5]. The STM establishes a non-dimensional relationship between economic value added by the business and the resulting environmental impact caused. Simply stated, the STM quantifies and answers the question… does your business generate sufficient value to justify the resources consumed and environmental impact caused?

NJ-IES uses the Theory of Constraints to create sustainability strategies that focus on the most important environmental impact first. Then, when the corporation has successfully improved its eco-efficiency value for this worst-case scenario, another impact category becomes more important and, therefore, becomes the focus for improvement. This continuous improvement principle is consistent with Total Quality Management (TQM) programs implemented widely across New Jersey's business and industry sector.

The most significant environmental impact category or constraint is given as $I_{critical}$, defined as follows:

$$I_{critical} = Max\left(\frac{EI_i}{ECC_i}\right)$$

Where, EI_i is the indicator value for the i-th environmental impact category and, ECC_i is the Earth's carrying capacity value for the i-th environmental impact category

While different industries face different challenges regarding environmental impacts, all businesses today are concerned with global warming and climate change; consequently, NJ-IES considers energy consumption and greenhouse gas emissions as the primary impact category. However, other impact categories given below may be important and are included in the analysis.

For Global Warming and Climate Change, the indicator value is Greenhouse Gas (GHG) and is expressed in terms of kg of CO2 equivalent [6]. So, let $GHG = EI_i$ and $ECC_{CO2eq} = ECC_i$.

For sustainability, the share of economic value added must be proportional to the share of environmental impact created, as shown in Fig. I.2.1. Since Global Warming is a global impact and not

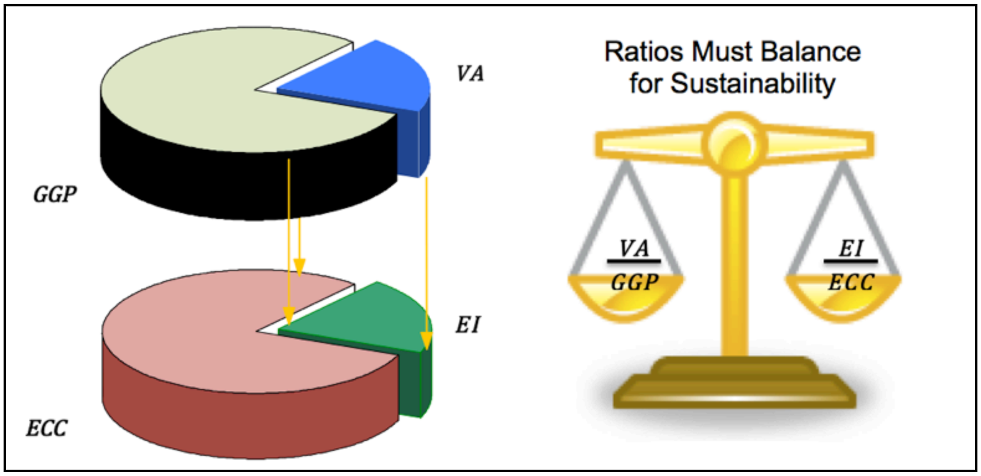


Fig. I.2.1 – Value Creation Ratio Balances Environmental Impact Ratio For Sustainability

regional or local, the share of economic value added by a business is the ratio of annual business income generated to the overall annual level of global economic activity, defined as the global gross product (GGP). Also, the share of global warming impact created by the business is the ratio of the total GHG emitted annually by the business to the sustainable level of global GHG allowable, so as not to create irreparable or permanent environmental damage. This sustainable level of GHG is referred to as the Earth's Carrying Capacity. Over the past two decades, climate change research has examined various scenarios and potential futures based on various models and empirical data. The UN International Panel on Climate Change (IPCC) has issues several reports and predictions for which Earth Carrying Capacity estimates can be made. In addition, previous work at NJIT has provided initial estimates for the Earth's Carrying Capacity for other impact categories, including Ozone Depletion, Eutrophication, Photochemical Smog and others [4]. *Note: For regional impacts, e.g. smog or fresh water consumption, the economic activity must also be considered at the regional level.*

In other words, for sustainability the ratio of business value added (VA) to total economic activity (GGP) must be at least equal to the ratio of environmental impact (EI) to the Earth's carrying capacity (ECC). Expressed in equation form gives

$$\frac{VA}{GGP} = \frac{EI}{ECC}$$

And rearranging gives the following relationship:

$$\frac{VA}{EI} = \frac{GGP}{ECC}$$

Now, let VP be defined as the value productivity for the business, in units of dollar value added per unit of environmental impact caused, e.g., GHG emissions in terms of kg CO_{2equiv} for global warming impact.

$$VP = \frac{VA}{EI}$$

And let VPS be defined as the value productivity level necessary for sustainability, also in terms of dollar value of economic activity per unit of environmental impact as determined by the Earth's carrying capacity.

$$VPS = \frac{GGP}{ECC}$$

Then, defining Eco-Efficiency ($EcoE$) as the ratio of VP to VPS gives the following equation,

$$EcoE = \frac{VP}{VPS}$$

If $EcoE \geq 1$, then the value productivity for the business equals or exceeds VPS and the business is SUSTAINABLE. Similarly, if $EcoE < 1$, then the value productivity for the business is less than VPS indicating that the business does not generate sufficient value to justify the environmental impact caused: the business is NOT SUSTAINABLE.

The value of EcoE is an absolute measure for sustainability, indicating quantitatively how far the business is from its target of sustainability.

Note: Dickinson, Mosovsky and Morabito denote eco-efficiency as "EE"; however, NJ-IES uses the notation "EcoE" and reserves "EE" to indicate energy efficiency, a more widely accepted nomenclature.

I.3 Corporate Profile. Basic information on the company and user are maintained in the Corporate Profile module. In the Corporate Social Responsibility (CSR) tab, the user can indicate the company's demonstrated commitment to broad CSR activities including an annual CSR report, product lifecycle management, active involvement in community outreach programs, opportunities for professional growth and advancement of employees, and to maintain a safe and healthy work environment. In addition, the corporation's NAICS industry sector is identified in order to determine benchmark values with information extracted from the Carnegie-Mellon University EIO-LCA database.

I.4 Facility Assessment. For the Facility Level Analysis, the assessment boundary is the facility envelope plus energy sources used at the facility. Fig.I.4.1 illustrates this boundary definition and shows inputs and outputs from the operation.

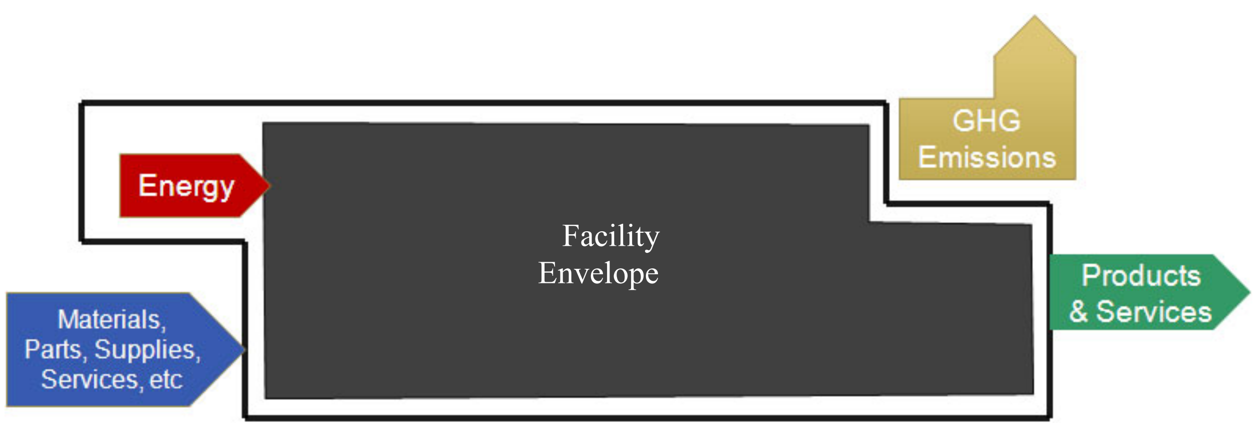


Fig. I.4.1 – Assessment Boundary for Facility Level Analysis

Data requirement for the facility analysis consists of information based on internationally recognized guidelines and protocol for Scope 1 and 2 reporting of greenhouse gases plus additional operational and business economic data necessary for STM eco-efficiency assessment. The following information is gathered: Corporate profile including facility characteristics, business sector and economic data, facility energy usage and consumption data, employee travel/commuter data/telework patterns, on-site renewable energy sources and other sources of greenhouse gas (GHG).

The baseline system architecture for NJ-IES is shown in Fig. I.4.2. The primary elements in the NJ-IES analytics and framework construct consist of EcoAudit, STM assessment, Simulation and Analytics Engine, Management Best Practices (MBP), and the Decision Support System (DSS). The cloud-based architecture is adapted to maximize user access to NJ-IES with minimal dedicated software and hardware requirements.

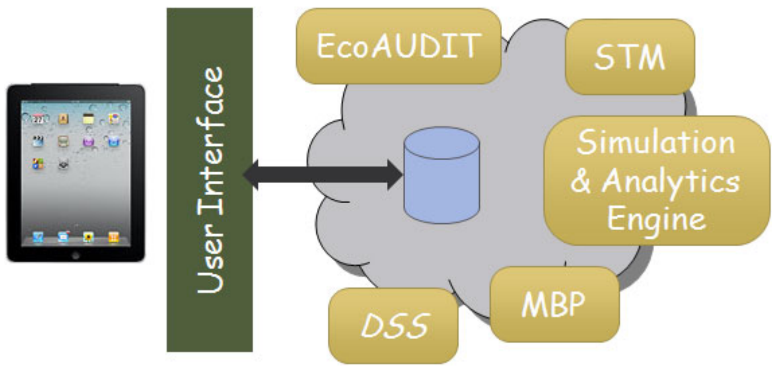
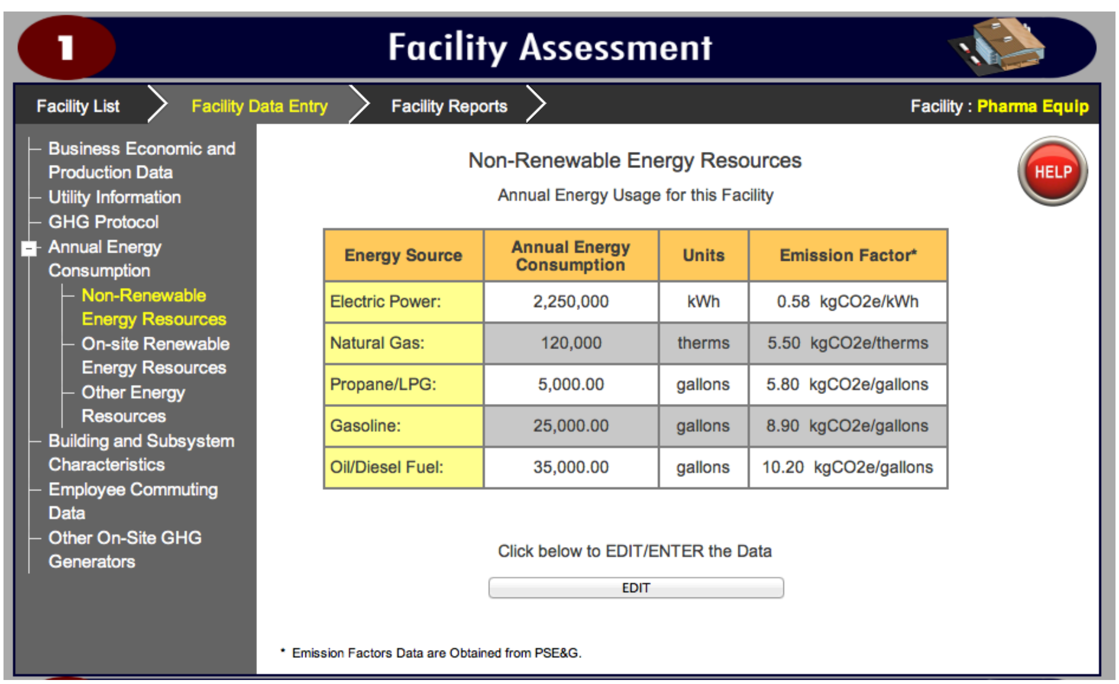


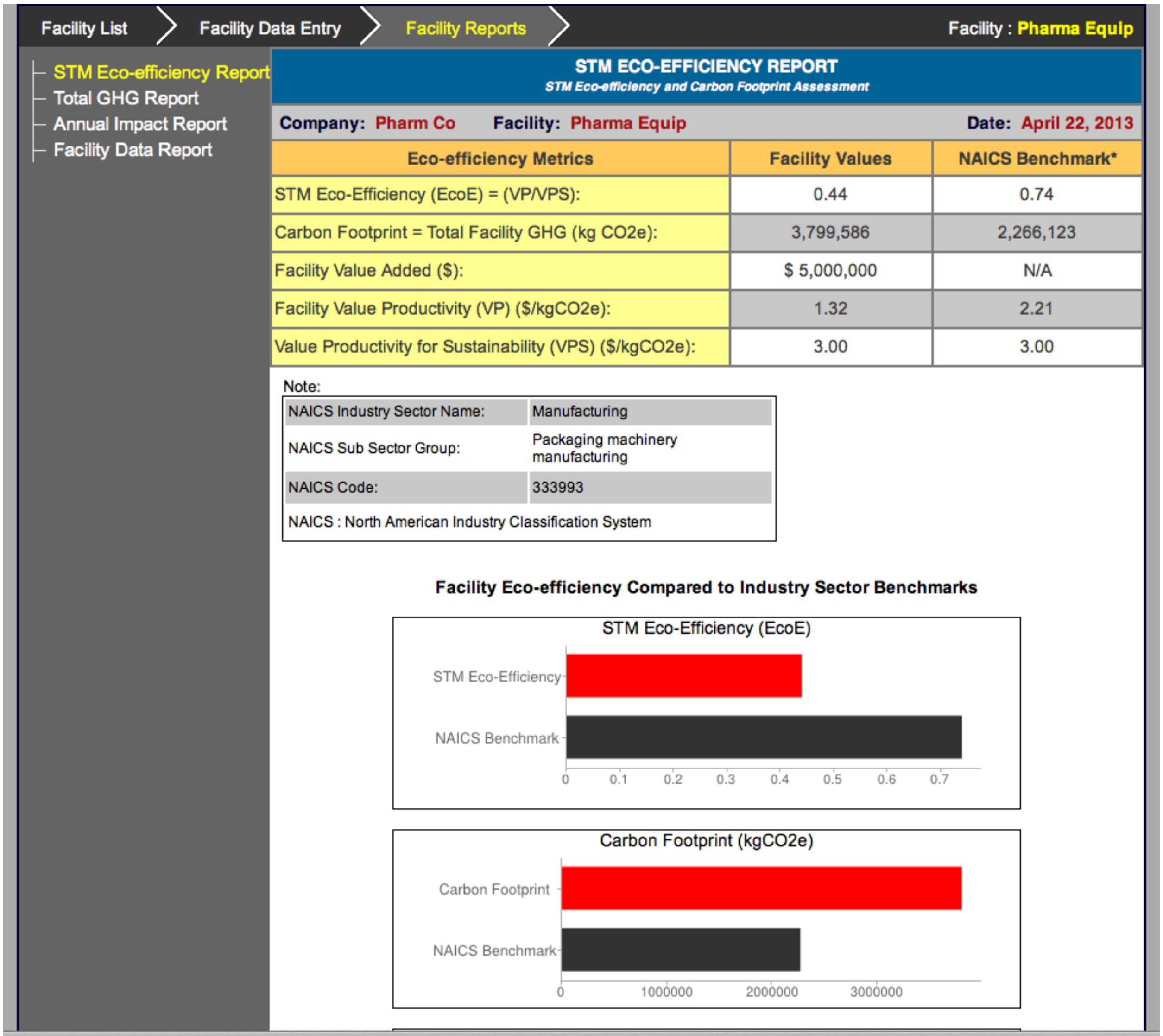
Fig. I.4.2 - NJ-IES Architecture and Module Integration

Facility Data Requirements. EcoAudit includes capturing the facility level data, as described above, with annual energy consumption data window shown in Fig. I.4.3 below. Emission factors are set based on PSE&G power generation network and current distribution of primary energy sources—coal, natural gas, nuclear, and others.



Energy Source	Annual Energy Consumption	Units	Emission Factor*
Electric Power:	2,250,000	kWh	0.58 kgCO2e/kWh
Natural Gas:	120,000	therms	5.50 kgCO2e/therms
Propane/LPG:	5,000.00	gallons	5.80 kgCO2e/gallons
Gasoline:	25,000.00	gallons	8.90 kgCO2e/gallons
Oil/Diesel Fuel:	35,000.00	gallons	10.20 kgCO2e/gallons

Fig. I.4.3 - Screen capture of Facility Energy, Economic and Production Data


Facility List | Facility Data Entry | Facility Reports | Facility : Pharma Equip

- STM Eco-efficiency Report
- Total GHG Report
- Annual Impact Report
- Facility Data Report

STM ECO-EFFICIENCY REPORT

STM Eco-efficiency and Carbon Footprint Assessment

Company: Pharm Co **Facility:** Pharma Equip **Date:** April 22, 2013

Eco-efficiency Metrics	Facility Values	NAICS Benchmark*
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.44	0.74
Carbon Footprint = Total Facility GHG (kg CO2e):	3,799,586	2,266,123
Facility Value Added ($):	$ 5,000,000	N/A
Facility Value Productivity (VP) ($/kgCO2e):	1.32	2.21
Value Productivity for Sustainability (VPS) ($/kgCO2e):	3.00	3.00

Note:

NAICS Industry Sector Name:	Manufacturing
NAICS Sub Sector Group:	Packaging machinery manufacturing
NAICS Code:	333993
NAICS : North American Industry Classification System	

Facility Eco-efficiency Compared to Industry Sector Benchmarks

Fig. I.4.4 – Facility Level Analysis STM Eco-Efficiency Report

Facility Reports. Once the facility data is entered, NJ-IES generates a series of reports assessing and summarizing facility performance. In the sample STM eco-efficiency report, shown in Fig. I.4.4, the STM Eco-efficiency (EcoE) value and Carbon Footprint are calculated and compared against the average industry sector benchmarks. The benchmark values were obtained using environmental lifecycle data from the economic input-output LCA database, as indicated above. The STM EcoE is an absolute measure of sustainability: if EcoE is greater than or equal to one, the facility is sustainable; if EcoE is less than one, then the facility is not sustainable. For the data given here, the facility EcoE is 0.44, indicating the facility is not sustainable. Also, note that the average STM EcoE for the industry sector (NAICS 333993-Package Machinery Manufacturing) is 0.77—much higher than the facility value; consequently, there should be opportunities for improving eco-efficiency and making the facility more sustainability.

Two other facility level reports are shown below in Fig. I.4.5-I.4.6: Fig. I.4.5 gives GHG emissions by facility consumption category and summarized by energy source; and, Fig. I.4.6 is an annual environmental impact report and shows ozone depletion, acidification, eutrophication, and other impacts, as well as GHG emissions.

Facility List > Facility Data Entry > Facility Reports | Facility : Pharma Equip

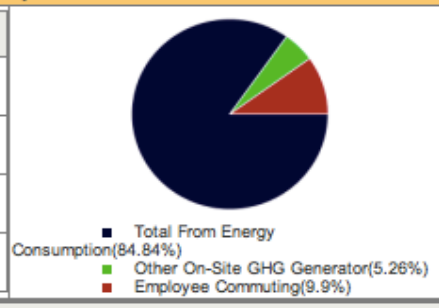
- STM Eco-efficiency Report
- Total GHG Report
- Annual Impact Report
- Facility Data Report

TOTAL GHG REPORT
Total GHG Emission by Energy Source

Company: Pharm Co **Facility:** Pharma Equip **Date:** April 28, 2013

Facility GHG Emission

Emission Source by Category	GHG Emission (kg CO2e)
Energy Consumption:	3,223,500
On-Site GHG Generator	200,000
Employee Commuting	376,087
Total Facilty	**3,799,587**



GHG Emission Report

Energy Source	Emission Factor* (kg CO2e)	GHG Emission (kg CO2)
Electric Power	0.5800 /kWh	1,305,000
Natural Gas	5.50 /therm	660,000
Propane/LPG	5.80 /gallon	29,000
Gasoline	8.90 /gallon	222,500
Oil/Diesel Fuel	10.20 /gallon	357,000
Total Non-Renewable Energy Consumption	--	2,573,500
Coal	2,600.00 /ton	650,000
Total Other Energy Consumption	--	650,000
Total From Energy Consumption:	--	**3,223,500**

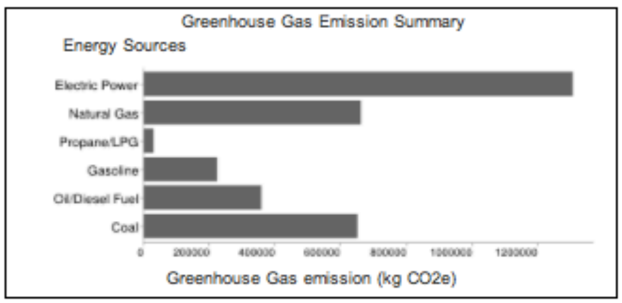


Fig. I.4.5 - Total GHG Report

- STM Eco-efficiency Report
- Total GHG Report
- Annual Impact Report
- Facility Data Report

ANNUAL IMPACT REPORT
Annual Impact Emission Report

Company: Pharm Co **Facility:** Pharma Equip **Date:** April 28, 2013

Emission Source	Greenhouse gas (kg CO2)	Ozone layer (kg CFC11)	Acidification (kg SO2)	Eutrophication (kg PO4)	Heavy Metals (kg Pb)	Summer Smog (kg C2H4)	Winter Smog (kg SPM)
Electric Power:	1,305,000.0	0.1	2,535.8	665.6	13.4	179.1	1,656.4
Natural Gas:	660,000.0	0.0	7,278.1	88.8	6.4	236.8	6,989.8
Propane/LPG:	29,000.0	0.0	115.1	13.4	0.1	8.4	84.0
Gasoline:	222,500.0	0.0	702.2	82.0	0.7	51.3	512.4
Oil/Diesel Fuel:	357,000.0	0.1	5,874.6	1,000.9	0.9	270.5	1,693.7
Coal:	650,000.0	0.0	14,796.3	4,556.9	105.6	105.6	10,792.9
Facility Total:	**3,223,500.0**	**0.3**	**31,302.0**	**6,407.6**	**127.1**	**851.8**	**21,729.3**
NAICS Benchmark*:	2,266,123.0	1.6	271.8	0.1	N/A	68.2	N/A

Fig. I.4.6 – Annual Impact Report

I.5 Process Assessment. The process level assessment goes inside the facility and evaluates the eco-efficiency and sustainability of individual activities and work tasks.

Process Model and Data Requirements. The overall facility operation is modeled as a set of processes. Each process has specific inputs and outputs and a series of activities that work together to achieve a desired output. Fig. I.5.1 defines the analysis boundary for the Process Assessment with internal process flow structure.

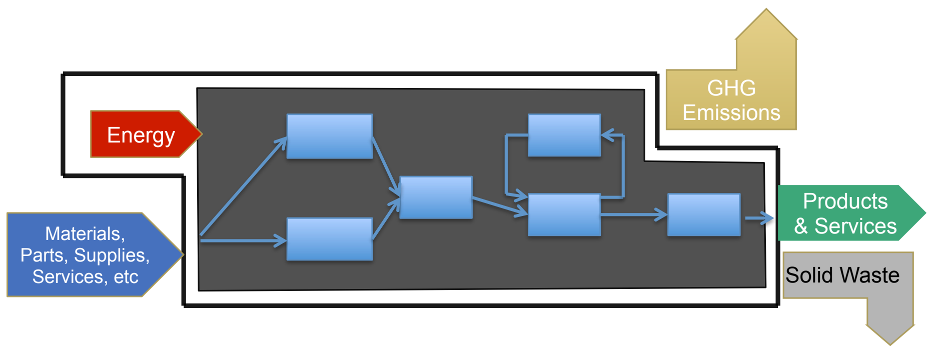
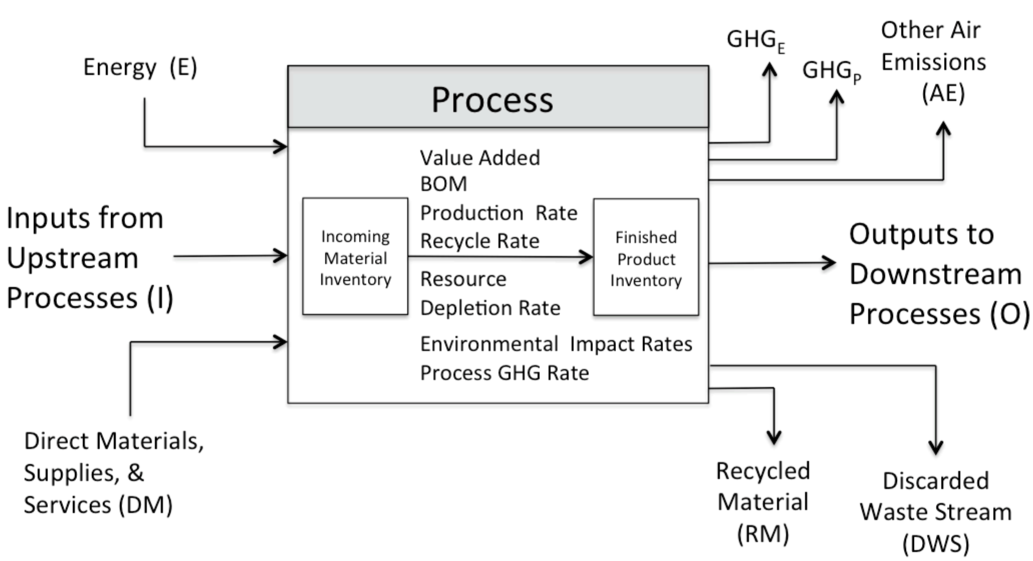


Fig. I.5.1 – Process Level Assessment Boundary

This modeling structure is generic and widely used in engineering to analyze both manufacturing and service companies.

The basic structure of a process is shown in Fig. I.5.2 below. Energy, direct materials, supplies, & services, and materials flowing from upstream processes are inputs to the process. Process outputs include the materials/goods transferred to downstream processes, recycled and discarded waste stream materials, and air emissions. Quantities of greenhouse gases from energy consumption and other process-related sources are tracked, as well as other relevant air emissions.



Note: Energy (E) includes process energy and appropriate allocation of employee commuter consumption

Fig. I.5.2 - General Process Structure

The additional data needed for the Process Assessment includes the facility inputs (direct materials, supplies and services purchased), the internal activities or processes performed, and the products and services produced at the facility. Environmental lifecycle data for standard materials and processes are provided by the Ecoinvent database.

Process Linking. Process linking creates the internal process value chain connecting processes to inputs and outputs. The results of this linking procedure is illustrated in Process Flow View, shown in Fig. I.5.3.

Process Data > Process Linking > Simulation > Process Assessment Reports >

- Select Output
  - Linked Processes
    - Link New Process
  - Flow Data
    - Time & Value
    - Input Material
- Process Flow View

Process Flow View

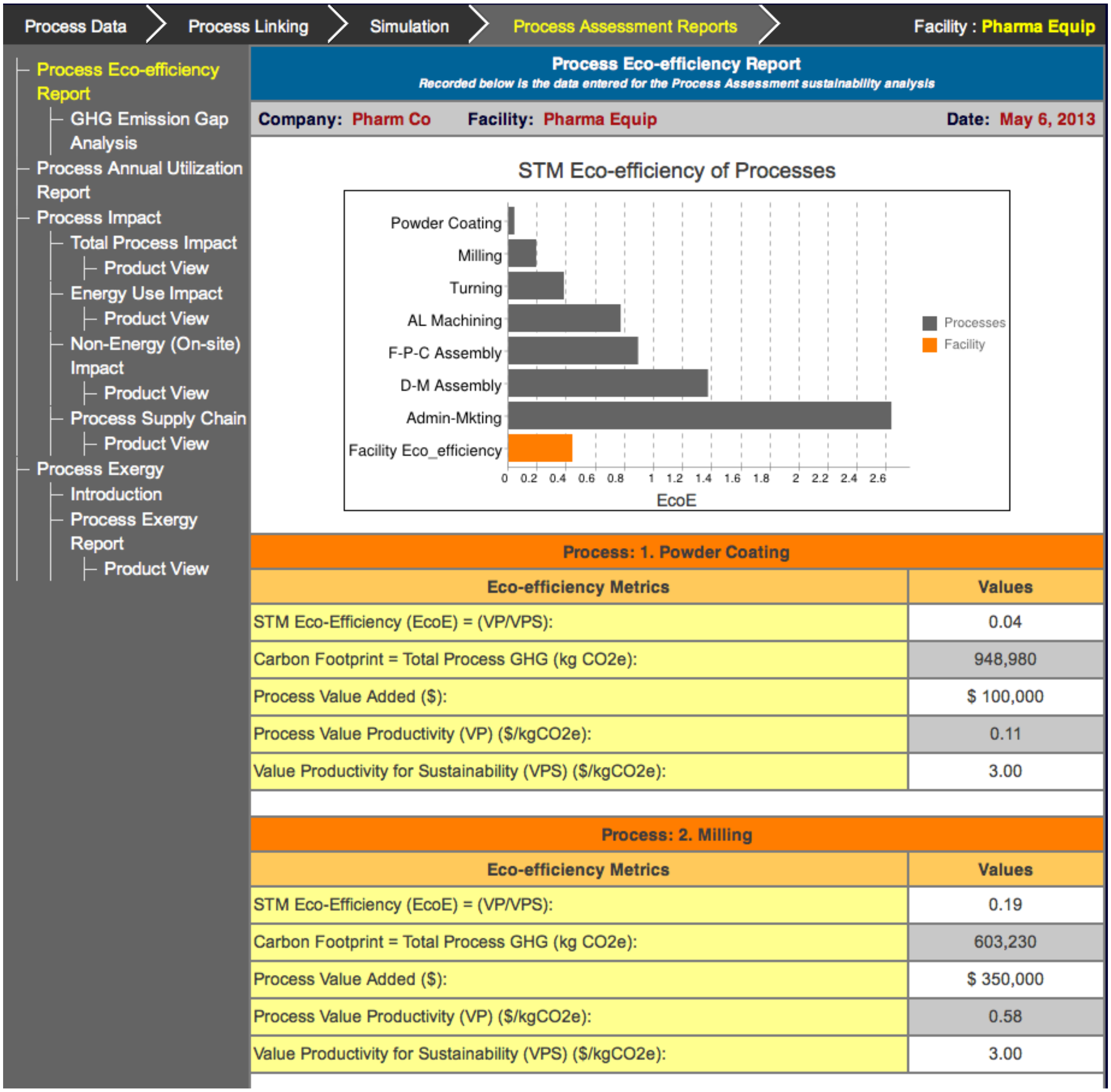
Pharma Equip

All Process And Material Linked To Its Output

Process Flow View for Product: Dry Mixer			
Facility Output	Dry Mixer	Annual Output Qty	100.00 units
Unit Value in $	10,000.00/units	Annual Output value	$1,000,000.00
1. Process Name : Milling			
Labor time/unit in hours	200.0000	Process time/unit in hours	160.0000
Annual Labor time in hours	20,000.0000	Annual Process time in hours	16,000.0000
Input #	**Material Input Name**	**Qty/Unit output**	**Annual Use**
1	Steel	400 kg	40,000.00 kg
2. Process Name : Turning			
Labor time/unit in hours	100.0000	Process time/unit in hours	100.0000
Annual Labor time in hours	10,000.0000	Annual Process time in hours	10,000.0000
Input #	**Material Input Name**	**Qty/Unit output**	**Annual Use**
No Inputs Linked			
3. Process Name : Powder Coating			
Labor time/unit in hours	50.0000	Process time/unit in hours	50.0000
Annual Labor time in hours	5,000.0000	Annual Process time in hours	5,000.0000
Input #	**Material Input Name**	**Qty/Unit output**	**Annual Use**
1	Paint	20 L	2,000.00 L
4. Process Name : D-M Assembly			
Labor time/unit in hours	80.0000	Process time/unit in hours	80.0000
Annual Labor time in hours	8,000.0000	Annual Process time in hours	8,000.0000
Input #	**Material Input Name**	**Qty/Unit output**	**Annual Use**
1	Cardboard	10 kg	1,000.00 kg
2	Electronics	1 units	100.00 units
5. Process Name : Admin-Mkting			
Labor time/unit in hours	5.0000	Process time/unit in hours	5.0000
Annual Labor time in hours	500.0000	Annual Process time in hours	500.0000
Input #	**Material Input Name**	**Qty/Unit output**	**Annual Use**
No Inputs Linked			

Fig. I.5.3 – Process Flow View Linking Inputs and Processes to Products

<u>Process Assessment Reports.</u> With the process flow view, process value added, and lifecycle environmental data, the STM eco-efficiency (EcoE) of each process is determined. Recall, EcoE greater than or equal to one indicates that the process is sustainable. The Process Eco-Efficiency Report, given in Fig. I.5.4, lists processes from the least sustainable to the most sustainable. Those processes, such as Powder Coating, with low EcoE values represent targets for improvement.

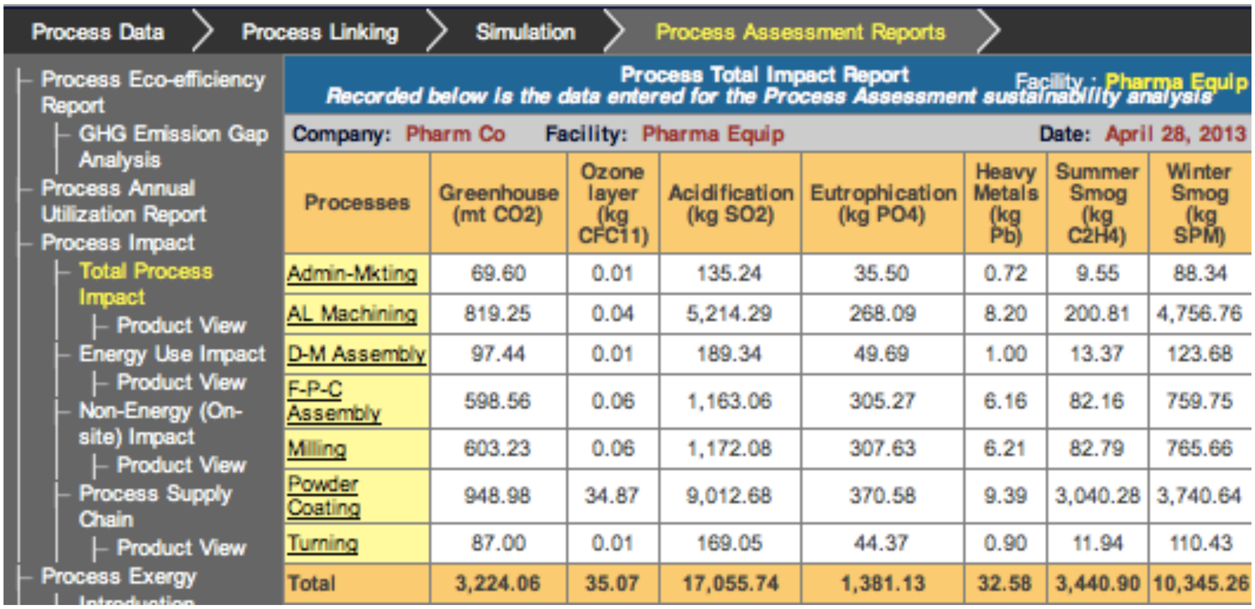


Eco-efficiency Metrics (Process: 1. Powder Coating)	Values
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.04
Carbon Footprint = Total Process GHG (kg CO2e):	948,980
Process Value Added ($):	$ 100,000
Process Value Productivity (VP) ($/kgCO2e):	0.11
Value Productivity for Sustainability (VPS) ($/kgCO2e):	3.00

Eco-efficiency Metrics (Process: 2. Milling)	Values
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.19
Carbon Footprint = Total Process GHG (kg CO2e):	603,230
Process Value Added ($):	$ 350,000
Process Value Productivity (VP) ($/kgCO2e):	0.58
Value Productivity for Sustainability (VPS) ($/kgCO2e):	3.00

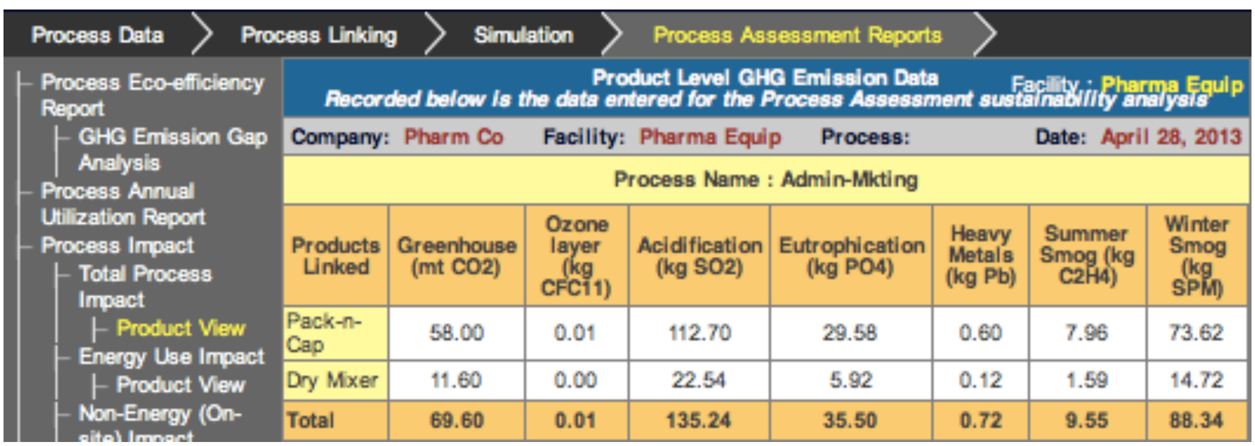
Fig. I.5.4 – Process Eco-efficiency Report

The Total Process Impact Report, as shown in Fig. I.5.5a, provides a summary of the broad environmental impacts associated with each process, including, GHG emissions, ozone depletion, acidification and eutrophication. By clicking on a particular process, the process environmental impacts are displayed for each product for which that process is involved, as shown in Fig. I.5.5b.



Processes	Greenhouse (mt CO2)	Ozone layer (kg CFC11)	Acidification (kg SO2)	Eutrophication (kg PO4)	Heavy Metals (kg Pb)	Summer Smog (kg C2H4)	Winter Smog (kg SPM)
Admin-Mkting	69.60	0.01	135.24	35.50	0.72	9.55	88.34
AL Machining	819.25	0.04	5,214.29	268.09	8.20	200.81	4,756.76
D-M Assembly	97.44	0.01	189.34	49.69	1.00	13.37	123.68
F-P-C Assembly	598.56	0.06	1,163.06	305.27	6.16	82.16	759.75
Milling	603.23	0.06	1,172.08	307.63	6.21	82.79	765.66
Powder Coating	948.98	34.87	9,012.68	370.58	9.39	3,040.28	3,740.64
Turning	87.00	0.01	169.05	44.37	0.90	11.94	110.43
Total	3,224.06	35.07	17,055.74	1,381.13	32.58	3,440.90	10,345.26

(a) Process Total Impact Report for Each Process



Products Linked	Greenhouse (mt CO2)	Ozone layer (kg CFC11)	Acidification (kg SO2)	Eutrophication (kg PO4)	Heavy Metals (kg Pb)	Summer Smog (kg C2H4)	Winter Smog (kg SPM)
Pack-n-Cap	58.00	0.01	112.70	29.58	0.60	7.96	73.62
Dry Mixer	11.60	0.00	22.54	5.92	0.12	1.59	14.72
Total	69.60	0.01	135.24	35.50	0.72	9.55	88.34

(b) Product Total Impact Report for Selected Process

Fig. I.5.5 - Process Total Impact Report

Process Simulation. One of the unique features of NJ-IES is the fully web-enabled stochastic process simulation engine with a graphical user interface (GUI). Simulation is a powerful analysis tool used widely across all engineering and operations management fields to better understand material and energy flows in order to improve operations and reduce cost. As shown in Fig. I.5.6, the GUI provides users with a simple graphical display of processes with inputs and outputs and patterns of material and operational flow between processes. Also, the data manually entered in defining processes, inputs and outputs is automatically transferred into the simulation module.

As an example, consider the graphical layout of processes, inputs and outputs as shown in Fig. I.5.6. The blue rectangles, red pointed-blocks, and green ovals represent processes, inputs, and outputs, respectively. And, the green arrows represent material and operational flows.

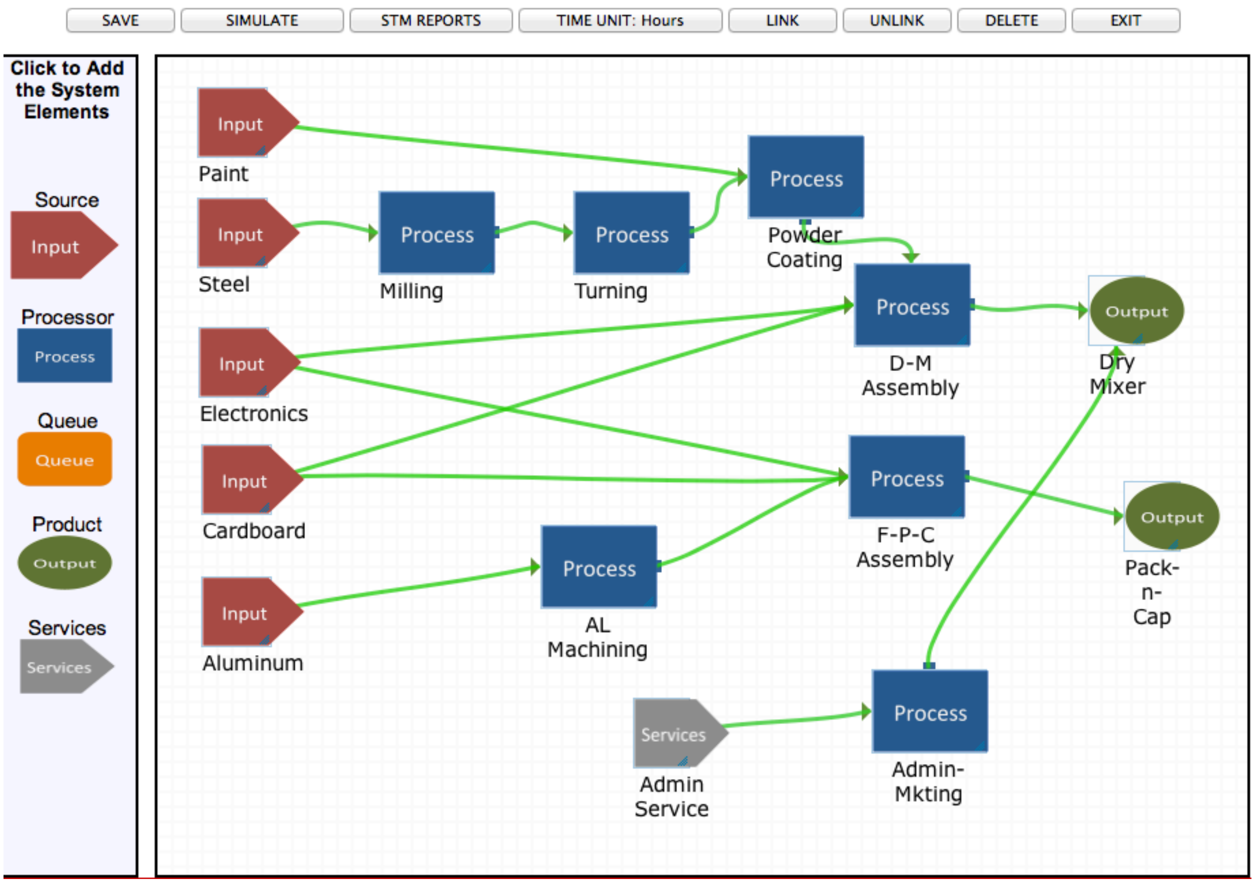


Fig. I.5.6 – NJ-IES Graphical User Interface for Web-enabled Process Simulation Engine

Once the process model is complete, process parameters can be changed through the process parameter/properties window by double-clicking on the process image and editing values. To simulate the effects of uncertainty or random behaviors for supplier materials and processing times, standard distributions have been integrated into the model structure—these are set by the user in the parameter/properties windows. To run a simulation, click on the SIMULATE button in the toolbar, enter the simulation time desired, and click UPDATED SIMULATION.

As shown in Fig. I.5.7, the simulation results are displayed by process for each product. The results of the simulation include the number of products output from that process, the average waiting time for each input to that process, and the total idle time, utilization and energy consumption (kWh) for the process.

A second report is the STM Eco-efficiency report which compares the performance of the baseline initial system with the current version of the system as defined in the simulation module. The report structure is the standard Process Assessment Eco-efficiency Report, shown previously in Fig. I.5.4, with the baseline system operation on the left and the updated system version on the right. As an example, a proposed energy efficiency improvement in the milling operation led to a significant improvement in the STM eco-efficiency value for that process—this is evident in comparing the process bar charts in Fig. I.5.4.

NJ-IES: New Jersey - Industry Eco-efficiency and Sustainability Guide

Simulation Report

Company: Pharm Co **Facility:** Pharma Equip **Date:** April 29, 2013

SIMULATION TIME	2000	UNITS: Hours

OUTPUT: Pack-n-Cap

Process: F-P-C Assembly						
Number Of Units Produced	Average Waiting of Electronics	Average Waiting of AL Machining	Average Waiting of Cardboard	Idle Wait of F-P-C Assembly	Utilization of F-P-C Assembly	Energy Consumption of F-P-C Assembly in kWh
35	0.06	0.01	0.05	0.00	0.97	668.16

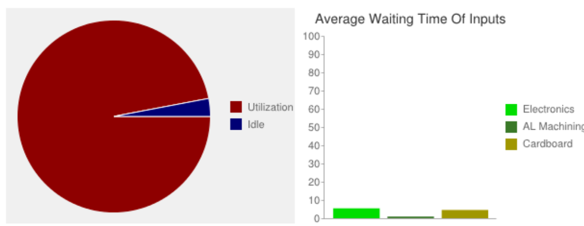
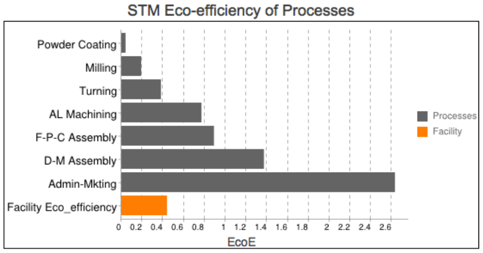


Fig. I.5.7 – Simulation Report for Each Process By Product

Process Level GHG Emission Data

Recorded below is the data entered for the Process Assessment sustainability analysis

Company: Pharm Co **Facility:** Pharma Equip **Date:** April 29, 2013



Process: 1. Powder Coating	
Eco-efficiency Metrics	**Values**
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.04
Carbon Footprint = Total Process GHG (kg CO2e):	948,980
Process Value Added ($):	$ 100,000
Process Value Productivity (VP) ($/kgCO2e):	0.11
Value Productivity for Sustainability (VPS) ($/kgCO2e):	3.00

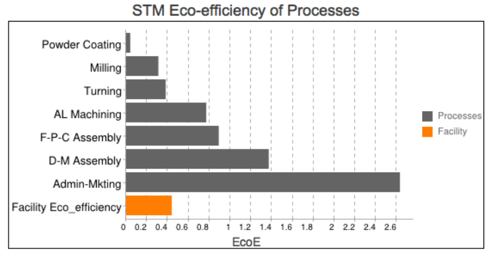
Process: 2. Milling	
Eco-efficiency Metrics	**Values**
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.19
Carbon Footprint = Total Process GHG (kg CO2e):	603,230
Process Value Added ($):	$ 350,000
Process Value Productivity (VP) ($/kgCO2e):	0.58
Value Productivity for Sustainability (VPS) ($/kgCO2e):	3.00

Process: 3. Turning	
Eco-efficiency Metrics	**Values**
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.38

Process Level GHG Emission Data

Recorded below is the data entered for the Process Assessment sustainability analysis

Company: Pharm Co **Facility:** Pharma Equip **Date:** April 29, 2013



Process: 1. Powder Coating	
Eco-efficiency Metrics	**Values**
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.04
Carbon Footprint = Total Process GHG (kg CO2e):	948,980
Process Value Added ($):	$ 100,000
Process Value Productivity (VP) ($/kgCO2e):	0.11
Value Productivity for Sustainability (VPS) ($/kgCO2e):	3.00

Process: 2. Milling	
Eco-efficiency Metrics	**Values**
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.31
Carbon Footprint = Total Process GHG (kg CO2e):	371,230
Process Value Added ($):	$ 350,000
Process Value Productivity (VP) ($/kgCO2e):	0.94
Value Productivity for Sustainability (VPS) ($/kgCO2e):	3.00

Process: 3. Turning	
Eco-efficiency Metrics	**Values**
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.38

Fig. I.5.8 – STM Eco-efficiency Report Comparing Simulated System to Baseline System

Process Exergy Analysis. Exergy analysis is well developed and has been widely used in recent years to assess process efficiency and evaluate environmental impacts [7-39]. Exergy is related to the entropy, a measure of irreversibility in a system, and quantifies the maximum possible work that can be done by a system as it is brought from its initial state into equilibrium with a reference state. While the energy efficiency measures a process's thermodynamic First Law Efficiency, exergy efficiency measures a process's thermodynamic Second Law Efficiency. Exergy analysis provides deeper insights into the environmental impact than energy analysis alone due to its ability to identify the source and magnitude of the exergy loss associated with thermodynamic irreversibility (such as friction, chemical reactions, heat transfer through finite temperature difference, etc.) of a process. The following expression for exergy is used in this study as it focuses on the exergy associated with material resources and energy carriers [7]:

$$Exergy(MJ) = \sum_i m_i \times Ex_{ch,i} + \sum_j n_j \times r_{ex-e(k,p,n,r,t),j}$$

Where,

m_i	= mass of material resource i (kg)
$Ex_{ch,i}$	= exergy per kg of material i (MJeq/kg)
n_j	= quantity of energy from energy carrier j (MJ)
$r_{ex-e(k,p,n,r,t),j}$	= exergy to energy ratio (quality factor) for energy carrier j (MJeq/MJ)
ch	= chemical
k	= kinetic
p	= potential
n	= nuclear
r	= radiative
t	= thernal exergy

Among the six types of exergy: chemical, kinetic, potential, thermal or physical, nuclear, and radiative, chemical exergy of resource materials—metals, minerals, water, wood, etc—are calculated based on molar fractions as shown in the following equations:

$$Ex_{ch} = \sum_j n_j \times ex_{ch,j}$$

$$ex_{ch,j} \approx ex^0_{ch,j} = \Delta_i G^0_i + \sum_{el} n_{el} \times ex^0_{ch,el}$$

Where,

Ex_{ch}	= molar chemical exergy of material (kJ/mol)
n_j	= mole fraction of substance j in the material
$ex_{ch,j}$	= standard molar chemical exergy of j (kJ/mol)
$ex^0_{ch,j}$	= standard molar chemical exergy of j from the reference environment (kJ/mol)
$ex^0_{ch,el}$	= standard partial molar chemical exergy of elements in substance j (kJ/mol)
$\Delta_i G^0_i$	= standard Gibb's free energy of formation of j (kJ/mol)
n_{el}	= number of elements in substance j

The exergy associated with energy carriers is taken to be the product of the gross heating value of the carrier and the quality factor. Appendix A contains additional details on exergy analysis and tables of gross heating values and other factors.

Exergy Flow Simulation Model: This model is an extension of energy flow simulation. Energy flow analysis focuses only on energy and ignored the quality of energy and the degradation of energy quality. Exergy analysis evaluates the quality of the energy lost, and distinguishes between recoverable and non-recoverable energy.

The NJ-IES exergy analysis is formulated based on the exergy balance within each system, which can represent a facility, process or product group. The total exergy input to the system should equal to the sum of total exergy output and the exergy destructed by the system. The Exergy Footprint, a novel technique developed by Dr. Reggie Caudill and the research team at NJIT [7], is structured similar to the carbon footprint but includes all resource consumption categories: materials, water, energy, and employee commuting. This approach is applied to facility, process and product levels by using their respective boundaries. Since the exergy simulation model is an extension on the energy simulation model, basic data needed are already available from the energy consumption, the incoming material inventory and finished product inventory obtained for the energy simulation. The exergy flow at the process level is shown in Fig. I.5.9, where the simulation model uses Energy Quality Factors and Exergy Factors to convert the basic data to obtain the exergy destruction by the process and the resulted environmental impact.

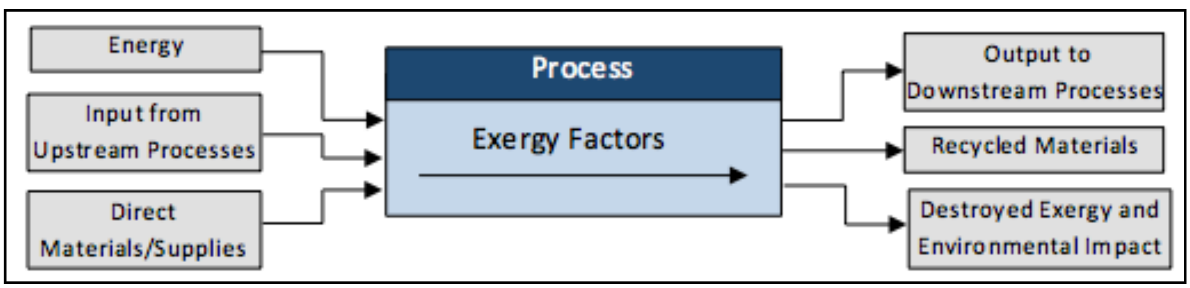


Fig. I.5.9 – Exergy Flow at the Process Level

The total exergy on the input side of the process comes from the exergy in the energy consumed by the process, the exergy contained in the input from the upstream processes, and the exergy contained by the direct materials and supplies. The total exergy on the output side of the process includes the exergy contained in the output to the downstream processes, and the exergy in the produced recyclable wastes (after taking into account of exergy loss during the recycling process). The balance of the exergy is the destroyed exergy by the process. Further details on exergy analysis are provided in Appendix A.

Fig. I.5.10 shows the Exergy Analysis report containing total exergy for each process and a summary chart indicating exergy consumption allocation across material and energy sources. Similar to other process assessment reports, if you click on any process further details are displayed to show exergy consumption for each product in which the selected process is involved.

Process Exergy Impact Report

Recorded below is the data entered for the Process Assessment sustainability analysis

Company: Pharm Co **Facility:** Pharma Equip **Date:** May 2, 2013

Processes	Annual Exergy Value (Material Impact + Process Energy Impact) (MJ)
Admin-Mkting	1,363,200
AL Machining	17,588,955
D-M Assembly	19,497,684
F-P-C Assembly	31,221,453
Milling	43,038,609
Powder Coating	61,319,881
Turning	63,023,881
Total	**237,053,661**

Exergy Analysis

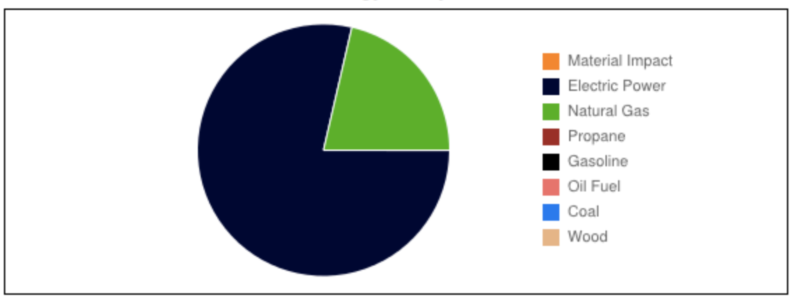


Fig. I.5.10 – Exergy Report for Process Assessment

I.6 Product Assessment. The product level assessment is focused on individual products or services produced at the facility. The analysis boundary includes the facility envelope, energy inputs and the upstream supply chain. Note: the analysis may also include downstream product end of life management operations, if desired. As shown in the analysis boundary in Fig. I.6.1, the product level analysis includes process flow and modeling as described in Section I.5 Process Assessment.

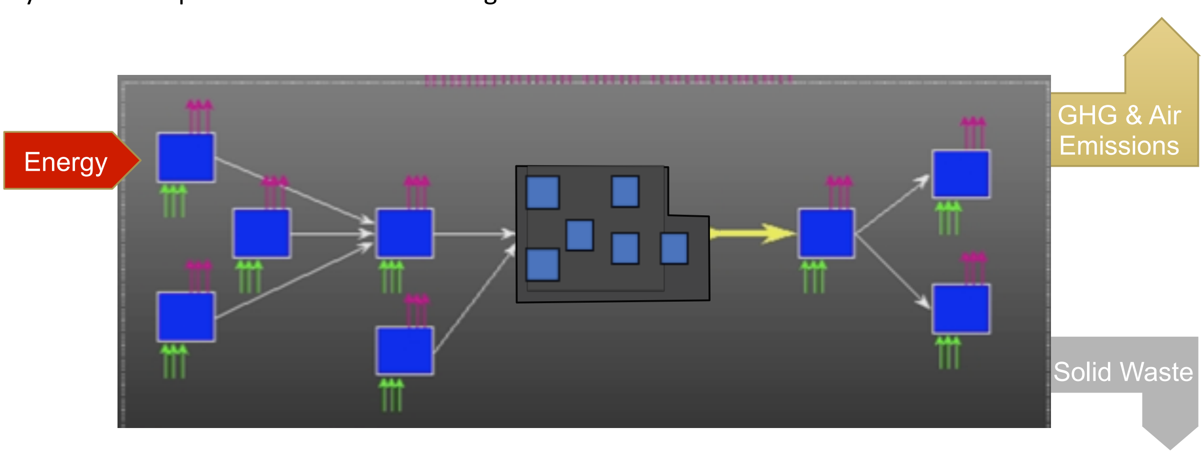
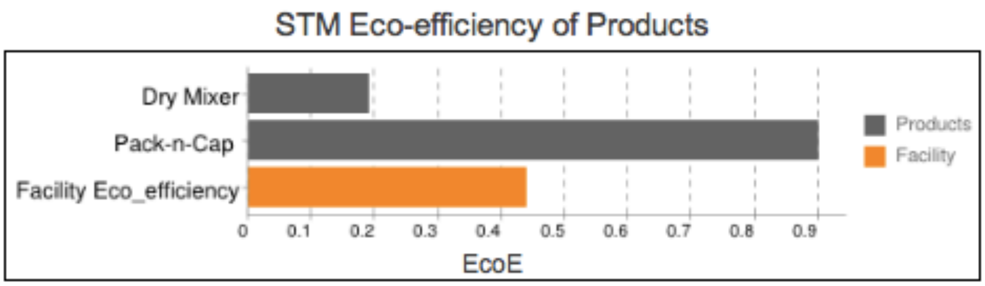


Fig. I.6.1 – Product Level Assessment Boundary

With data from the Ecoinvent database, the product assessment captures all in-facility flows through the processes and the incoming materials and supplies. The environmental lifecycle and economic value added data are used to calculate the STM EcoE and Carbon Footprint metrics for each product. This information is presented in the Product Assessment Reports, as shown in Fig. I.6.2-I.6.4.



Product: 1. Dry Mixer	
Eco-efficiency Metrics	**Values**
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.19
Carbon Footprint = Total Product GHG (kg CO2e):	1,748,250
Product Value Added ($):	$ 1,000,000
Product Value Productivity (VP) ($/kgCO2e):	0.57
Value Productivity for Sustainability (VPS) ($/kgCO2e):	3.00

Product: 2. Pack-n-Cap	
Eco-efficiency Metrics	**Values**
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.90
Carbon Footprint = Total Product GHG (kg CO2e):	1,475,810
Product Value Added ($):	$ 4,000,000
Product Value Productivity (VP) ($/kgCO2e):	2.71
Value Productivity for Sustainability (VPS) ($/kgCO2e):	3.00

Fig. I.6.2 - Product Assessment Eco-Efficiency Report

Products	Greenhouse (kg CO2)	Ozone layer (kg CFC11)	Acidification (kg SO2)	Eutrophication (kg PO4)	Heavy Metals (kg Pb)	Summer Smog (kg C2H4)	Winter Smog (kg SPM)
Dry Mixer	1,748,250.24	34.95	10,521.24	778.18	17.62	3,149.78	4,755.13
Pack-n-Cap	1,475,810.00	0.11	6,490.05	602.94	14.96	290.93	5,590.13
Total	**3,224,060.24**	**35.07**	**17,011.30**	**1,381.12**	**32.58**	**3,440.70**	**10,345.26**

Fig. I.6.3 - Product Environmental Impact Report

Product Name : Dry Mixer							
Processes Linked	Greenhouse (kg CO2)	Ozone layer (kg CFC11)	Acidification (kg SO2)	Eutrophication (kg PO4)	Heavy Metals (kg Pb)	Summer Smog (kg C2H4)	Winter Smog (kg SPM)
Milling	603,230.24	0.06	1,172.08	307.63	6.21	82.79	765.66
Turning	87,000.00	0.01	169.05	44.37	0.90	11.94	110.43
Powder Coating	948,980.00	34.87	9,012.68	370.58	9.39	3,040.28	3,740.64
D-M Assembly	97,440.00	0.01	189.34	49.69	1.00	13.37	123.68
Admin-Mkting	11,600.00	0.00	22.54	5.92	0.12	1.59	14.72
Total	**1,748,250.24**	**34.95**	**10,565.68**	**778.19**	**17.62**	**3,149.98**	**4,755.13**

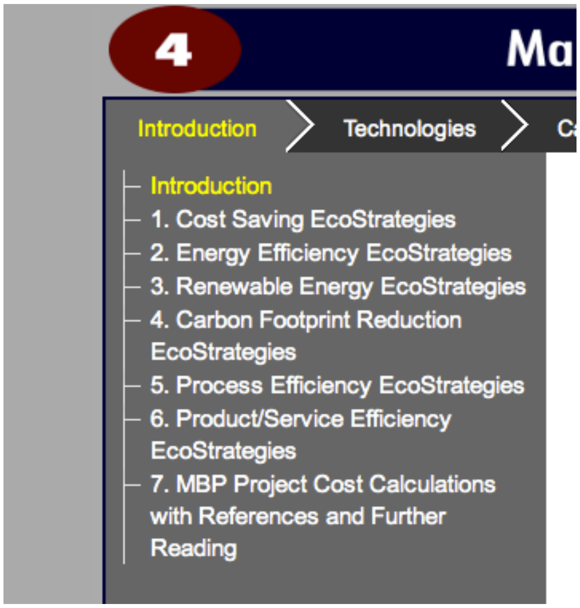
Fig. I.6.4 - Process Environmental Report for Selected Product

I.7 Management Best Practices. The Management Best Practices (MBP) module provides an integrated guide to a variety of information and technical resources on energy efficiency, renewable energy technologies and other sustainability practices. Appendix B contains significantly more details regarding the MBP module.

In broad terms defining the STM eco-efficiency metric, there are six primary categories of EcoStrategies or Management Best Practices as described below that will lead toward improvements in eco-efficiency and move companies toward sustainability. These are also presented in the STM Strategy Map described in Section I.8 EcoStrategies and Sustainability Improvements.

Cost Saving EcoStrategies. EcoStrategies that target cost savings by reducing vendor supplied materials or services, reducing energy consumption or other operational costs are referred to as Cost Saving or Value Added EcoStrategies. Examples of potential strategies that increase value added include eliminating process waste streams including rework and scrap; conserving resources and reducing vendor purchases; improved controls for pumps, compressors, lighting, HVAC systems; and, other production cost saving initiatives.

Energy Efficiency EcoStrategies. The connection between energy consumption and global warming is well recognized; consequently, initiatives that improve energy efficiency are fundamental to increasing eco-efficiency and improving sustainability across the corporation. Energy efficiency programs not only reduce cost (Cost Saving EcoStrategies), but also reduce greenhouse gas (GHG) emissions. As noted, reducing costs leads to higher value added for the corporation while reducing GHG emissions yields lower environmental footprint. Both of these results improve the STM EcoE value effectively having a dual impact on sustainability. Examples of potential strategies that increase energy efficiency include



implementing more effective Energy Management Systems; improved controls for pumps, compressors, lighting, HVAC systems; and, updating energy intensive equipment and processes.

Renewable Energy EcoStrategies. Solar power, wind turbines, smart grid and biofuel technologies are advancing rapidly and becoming more economically viable as alternative energy sources. These renewable energy technologies have significant advantages over traditional fossil fuel sources with respect to greenhouse gas emission per unit of energy produced. This advantage in carbon intensity directly leads to lower GHG emissions for the corporation, reducing the carbon footprint; however, with the cost of these technologies remain high compared to traditional energy sources. With further advances in underlying technologies and manufacturing, this cost differential is narrowing. Reducing carbon intensity (kgCO2e per kWh) directly improves GHG emissions for the corporation and increases sustainability, as reflected in STM EcoE value. However, if the costs for renewable energy technologies are too high, then corporate value added is reduced which lowers EcoE.

Carbon Reduction EcoStrategies. EcoStrategies that reduce the corporation's carbon footprint lead to lower greenhouse gas emissions. As described above, Renewable Energy EcoStrategies reduce carbon intensity (kgCO2e per kWh) by substitution of cleaner energy sources; consequently, renewable energy systems are also Carbon Reduction EcoStrategies. However, shifting from higher carbon intensity energy sources, like coal, to natural gas, for example, reduces carbon intensity with traditional energy sources. There are other initiatives that reduce carbon emissions which are also considered Carbon Reduction EcoStrategies. Some of these carbon reduction strategies range from advanced technologies, such as carbon sequestration systems to simple, low-cost employee ride sharing and virtual work programs. The underlying impact is to reduce carbon emissions at the source, shift consumption to l or to reduce employee commuter travel.

Process Efficiency EcoStrategies. As indicated above, the reduction in process cycle time directly leads to a sequence of responses that lead improvement in eco--efficiency and sustainability. Process changes that lead to energy savings, improved product quality, or reduced process cycle time result in increased value added and/or reduced environmental impacts (e.g., greenhouse gas reduction) which directly lead to increased STM eco-efficiency. In the STM Strategy Map--shown in the Interactive Chart 3.1--is the potential for lean production principles--including, eliminate waste, reduce cycle times, total quality--to be EcoStrategies that improve production processes leading to higher eco-efficiency and moving the corporation towards sustainability.

Product/Service Efficiency EcoStrategies. There is a direct connection between the business outputs--products produced or services rendered--and the input materials purchased from supply chain partners and processes and activities performed at the facility. In terms of product lifecycle management, decisions made at the product design stage drive manufacturing operations, purchasing and end-of-life product recycling and material recovery. As such, EcoStrategies concerning product level decisions related to materials and processing alternatives may yield cost savings and process changes that lead to improvement in eco--efficiency and sustainability. These efforts are referred to Product/Service Efficiency EcoStrategies.

Fig. I.7.1 shows a screen capture containing a graphical and linkable content with combinations of images, video clips, hyperlinks as well as some advanced interactive multimedia panoramas and descriptions to help guide NJ-IES users. In addition, a case study is presented illustrating step-by-step procedures for using the NJ-IES eco-efficiency and sustainability system. The results and impacts of this case study are described in the Pilot Case Study section of this report.

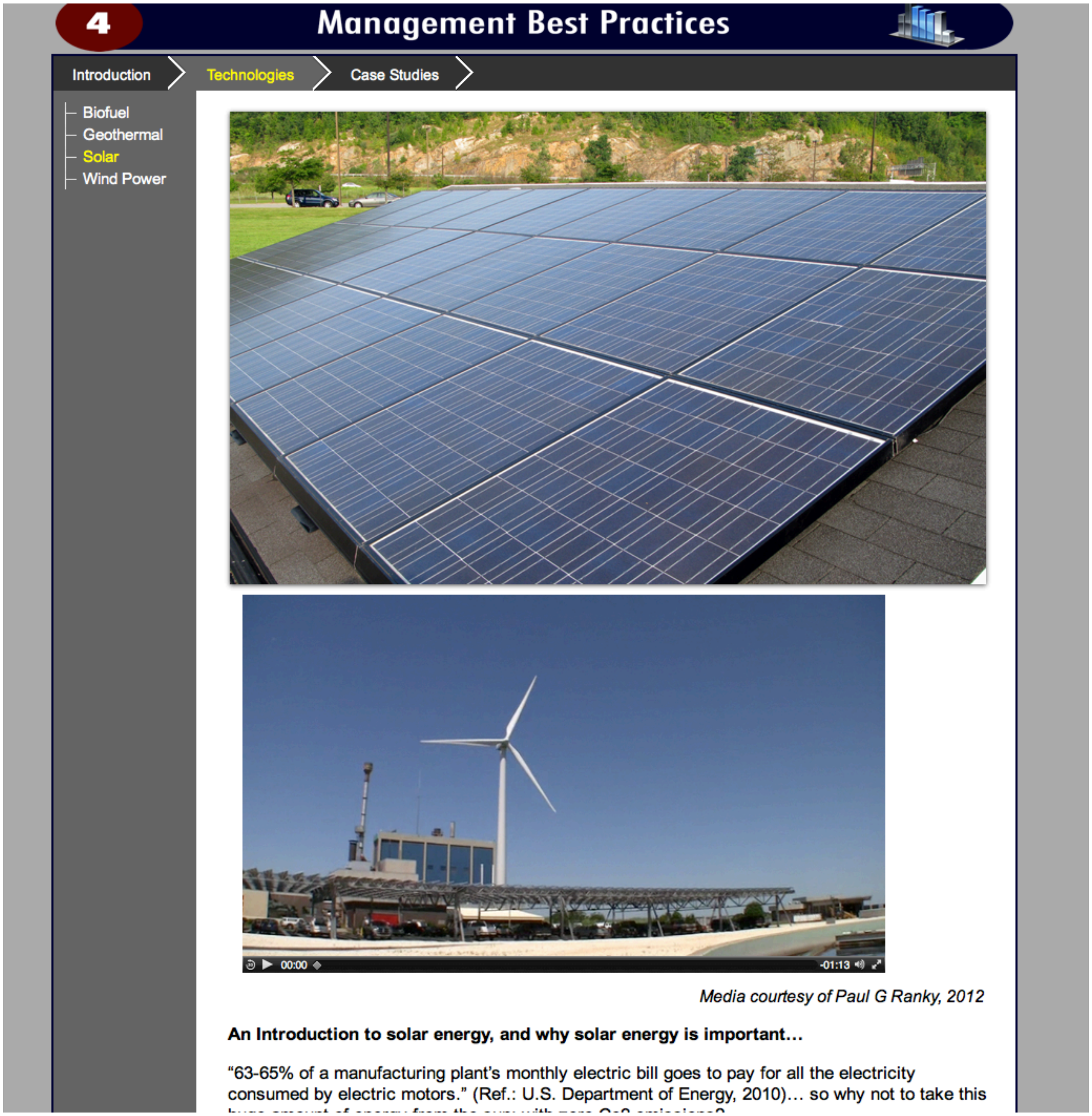


Fig. I.7.1 – Management Best Practices Module Showing Example of Solar Energy Installations

Social Networking Initiative. One of the objectives of NJ-IES project is to create a broad network of individuals and companies interested in exploring sustainable businesses strategies, implementing energy efficiency projects, exchanging ideas, and sharing best practice information. Significant progress has been made on the social networking aspects of this project, with the fundamental goal of eventually using social networks for feedback, evaluation, test, dissemination and discussion of our results for further improvements.

The NJ-IES social networking initiative has over 22,000 links in New Jersey and beyond. Dr. Ranky's email traffic is now over 200 emails a day! Furthermore, we are pleased to report, that as part of the American Society of Quality (ASQ) Ott Conference we helped to organize at NJIT we have extended our social network to ASQ members too. (There are over 600 ASQ professionals in New Jersey!). Since quality and sustainability are important compatible terms (ref. Dr. Caudill, June 21, 2012, Ott Conference keynote) we are very keen to develop these links with the NJ ASQ professional network.

I.8 EcoStrategies and Sustainability Improvement. The EcoStrategies and Sustainability Improvements module is designed to help create sound, economically viable strategies to improve eco-efficiency and move companies toward sustainability. Sustainability is a very complex issue and bringing sustainability into corporate decision-making with all of the other business priorities and concerns can be difficult. However, NJ-IES and the STM eco-efficiency metric make this process easier and more explicit.

Sustainability Economics. EcoStrategy projects must not only move the corporation towards improved eco-efficiency, but must also be economically viable. The theoretical development presented above provides the basis for defining whether or not a sustainability project is economic viability.

As derived in Section V.I.1 of this report, the total change in value added, ΔVA_T, is given as the following equation:

$$\Delta VA_T = \Delta VA - VP_0 \, \Delta GHG$$

EcoStrategies are designed to change the core behavior and operational characteristics of the corporation. These changes have direct economic impact by saving costs and direct environmental impact by reducing greenhouse gas emissions, for example.

Due to the inherent structure of the STM metric to relate economic behavior and environmental performance, the total change in value added is composed of a direct change in economic value added ΔVA and change in value added due to decreased environment impact $VP_0 \, \Delta GHG$.

Note: the negative sign for this term in the equation above indicates that a decrease in GHG results in a positive value added. Also, note that this equation is derived based on well-known mathematical techniques--Taylor Series--and the basic definition of the STM metric expresses an economic value associated with GHG reductions (See Section V.I.1 *for further details and derivation). The value added per kgCOE2e is the original Value Productivity for the corporation before any sustainability improvements are implemented, represented by* VP_0.

As stated above, the total change in value added is considered as profit to the corporation from the EcoStrategy project and wealth is generated if the project cost is less than or equal to the total change in value added divided by the corporate finance rate.

Therefore, the STM Breakeven Project Cost is defined as follows:

$$\text{STM Breakeven Project Cost} = \Delta VA_T / \text{Finance Rate}$$

Then, if the actual project cost is less than or equal to the STM Breakeven Project Cost, then the project generates wealth for the corporation and is economically viable. If not, then the project is not economically viable and should not be undertaken. The Finance Rate is corporate dependent and is considered a user input with default value of 12%.

<u>STM Decision Space.</u> Because of the rigorous relationship between environmental impact and economic performance embedded in the STM approach, a two-dimensional decision space is created with eco-efficiency improvement on one axis and project cost on the other. The underlying mathematical formulation and theoretical foundation for the STM Decision Space Analysis are presented in Section V.I.1. The decision space, shown in Fig. I.8.1, is divided by the STM breakeven line which clearly identifies economically viable projects in the green region from the nonviable projects in the red region. Using this information, you can quickly evaluate strategies, which are points in this space, and select the most effective eco-efficiency projects. The STM Breakeven line is determined based on the STM Breakeven Project Cost equation given above with an assumed corporate finance rate of 12%.

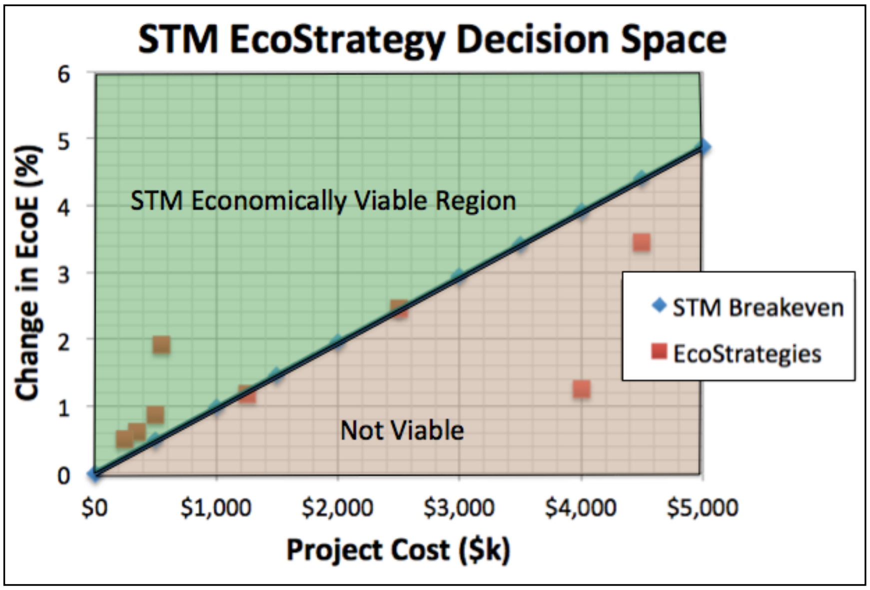


Fig. I.8.1 – STM EcoStrategy Decision Space

Note: the Corporate Finance Rate is assumed to be 12% for this diagram.

<u>STM Corporate Sustainability Map.</u> The Balanced Scorecard approach is a well-recognized and widely used business management technique to assure that corporate goals and shareholder values are integrated into all operational aspects and strategies of the corporation. Traditionally, this approach considers four business perspectives: (1) Learning, Growth and Infrastructure; (2) Internal Process; (3) Customer; and, (4) Financial. A unique extension of the Balanced Scorecard technique for NJ-IES, based on the original work of Dr. Reggie Caudill, has been implemented to incorporate Sustainability as a fifth business perspective. The STM Corporate Sustainability Map shown in Fig. I.8.2 illustrates the system actions, responses and interdependencies, as well as the interconnectivity that exist across the various levels or perspectives of the corporation.

Actions within each business perspective are represented by boxes whereas the arrows depict the action/reaction relationships that exists between the system elements. These relationship can be considered as a sequence of "If..., then..." behaviors that link the actions of EcoStrategies with explicit responses that result within and across business perspectives. For example, "If" a workforce training program is implemented "then" the added skills of the workers lead to improvements in the workplace, including reduced process cycle time. "If" the process cycle time is reduced, "then" energy consumption is reduced, process costs are lowered; and, the overall reliability of product delivery is improved. All leading to improved customer satisfaction, increased eco-efficiency and overall corporate stakeholder value. Consequently, workforce training can and should be considered an EcoStrategy, leading to improved eco-efficiency and sustainability, as well as improved production operations and realization of customer value.

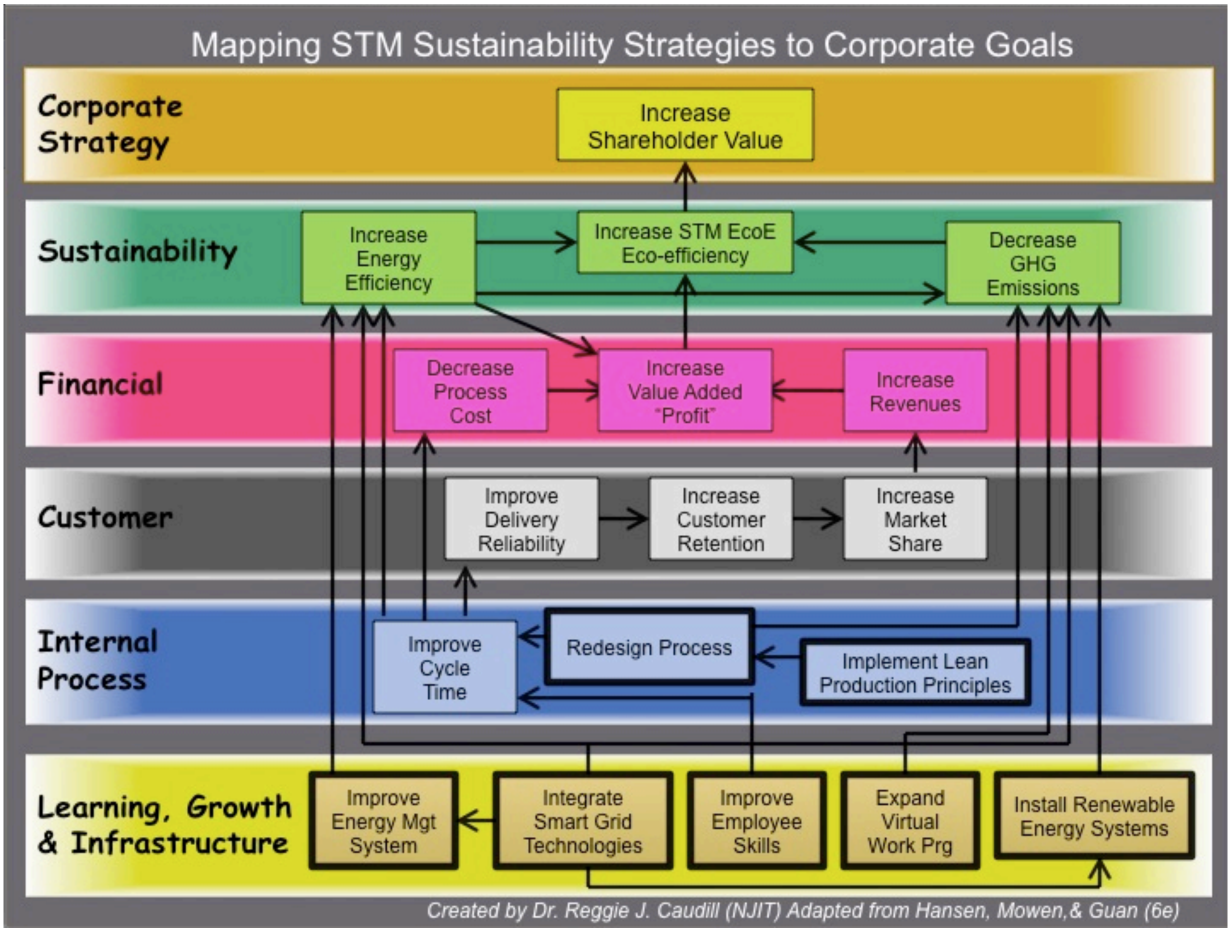
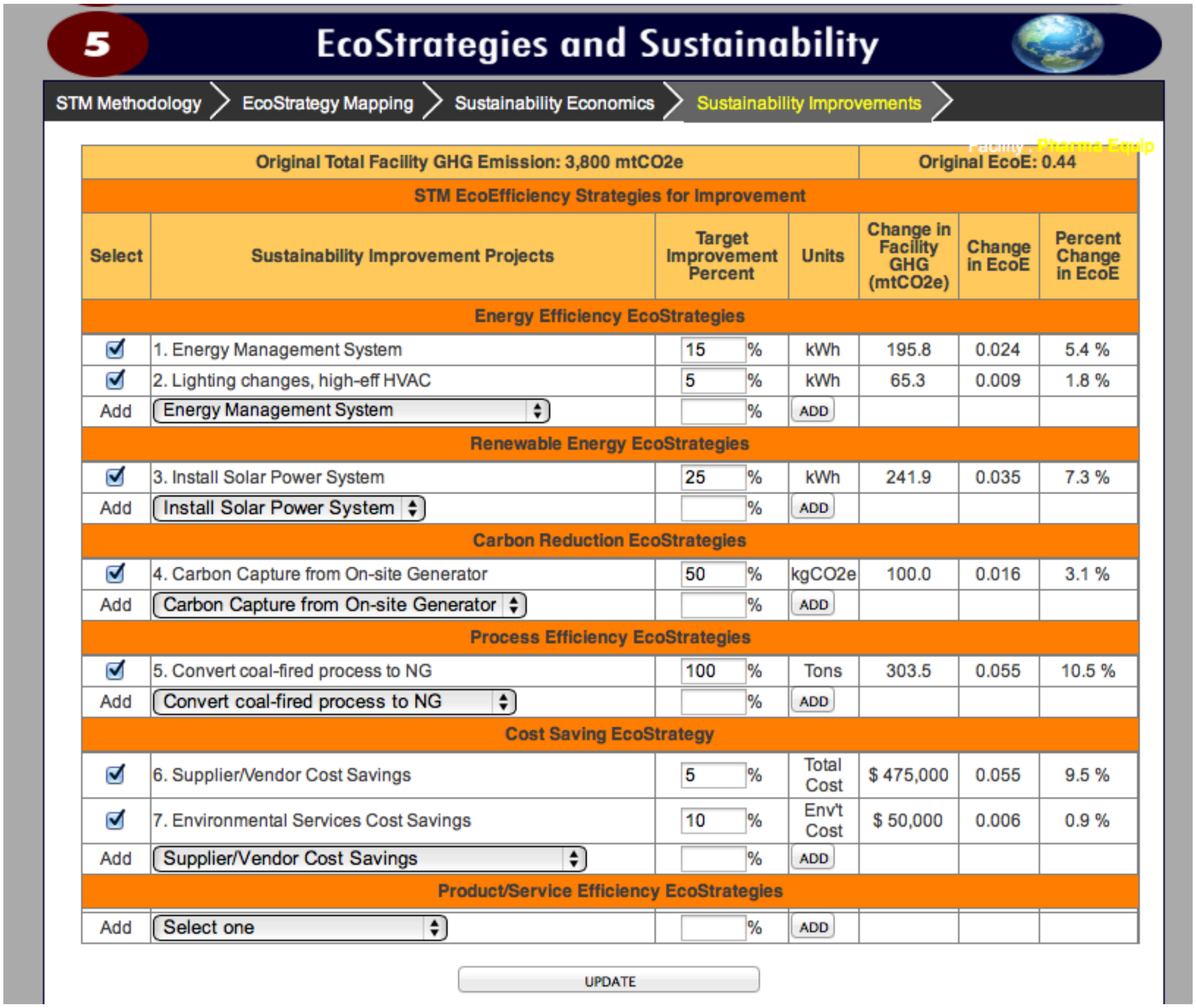


Fig. I.8.2 – STM Corporate Sustainability Map

Sustainability Improvements. As indicated in Section I.7 above, six categories of sustainability strategies or EcoStrategies have been identified: increasing value added (cost savings), improving energy efficiency, implementing renewable energy systems, installing carbon capture technology, improving process operations, and redesigning products or services. Specific improvement strategies can be defined, evaluated and selected for further consideration and comparison, as shown in Fig. I.8.3. Common strategies are shown in dropdown lists and custom strategies can be added. Clicking the checkbox next to each strategy will allow the user to specifically include or exclude that strategy from further consideration—unchecking the box will also allow the user to decide if that strategy is to be deleted entirely.

For those strategies selected for further consideration, NJ-IES will determine the change in STM eco-efficiency (ΔEcoE) that will occur when the strategy is fully implemented. This information is shown in Fig. I.8.4 for each strategy, expressed as a percent of the original EcoE value.



5 EcoStrategies and Sustainability

STM Methodology > EcoStrategy Mapping > Sustainability Economics > Sustainability Improvements

Facility : Pharma Equip

Original Total Facility GHG Emission: 3,800 mtCO2e				Original EcoE: 0.44		
STM EcoEfficiency Strategies for Improvement						
Select	**Sustainability Improvement Projects**	**Target Improvement Percent**	**Units**	**Change in Facility GHG (mtCO2e)**	**Change in EcoE**	**Percent Change in EcoE**
Energy Efficiency EcoStrategies						
☑	1. Energy Management System	15 %	kWh	195.8	0.024	5.4 %
☑	2. Lighting changes, high-eff HVAC	5 %	kWh	65.3	0.009	1.8 %
Add	Energy Management System	%	ADD			
Renewable Energy EcoStrategies						
☑	3. Install Solar Power System	25 %	kWh	241.9	0.035	7.3 %
Add	Install Solar Power System	%	ADD			
Carbon Reduction EcoStrategies						
☑	4. Carbon Capture from On-site Generator	50 %	kgCO2e	100.0	0.016	3.1 %
Add	Carbon Capture from On-site Generator	%	ADD			
Process Efficiency EcoStrategies						
☑	5. Convert coal-fired process to NG	100 %	Tons	303.5	0.055	10.5 %
Add	Convert coal-fired process to NG	%	ADD			
Cost Saving EcoStrategy						
☑	6. Supplier/Vendor Cost Savings	5 %	Total Cost	$ 475,000	0.055	9.5 %
☑	7. Environmental Services Cost Savings	10 %	Env't Cost	$ 50,000	0.006	0.9 %
Add	Supplier/Vendor Cost Savings	%	ADD			
Product/Service Efficiency EcoStrategies						
Add	Select one	%	ADD			

UPDATE

Fig. I.8.3 - Sustainability Improvement Project Specification

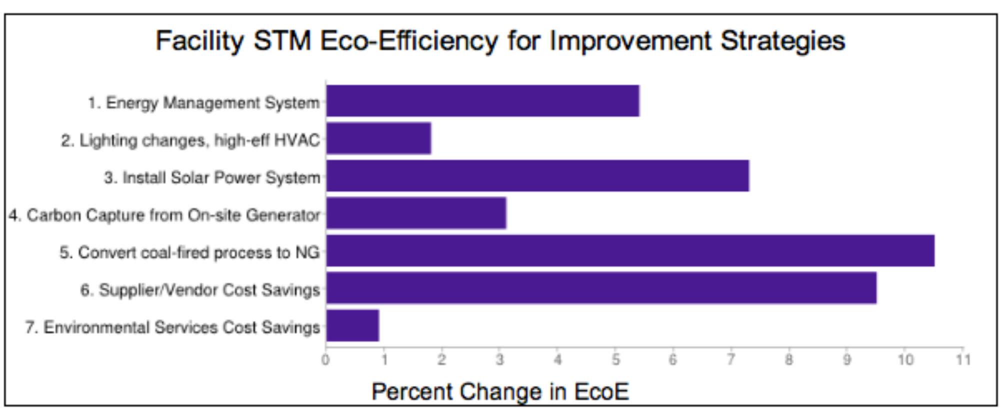


Fig. I.8.4 – STM Eco-Efficiency of Each Improvement Strategy Expressed as the Percent Change in EcoE

Sustainability strategies must not only improve eco-efficiency but must also be economically viable. To determine which strategies are economically viable, the project cost for each strategy must be defined and entered. Using the table shown in Fig. I.8.5, the user enters the estimated project cost for each strategy and updates the window. With the update, the EcoStrategies are divided as to being economically viable (YES) or not (NO) and ordered according to their STM Effectiveness value—ΔEcoE per Dollar of Project Cost. The Project Viability shown in the last column of the table identifies which projects are considered to be economically viable based on the STM Decision Space, discussed previously, and shown below as Fig. I.8.6.

STM Sustainability Economic Analysis and EcoStrategy Viability								
EcoStrategy	Change in Eco-Efficiency		Annual Cost Savings	Reduction in GHG (mtCO2e)	STM Breakeven Project Cost	Estimated Project Cost	STM Effectiveness (Chg EcoE/$)	Project Viability*
	EcoE	%						
6. Supplier/Vendor Cost Savings	0.05	9.5 %	$ 475,000	0	$ 3,958,333	$ 950,000	58	YES
3. Install Solar Power System	0.03	7.3 %	$ 61,875	241.9	$ 3,168,052	$ 620,000	56	YES
7. Environmental Services Cost Savings	0.01	0.9 %	$ 50,000	0	$ 416,667	$ 120,000	48	YES
2. Lighting changes, high-eff HVAC	0.01	1.8 %	$ 12,375	65.3	$ 818,663	$ 250,000	34	YES
1. Energy Management System	0.02	5.4 %	$ 37,125	195.8	$ 2,455,990	$ 1,250,000	19	YES
5. Convert coal-fired process to NG	0.05	10.5 %	$ -60,404	303.5	$ 2,824,647	$ 5,500,000	10	NO
4. Carbon Capture from On-site Generator	0.02	3.1 %	$ 0	100.0	$ 1,096,611	$ 4,000,000	4	NO

***Note:** If Actual Project Cost is less than or equal to the STM Breakeven Project Cost, then Sustainability Project Generates WEALTH for the Company and is Economically Viable.

UPDATE

Fig. I.8.5 – STM Sustainability Economics Analysis and EcoStrategy Viable Table

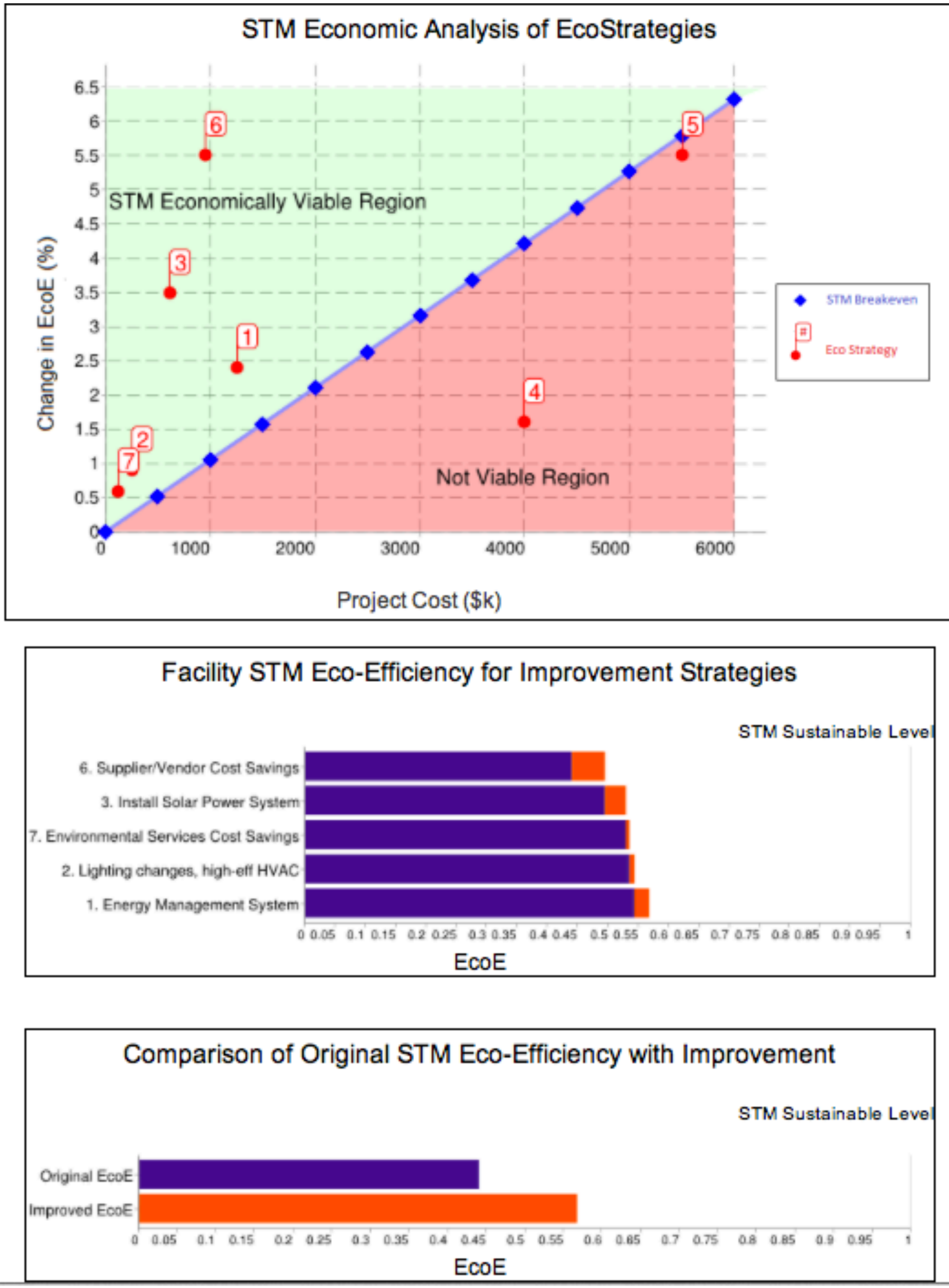


Fig. I.8.6 – STM Decision Space Analysis with EcoStrategies EcoE Improvements Shown Incrementally and Overall Improvement Expected If All Strategies Selected Are Implemented.

Comparison of Original with Improved		
Energy Source	**Original Facility GHG Emissions (mtCO2e)**	**Improved Facility GHG Emissions (mtCO2e)**
Electric Power	1,305	867
Natural Gas	660	1,007
Propane	29	29
Gasoline	223	223
Oil/Diesel Fuel	357	357
Solar Power	0	84
Wind	0	0
Bio-Fuels	0	0
Other Renewable	0	0
Coal	650	0
Wood	0	0
Other On-site GHG Generator	200	200
Total Employee Commuting	376	376
Total Facility GHG Emissions	**3,800**	**3,143**

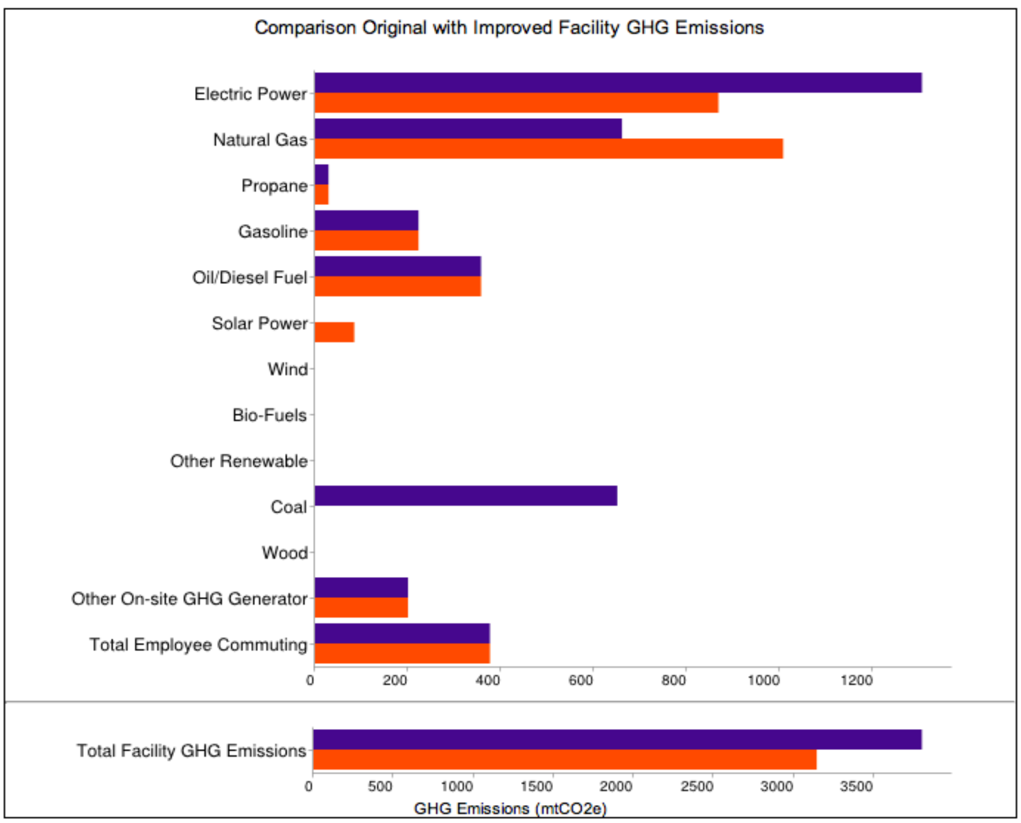


Fig. I.8.7 – Summary of GHG Emissions by Source for Original and Improved Facility

Decision Support System (DSS). As described above, the user identified several possible sustainability improvements projects for consideration and evaluation. Each project has an accompanying set of costs, benefits and constraints. As the set of projects increase then it becomes challenging to select the best of projects to meet the sustainability goals. The objective of the NJ-IES Decision Support (DSS) module is to help the users select from the list of identified projects the set of best projects which meet the defined sustainability objectives and satisfy all constraints. Note: if no projects are listed in the sustainability improvements section then the DSS cannot be executed. The DSS is organized into four sequential steps:

Step 1: Sustainability Project Constraints **-** The user defines in quantitative terms the constraints within which it wants to implement the sustainability projects. Specifically, three constraints are to be entered:

- *C1 - Budget Limit* – Total funds available for implementation of all sustainability projects during the time horizon, expressed in dollars.
- *C2 - Risk Threshold* - Threshold level of the user organization for project failure due to either time to realize project benefits, complexity of project implementation and/or budget overruns. Risk is defined in a 1 to 10 scale. A level of 1 indicates the highest level of risk averseness, implying the organization expects projects will be completed definitely on time and on budget. Conversely a score of 10 indicates the highest level of risk, implying the company si willing to take on significant risk if the benefits are rewarding.
- *C3 - Time Horizon* - Planning horizon for successful implementation of all sustainability projects. By the end of the planning horizon it is anticipated all projects benefits are being realized and there are no additional project implementation expenses. Expressed in months.

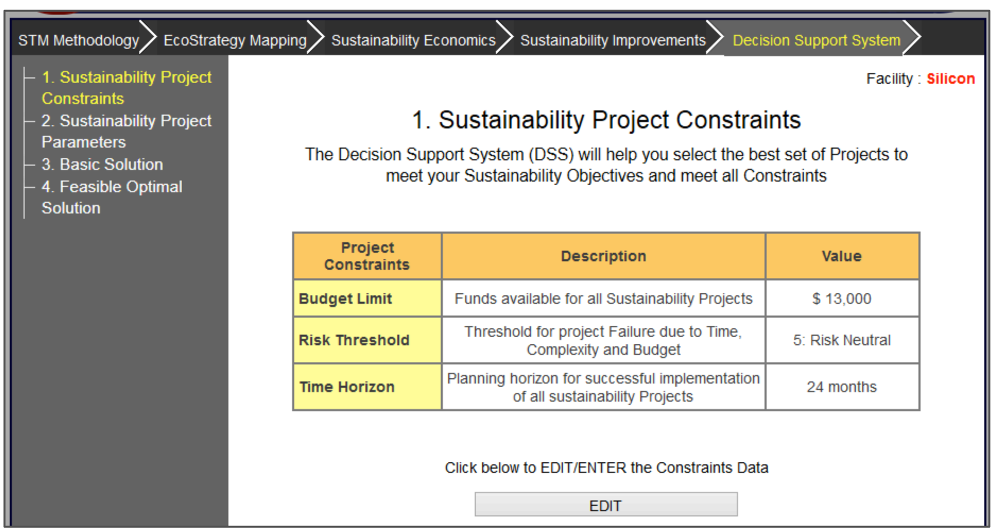
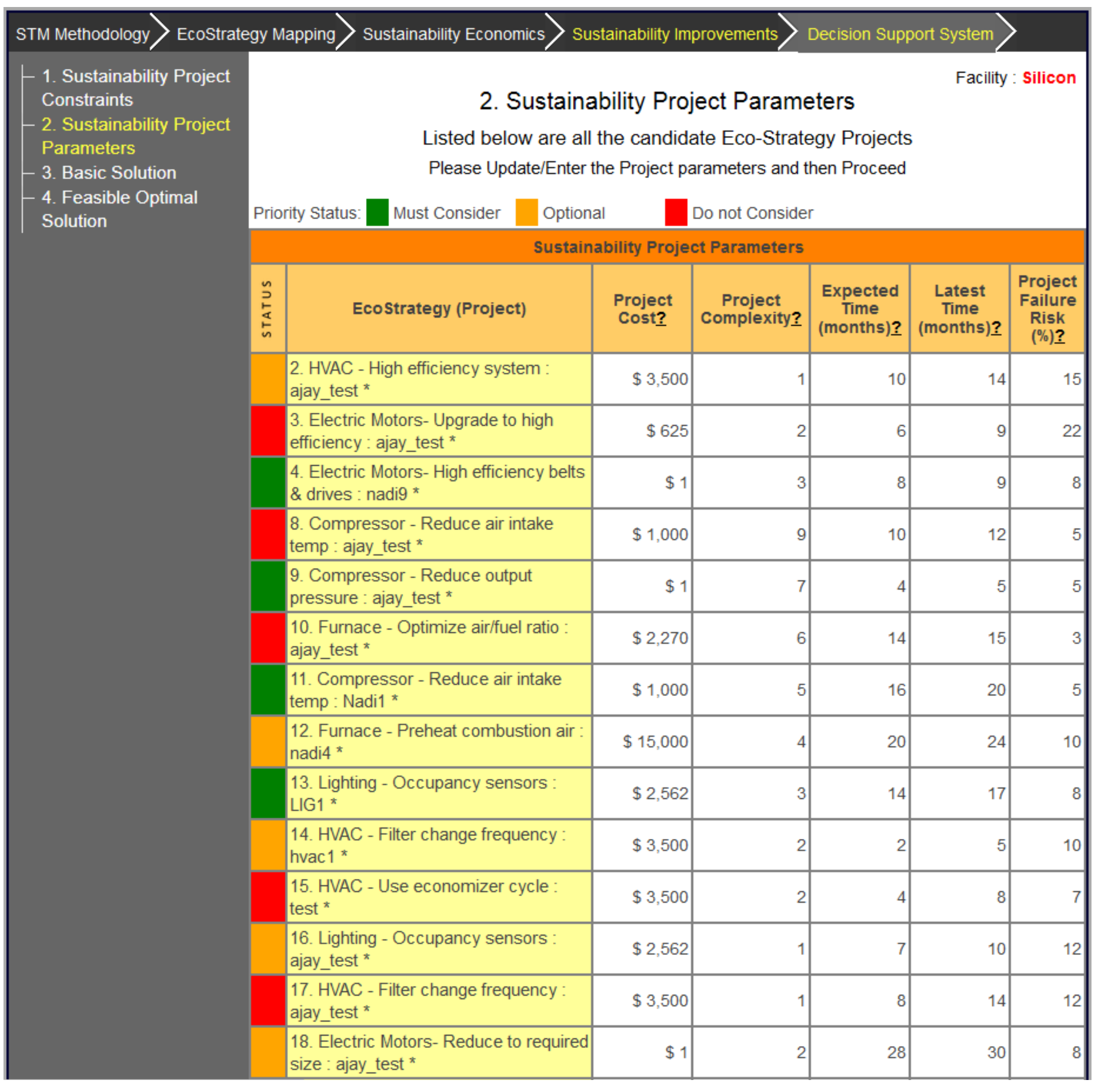


Fig. I.8.8. Web Interface for Entering project Constraints

Step 2: Sustainability Project Parameters – For each of the candidate eco-strategy projects the user must identify several implementation parameters, each of which are critical to the selection process. Specifically the following five parameters need to be entered, the subscript *i* denotes the *i th* project in the set:

P1(i) – Project Cost: Total implementation cost of the project in dollars. While at times it may not be possible to accurately estimate the cost, we assume that this is a 90% confidence estimate.
P2(i) - Project Complexity: Complexity, skills and knowledge required for a successful completion of the project Measured in a scale of 1 to 10, with a level of 1 being the easiest and 10 being the most difficult.
P3(i) – Expected Project Duration: This is the likely time to complete the project expressed in months.
P4(i) – Latest Project Duration: 90% confidence time for project completion. A classical two parameter distribution is used to describe project duration, that is the expected and latest times.
P5(i) - Project Failure Risk: The probability (expressed in percentage) that the project will fail to meet the target sustainability benefits. The risk is expressed in the 0-20% range, we assume that projects with risk in excess of 20% should not be considered.

The DSS initially assumes that all listed sustainability projects are candidates for implementation. As part of step-2 the user can label each project as either (i) Must implement (ii) Option to select, or (iii) Do not implement. It is important to note that there must be a sufficient of optional projects for the DSS to run effectively.



STATUS	EcoStrategy (Project)	Project Cost?	Project Complexity?	Expected Time (months)?	Latest Time (months)?	Project Failure Risk (%)?
Optional	2. HVAC - High efficiency system : ajay_test *	$ 3,500	1	10	14	15
Do not Consider	3. Electric Motors- Upgrade to high efficiency : ajay_test *	$ 625	2	6	9	22
Must Consider	4. Electric Motors- High efficiency belts & drives : nadi9 *	$ 1	3	8	9	8
Do not Consider	8. Compressor - Reduce air intake temp : ajay_test *	$ 1,000	9	10	12	5
Must Consider	9. Compressor - Reduce output pressure : ajay_test *	$ 1	7	4	5	5
Do not Consider	10. Furnace - Optimize air/fuel ratio : ajay_test *	$ 2,270	6	14	15	3
Must Consider	11. Compressor - Reduce air intake temp : Nadi1 *	$ 1,000	5	16	20	5
Optional	12. Furnace - Preheat combustion air : nadi4 *	$ 15,000	4	20	24	10
Must Consider	13. Lighting - Occupancy sensors : LIG1 *	$ 2,562	3	14	17	8
Optional	14. HVAC - Filter change frequency : hvac1 *	$ 3,500	2	2	5	10
Do not Consider	15. HVAC - Use economizer cycle : test *	$ 3,500	2	4	8	7
Optional	16. Lighting - Occupancy sensors : ajay_test *	$ 2,562	1	7	10	12
Do not Consider	17. HVAC - Filter change frequency : ajay_test *	$ 3,500	1	8	14	12
Optional	18. Electric Motors- Reduce to required size : ajay_test *	$ 1	2	28	30	8

Fig.I.8.9 - Project List with Parameters and Implementation Label

Step 3: Run Analysis to Derive Basic Implementation Solution – Each project is first evaluated individually against the following two constraints.

- *Time Constraint:* Whether the projected time to finish the project falls within the planning time horizon for successful implementation of all sustainability projects. Result is PASS/FAIL. Projected time T(i) is calculated as follows:

$$T(i) = P3(i) + \{P4(i)-P3(i)\}/3$$
$$\text{If } T(i) \leq C3 \text{ then PASS}$$

- *Risk Constraint:* Evaluates whether the project risk value is less than the organization's risk threshold for project failure due to time, complexity and budget. Result is PASS/FAIL. For each project the risk value R(i) is calculated using the following function

$$R(i) = \{P1(i)*P2(i)*P5(i)\}/\{20*C1\}$$
$$\text{If } R(i) \leq 0.2*C2 \text{ then PASS}$$

In the second part of this step the set of all projects (excluding the do not consider projects) are evaluated in combination for the following two constraints:

- *Risk Value Constraint:* Total risk for all projects is less than the threshold. That is:

$$\text{If } \textstyle\sum_i R(i) \leq 0.9*C2 \text{ then PASS}$$

- *Budget Constraint:* Total cost of implemented projects is less than available funds less safety factor. That is:

$$\text{If } \textstyle\sum_i P1(i) \leq 0.9*C1 \text{ then PASS}$$

If all projects get a PASS rating for both the time constraint and risk constraint, and the set of all project PASS the risk value and budget constraints, then the basic solution is feasible and optimal. The basic solution should then be implemented and he next step is not needed.

Step 4: Derive feasible and Optimal List of Sustainability Projects – If step 3 does not generate a feasible solution then it is necessary to select a feasible list of projects which optimizes the sustainability goals. This step is formulated as a linear program the decision variable being whether a project is implemented or not. The program is defined by the following components:

- *DSS Objective Function* – Maximize the positive change in Eco-Efficiency as a result of the implemented projects. For each project the projected greenhouse reduction and any associated value change were previously recorded in the sustainability improvements section. This same data is used to calculate the objective function.

- *DSS Constraints* – All four constraints introduced above in Step 4 are activated in the DSS linear program. Only selected projects are modeled in the constraint.

The linear program is solved using a total enumeration procedure with run times of less than 1 second. Results are displayed and all sustainability performance metrics recalculated.

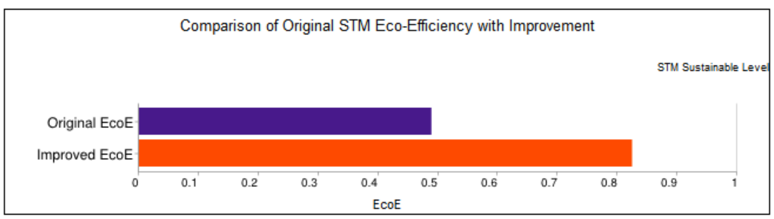
Facility : **Silicon**

4. Feasible and Optimal Sustainability Projects

Implementation solution is shown below

Decision Support System BEST Solution (Feasible Set)							
STATUS	EcoStrategy (Project)	Risk Value ?	Budget Component ?	Annual Cost Savings ?	Annual GHG Reduction (mtCO2e) ?	Change in EcoE ?	STM Effectiveness (Chg EcoE/$) ?
	7. Compressor - Reduce output pressure : ajay_test *	0.00	$ 1	$ 9,219	121.5	0.1121	154,955,483
	3. Electric Motors- High efficiency belts & drives : nadi9 *	0.00	$ 1	$ 1,236	0.0	0.0006	26,490,878
	8. Compressor - Reduce air intake temp : Nadi1 *	0.10	$ 1,000	$ 11,997	92.8	0.0842	287,977
	10. Lighting - Occupancy sensors : LIG1 *	0.24	$ 2,562	$ 30,400	0.0	0.0149	129,784
	11. HVAC - Filter change frequency : hvac1 *	0.27	$ 3,500	$ 50,000	0.0	0.0246	105,608
	2. HVAC - High efficiency system : ajay_test *	0.20	$ 3,500	$ 50,000	0.0	0.0246	7,395
	Total Risk Constraint	0.80 PASS					
	Total Budget Contraint		$ 10,564 PASS				

Fig. I.8.10 - Optimal Sustainability Project Solution



Total Summary		
Eco-efficiency Metrics	Original	Improved
STM Eco-Efficiency (EcoE) = (VP/VPS):	0.49	0.82
Carbon Footprint = Total GHG (kg CO2e):	678,574	464,267
Value Added ($):	$ 994,999	$ 1,147,851
Value Productivity (VP) ($/kgCO2e):	1.47	2.47
Value Productivity for Sustainability (VPS) ($/kgCO2e):	3.00	3.00

Fig. I.8.11 - Updated Sustainability Performance Metrics

References

1. J.A. Mosovsky, D.A. Dickinson and J.M. Morabito, "Creating Competitive Advantage Through Resource Productivity, Eco-Efficiency, and Sustainability in the Supply Chain", Proceedings of the IEEE International Symposium on Electronics and the Environment (ISEE), IEEE, May 2000, San Francisco CA.

2. J. Mosovsky, J. Dispenza, D. Dickinson, J. Morabito, R. Caudill, and N. Alli, "Assessing Product Design Alternatives with Respect to Environmental Performance and Sustainability: A Case Study for Circuit Pack Faceplates", Proceedings of the International Symposium on Electronics and the Environment (ISEE), IEEE, May 2001, Denver CO.

3. D.A. Dickinson, J.A. Mosovsky, R.J. Caudill, D.J. Watts, and J.M. Morabito, "Application of the Sustainability Target Method: Supply Line Case Studies", Proceedings of the International Symposium on Electronics and the Environment (ISEE), IEEE, May 2002, San Francisco CA.

4. C. Yossapol, L. Axe, R. Caudill, D. Watts, D. Dickinson, and J. Mosovsky, "Carrying Capacity Estimates for Assessing Environmental Performance and Sustainability", Proceedings of the International Symposium on Electronics and the Environment (ISEE), IEEE, May 2002, San Francisco CA.

5. T.E. Swarr, D.A. Dickinson, H.J. Cline, S. Jeong, and R.J. Caudill, "Evaluating Supply Line Sustainability and Business Environmental Risk", Proceedings of the International Symposium on Electronics and the Environment (ISEE), IEEE, May 2004, Scottsdale AZ.

6. D.A. Dickinson, "Business Value and Environmental Sustainability: Growing Sustainable Businesses" (Summary and Worksheets for applying the Sustainability Target Method), Partnership for Sustainable Business, January 2009.

7. Caudill, R.J; Olapiriyakul, S.; Seale, B., "An Exergy Footprint Metric Normalized to US Exergy Consumption per Capita", Proceeding of the 2010 IEEE International Symposium on Sustainable Systems and Technologies, Washington, D.C., May, 2010.

8. Ayres, R.U., Mass, Exergy, Efficiency in the US Economy, IIASA Interim Report IR-05-034 , International Institute for Applied Systems Analysis, July, 2005.

9. Bakshi, B.R.; Ukidwe, N.U. "The role of thermodynamics in life cycle assessment of existing and emerging technologies," IEEE International Symposium on Electronics and the Environment. 2006,15-20.

10. Ukidwe, N.U., Bakshi, B.R., "Industrial and ecological cumulative exergy consumption of the United States via the 1997 input-output benchmark model", Energy, 32, 2007, 1560-1592.

11. Olapiriyakul, S. and Caudill, R.J., "Thermodynamic Analysis to Assess the Environmental Impact of End-of-life Recovery Processing for Nanotechnology Products," Environ, Sci. Technol. 2009, 43, 8140-8146.

12. DeMeester, B., Dewulf, J. Janssens, A, and Van Langenhove, H., "An Improved Calculation of the Exergy of Natural Resources for Exergetic Life Cycle Assessment (ELCA)," Environ, Sci. Technol. 2006, Vol 40.

13. Wall, G., "Exergetics", Bucaramanga 2009.

14. Bosch, M.E., Hellweg, S., Huijbregts, M.A.J., Frischknecht, R., "Applying Cumulative Exergy Demand (CExD) indicators to the ecoinvent database," International Journal of Life Cycle Assessment 12 (3), pp. 181-190, 2007.

15. Reistad, G.M., "Available energy conversion and utilization in the United States," Journal of Engineering for Power ASME 97 Ser A (3), pp. 429-434, 1975.

16. Ertesvag, I.S., Mielnik, M., "Exergy analysis of the Norwegian society," Energy 25 (10), pp. 957-973, 2000.

17. Ertesvag, I.S., "Society exergy analysis: a comparison of different societies," Energy 26, pp. 253-270, 2001.

18. Hermann, W.A., "Quantifying global exergy resources", Energy, 2005.

19. Ibrahim Dincer and Marc A. Rosen, 2007, EXERGY, Energy, Environment and Sustainable Development, Elsevier.

20. Chemical Bandwidth Study, conducted for the U.S. Department of Energy by JVP International, Incorporated and Psage Research, LLC. 2006.

21. R. Rivero, M. Garfias, "Standard chemical exergy of elements updated", Energy 31 (2006) 3310–3326.

22. Mei Gong, "Exergy analysis of a pulp and paper mill", Int. J. Energy Res. 2005; 29:79–93.

23. Peter Michaelis, Tim Jackson and Roland Clift, "Exergy Analysis of the Life Cycle of Steel", Energy Vol. 23, No. 3, pp. 213–220, 1998.

24. Hüseyin Benli, "Experimentally derived efficiency and exergy analysis of a new solar air heater having different surface shapes", Renewable Energy, 50 (2013), 58-67.

25. Kotas, T.J., 1995. The Exergy Method of Thermal Plant Analysis. Butterwood. London.

26. Szargut, J, D.R. Morris and F.R. Steward. 1988. Exergy Analysis of thermal, chemical and metallurgical process. Hemisphere Pub. Corp.

27. Dewulf J, Bösch ME, De Meester B, Van der Vorst G, Van Langenhove H, Hellweg S, Huijbregts MA, "Cumulative exergy extraction from the natural environment (CEENE): a comprehensive life cycle impact assessment method for resource accounting", Environ Sci Technol. 2007 Dec 15;41(24):8477-83.

28. Stanford University: Global Climate and Energy Project (GCEP) - Exergy and Carbon Data Explorer [http://www.energynavigator.org]

29. Christopher Koroneos, Dimitris Dimou, Nikos Andrinopoulos, Nicolas Moussiopoulos, "Application of life cycle assessment and exergy analysis in a combined cycle power plant using natural gas at Lavrion, Greece", International Journal of Power and Energy Conversion, 2011 - Vol. 2, No.4 pp. 365 – 386.

30. Matthew Branham, Timothy G. Gutowski, Alissa Jones, and Dusan P. Sekulic, "A Thermodynamic Framework for Analyzing and Improving Manufacturing Processes," IEEE International Symposium on Electronics and the Environment, May 19-22, 2008, San Francisco, CA.

31. Adam P. Simpson, Chris F. Edwards, "An exergy-based framework for evaluating environmental impact," Energy 36, 2011, pp. 1442-1459. [http://dx.doi.org/10.1016/j.energy.2011.01.025]

32. Timothy G. Gutowski, Matthew S. Branham, Jeffrey B. Dahmus, Alissa J. Jones, Alexandre Thiriez, and Dusan P. Sekulic, "Thermodynamic Analysis of Resources Used in Manufacturing Processes," Environ. Sci. Technol., 2009, 43 (5), 1584-1590.

33. Yoshihiko Soeno, Hiromitsu Ino, Kiiti Siratori, and Kohmei Halada, "Exergy Analysis to Evaluate Integrated Environmental Impacts," Materials Transactions, Vol. 44, No. 7 (2003) pp. 1244- 1250.

34. M. A. Dittrich, T. G. Gutowski, J. Cao, J. T. Roth, Z. C. Xia, V. Kiridena, F. Ren, and H. Henning, "Exergy analysis of incremental sheet forming," Prod. Eng. Res. Devel. (2012) 6:169–177.

35. R. Rivero, and M. Garfias, "Standard chemical exergy of elements updated," Energy 31 (2006), 3310–3326.

36.] Weston A. Hermann, "Quantifying global exergy resources," Energy 31 (2006) 1685–1702.

37. Peter Michaelis, Tim Jackson, and Roland Clift, "Exergy Analysis of the Life Cycle of Steel," Energy 23(3), 1998, 213–220.

38. Karina Ojeda, Eduardo Sánchez, and Viatcheslav Kafarov, "Sustainable ethanol production from lignocellulosic biomass – Application of exergy analysis," Energy 36 (2011) 2119–2128.

39. J . Dewulf, H . Vanlangenhove, and B . Vandevelde, "Exergy-Based Efficiency and Renewability Assessment of Biofuel Production," Environ. Sci. Technol. 2005, 39, 3878-3882.

40. Viet-Ngu Hoang, and D.S. Prasada Rao, "Measuring and decomposing sustainable efficiency in agricultural production: Acumulative exergy balance approach," Ecological Economics 69 (2010) 1765-1776.