**SRCA Module - Case Study 1, Solution**

**Root cause analysis of the steam methane reforming process**

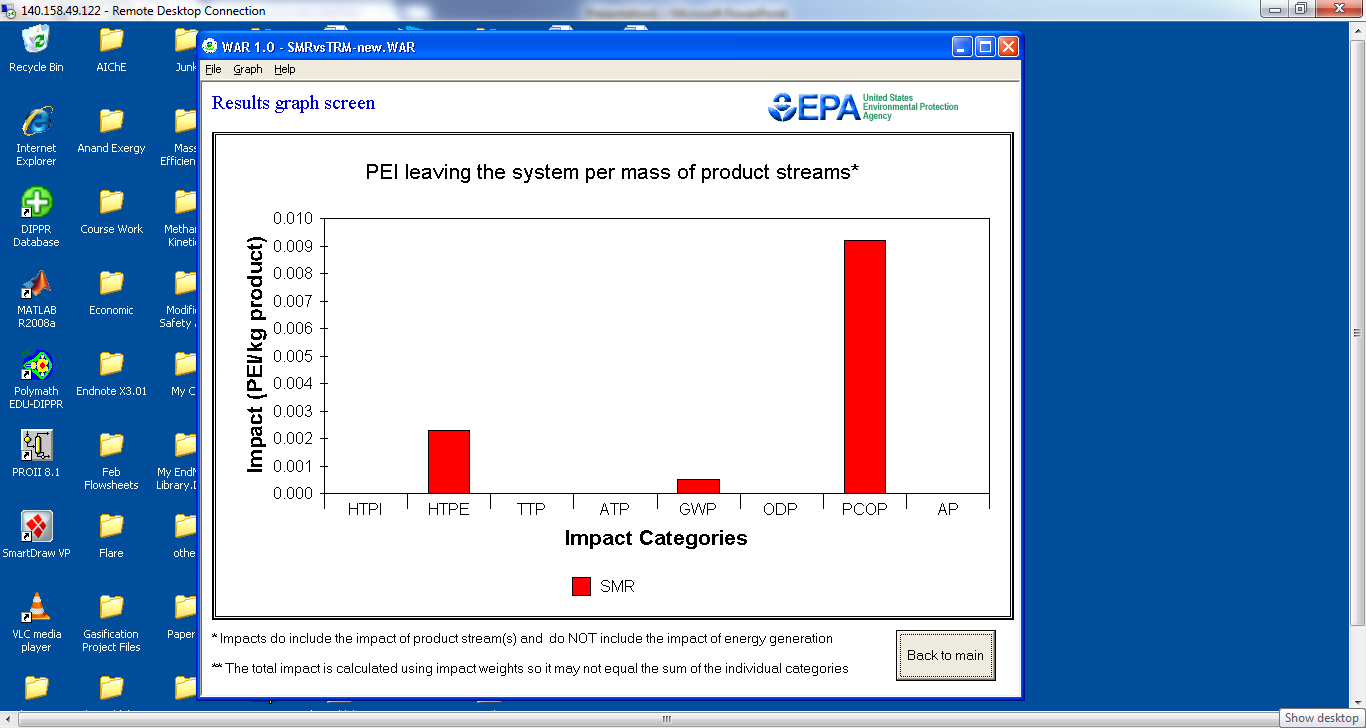
**(a) Economic Evaluation**

|  |  |  |  |
| --- | --- | --- | --- |
| Raw Material Costs | | | |
| Raw Material | **Price** | **Cost ($/hr)** | |
| Natural Gas | $3.5/MMBtu ($35.28/ton) | $1054.87 | |
| Water | 0.46/m3 ($0.46/ton) | $19.73 | |
| Utility Costs | | | |
| Utility | **Price** | **Usage** | **Cost ($/hr)** |
| Heating | $3.5/MMBtu | 169 MMBtu/h | $591.5 |
| Electricity | $0.067/kWh | 31518 kWh | $2111.71 |

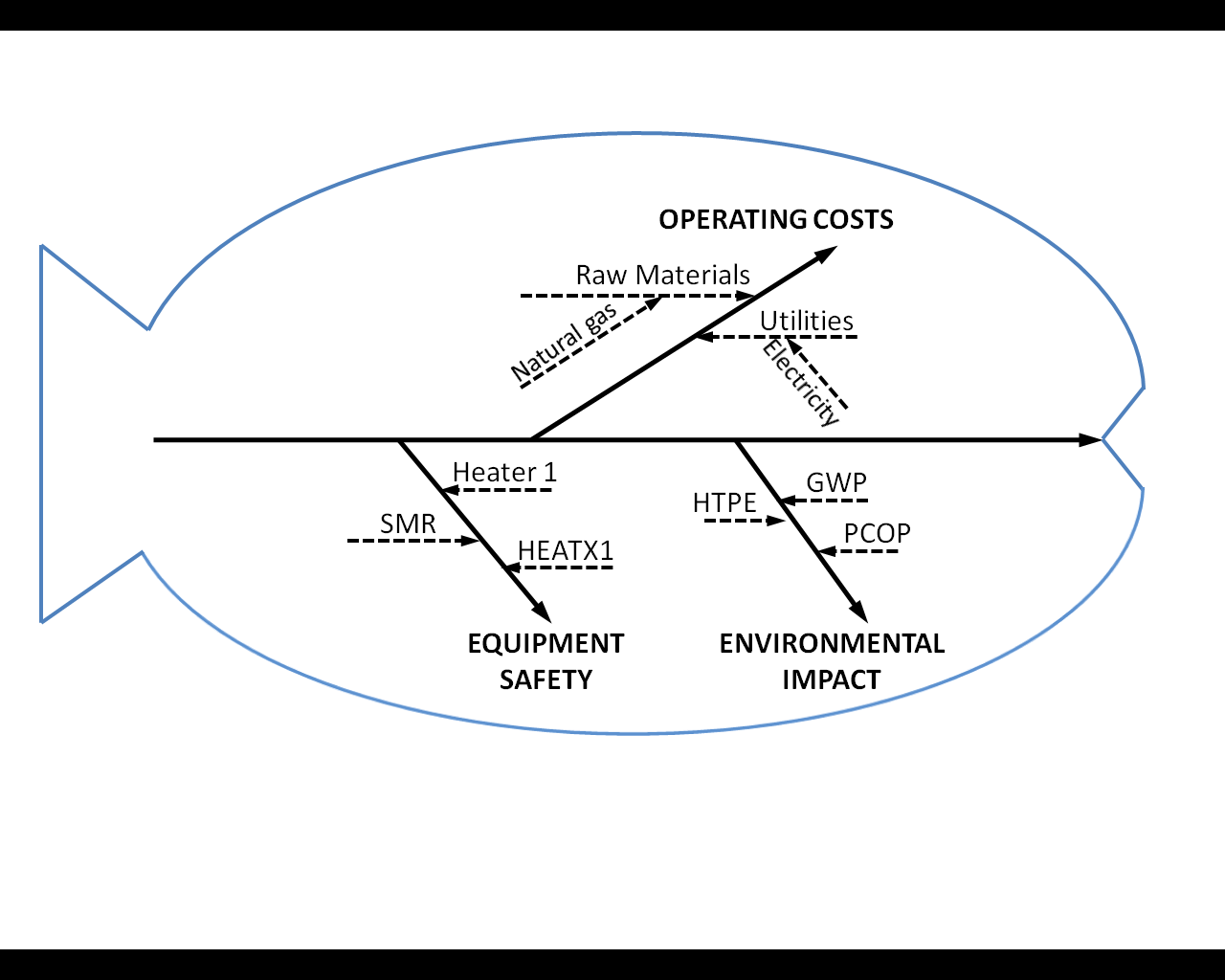
**(b) Safety Evaluation Results:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Equipment | Inventory | Process Temperature | Process Pressure | Equipment Safety | Process Inherent Index, IPI |
| HEATER1 | 3 | 4 | 0 | 1 | 8 |
| SMR | 3 | 4 | 0 | 2 | 9 |
| HEATX1 | 3 | 4 | 0 | 1 | 8 |
| COOLER1 | 3 | 4 | 0 | 1 | 8 |
| FLASH | 3 | 0 | 0 | 1 | 4 |
| Process Inherent Index, IPI |  |  |  |  | **37** |

**(c) Environmental Evaluation: WAR Algorithm Results**

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* Impacts on HTPE, GWP and PCOP are observed.
* The contributing chemicals are mainly methane, CO and CO2
* Methane can be controlled by improving the conversion rate. CO is a part of the product and therefore necessary. CO2 can be separated from the product syngas using a membrane or other methods if needed (depending on the end use of syngas)

**(d) Fish-bone diagram:** 

Suggested process modifications to improve sustainability performance:

* Reduce electricity consumption by utilizing heat for steam production, preheating etc., in other parts of the plant to reduce the load on COOLER1.
* To reduce natural gas consumption and environmental impact, steam methane reforming can be coupled with other processes like dry reforming that require less methane to produce an equivalent quantity of syngas.
* Recycling of CO2 can also be considered, which could then be used in dry reforming.

**SRCA Module - Case Study 2, Solution**

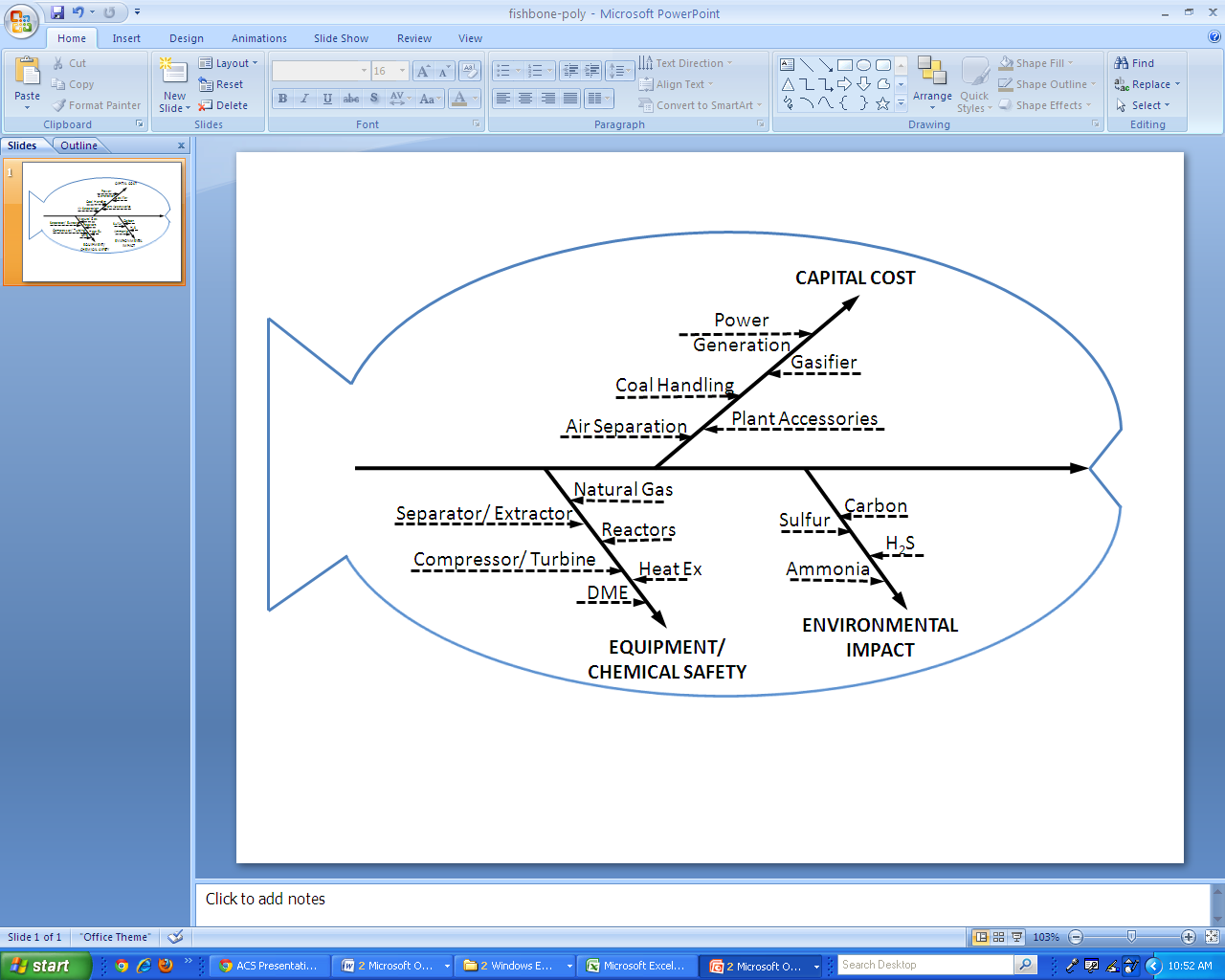
Capital Costs:

|  |  |  |  |
| --- | --- | --- | --- |
| Unit | Cost | Percentage Effect on Safety | Cumulative Percentage |
| Power Generation | $179,519,000 | 20.64161888 | 20.64161888 |
| Gasifier Section | $172,468,680 | 19.8309525 | 40.47257139 |
| Air Separation Unit | $131,525,000 | 15.1231286 | 55.59569999 |
| Plant Accessories | $114,871,550 | 13.20826629 | 68.80396628 |
| Coal Handling | $74,657,240 | 8.584307483 | 77.38827376 |
| Gas Cleaning | $65,350,840 | 7.514230433 | 84.90250419 |
| Water Systems | $59,069,820 | 6.79202041 | 91.6945246 |
| DME Synthesis | $57,194,083 | 6.576342692 | 98.2708673 |
| NG Reforming | $10,455,100 | 1.202157931 | 99.47302523 |
| CO2 Compression | $4,487,070 | 0.515936413 | 99.98896164 |
| Solvents and Catalysts | $96,000 | 0.01103836 | 100 |

Inherent Safety Analysis:

Environmental Analysis:

The fish-bone diagram:



The major causes in each category are:

|  |  |
| --- | --- |
| Economic:  Capital Cost | * Power Generation * Gasifier * Air Separation * Plant Accessories * Coal Handling |
| Safety:  Equipment and Chemicals | * Heat Exchanger * DME * Compressor/Turbine * Reactor * Separator/ Extractor * Natural Gas |
| Environmental:  Chemicals | * Carbon * H2S * Sulfur * Ammonia |

Coal is cheaper on a per MMBtu basis. Currently, the price of coal is $2.28 per MMBtu, compared to $3.5 per MMBtu for natural gas. Natural gas is cleaner than coal. Natural gas reforming is the cleaner process, since most of the carbon release occurs in coal gasification.

**SRCA Module - Case Study 3, Solution**

**(a): Inherent Safety Analysis**

1.Inherent Safety Analysis for Natural Gas Liquefaction

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Chemical Inherent Index, ICI | | | | | |
| Chemical | **Index** | | | | **Chemical Inherent Index**  **ICI** |
| **Flammability IFL** | **Explosiveness IEX** | **Toxic Limit ITOX** | **Corrosiveness ICOR** |
| Natural Gas | 140.56 | 35.14 | 0.00 | 70.28 | 245.98 |
| Water | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| DEA | 12.00 | 12.00 | 60.00 | 0.00 | 84.00 |
| Hydrogen Sulfide | 0.00 | 0.68 | 1.37 | 0.68 | 2.74 |
| Carbon dioxide | 0.00 | 0.00 | 1.19 | 0.00 | 1.19 |
| Chemical Inherent Index, ICI | **152.56** | **47.83** | **62.56** | **70.96** | **333.91** |
| Process Inherent Index, IPI | | | | | |
| Equipment | **Index** | | | | **Process Inherent Index**  **IPI** |
| **Inventory**  **II** | **Process Temperature IT** | **Process Pressure**  **IP** | **Equipment Safety**  **IEQ** |
| Pump | 0 | 0 | 0 | 0 | 0 |
| Heat Exchanger | 4 | 2 | 6 | 2 | 14 |
| Distillation Column | 7 | 2 | 9 | 3 | 21 |
| Compressor/Turbine | 2 | 1 | 3 | 3 | 9 |
| Process Inherent Index, IPI | **13** | **5** | **18** | **8** | **44** |
| TOTAL INHERENT SAFETY INDEX, ITI | | | | | **377.9** |

The result of the pareto analysis on safety is shown below:

|  |  |  |  |
| --- | --- | --- | --- |
| NATURAL GAS LIQUEFACTION | | | |
| Distillation Column | 21(47.7%) | Natural Gas | 245.98 (73.67%) |
| Heat Exchanger | 14 (31.8%) | DEA | 84.00 (25.16%) |
| Compressor/Turbine | 9 (20.5%) | Hydrogen Sulfide | 2.74 (0.82%) |
| Pump | 0 (0%) | Carbon Dioxide | 1.19 (0.35%) |

From the tables, it is obvious that the main contributors in the liquefaction case are the distillation columns and heat exchangers. Focusing on these would be the most effective means of alleviating the safety concern.

(Note: Since the chemicals in the system cannot be eliminated or substituted, only the equipment is considered.)

**(b) Energy Efficiency:**

Natural Gas Liquefaction: 85.89 %

The efficiency of the processes can be improved by focusing attention on the major contributors. In the case of Natural Gas Liquefaction,

|  |  |  |  |
| --- | --- | --- | --- |
| Equipment | Enthalpy | % Effect on Efficiency | Cumulative Percentage |
| CHILLER | 4689.92 | 68.67 % | 68.67 % |
| HX1 | 2032.1 | 29.76 % | 98.43 % |
| COMP1 | 107.63 | 1.57 % | 100 % |

The main contributor is the CHILLER, followed by the heat exchanger HX1.