# Process Mapping of Chemical Sector for CST Intervention

*UNDP GEF CSH Project*

*Ministry of New & Renewable Energy*

*Government of India*

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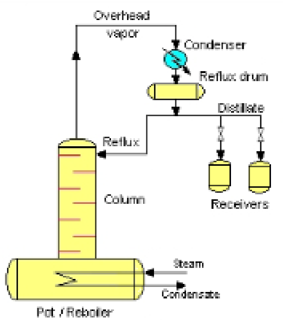
# Introduction

With a share of more than 30% of the total industrial energy use worldwide (including feed-stocks), the chemical and petrochemical sector is by far the largest energy user in industry. The sector is faced with the challenge of saving energy primarily for economic and environmental reasons. The chemical sector contributes significantly to the Indian economy. The size of the Indian chemical industry is estimated at $30 billion. The production volumes in the chemical industry have positioned India as the third–largest producer in Asia next to China and Japan, and the 12th largest in the world. The industry, comprising both small and large scale units (including MNCs) produces several ranges of products and by-products, ranging from plastics and petrochemicals to cosmetics and toiletries. The chemical industry accounts for about 13% in the manufacturing output, 5% in the total exports of the country, and contributes about 20% in the national revenue through various taxes and duties. According to a sector study conducted on the Indian chemical industry by Export-Import Bank of India (EXIM Bank) between the years 2005 and 2006, the total annual production of basic chemicals and petrochemicals stood at 16 million metric tonnes and petrochemical intermediaries stood at 10 million metric tonnes. The following sections of the document make an effort to estimate the energy requirement of actual processes in sample units where information was gathered by way of structured questionnaires and walk through audits. Selection of concentrating technologies and their indicative techno-economic feasibility is done in order to assist the industry in making an informed choice of concentrating technology based on their understanding as a result of this document.

# 1 Processes in chemical industry

The processes identified in the chemical industry were done on a sample basis and their energy requirements were mapped to assess the potential of solar thermal interventions. These data were in turn utilised to arrive at techno-economic feasibility as has been highlighted in the subsequent sections.

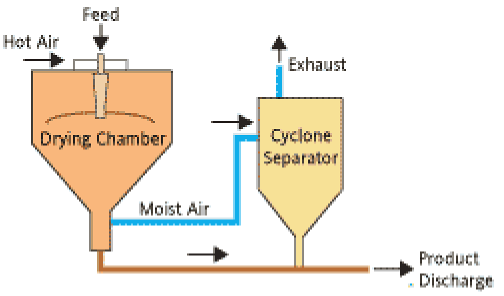
## 1.1. Reflux




Any typical chemical manufacturing process involves mixing of reaction chemicals via the distillation process. In this process the component substances from liquid mixtures are separated by selective vaporization and condensation. Many organic reactions are quite slow and need heating to achieve a reasonable reaction rate. However, most organic chemicals are quite volatile, and if heated they will evaporate and be lost. The solution to this problem is to heat the reaction mixture under reflux. The key advantage of this technique is that reaction components are not lost even in case of vigorous heating. Reflux which is a distillation technique is very widely used in industries such as chemical, petroleum etc. In this process a liquid reaction mixture is placed in a vessel open only at the top, such that any vapours given off are cooled back to liquid, and fall back into the reaction vessel. The vessel is then heated vigorously for the entire duration of the reaction. The purpose is to thermally accelerate the reaction by conducting it at an elevated temperature (i.e. the solvent's boiling point). After the reaction of components at high temperature the condensation also happens at very high temperature. Post the condensation the layer separation is undertaken where the solvent is distilled to get the final product.

## 1.2. Spray Drying

Spray drying is the most widely used industrial process for particle formation and drying. As the name suggests it is a process which assists in drying using a spray. A spray dryer mixes a heated gas with an atomized (sprayed) liquid stream within a vessel (drying chamber) to accomplish evaporation and produce a free flowing

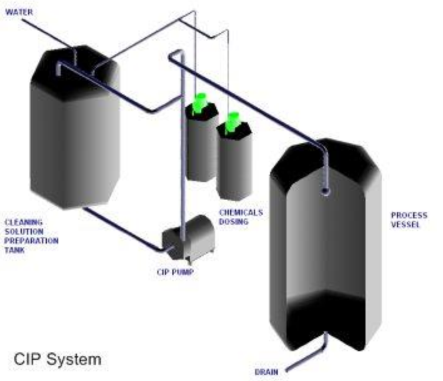



dry powder with a controlled average particle size. The unit operation of spray drying includes the following key components:

- A method for atomizing a solution or slurry
- An air/gas heater or a source of hot air such as a waste flue gas
- A gas/spray mixing chamber with adequate residence time and droplet trajectory distance for ahieving the heat and mass transfer
- A means for recovering the solids from the gas stream
- A fan to induce the required air/gas through the spray drying system

It is well suited for a continuous production of dry solids in powder or agglomerated particles form from a liquid feedstock. The unique feature of a spray dryer is the surface area per unit weight generated by atomization of the liquid feed.  It is this fact that enables a spray dryer to work. The feedstock can include solutions, emulsions, and pump-able suspensions. The technology is ideal when the end-product must comply with precise quality standards such as particle size distribution, residual moisture content, bulk density and particle morphology.

## 1.3. Cleaning in place



CIP System

Cleaning in Place (CIP) or sterilization in place as it is also known refers to the use of a mix of chemicals, heat and water to clean machinery, vessels or pipe work without dismantling plant. The process can be one shot, where everything goes to drain, or recovery, which recycles most of the liquid. The principles of CIP can be applied to any industry and plant where hygiene is critical; and the process is usually an integral part of any automated plant. CIP is principally concerned with soil removal: soil being anything that should not be present in a clean vessel. Industries that use CIP take advantage of the following features: cleaning is faster, less labour intensive and more repeatable, and is highly safer as per any possible chemical exposure risk to people.

## 1.4. Boiler feed water pre-heating

Pre heating of boiler feed water is a simple process where the temperature of input water to the boiler is raised so as to reduce the fuel requirement of the boiler. Boiler feed water pre heating is effective in two ways: a) it reduces the plant operational costs and b) it also reduces the thermal shock to the boiler metal when hot water is introduced instead of water at ambient temperature. This can be done in a number of ways including pre heating it by solar concentrator based thermal systems.

# 2 Process Information and existing setup

As has been highlighted earlier structured questionnaires and walk through audits were conducted to understand the current fuel dependence of the various sample units where these processes were identified. The current thermal energy requirements and generation details were captured so as to analyse the same from a solar thermal perspective. Although these processes shall be similar in different sample units but there quantum may differ according to their production requirements.

## 2.1. Reflux

The thermal energy requirement in the process is currently fulfilled by use of a natural gas based boiler. The process for a typical sample unit requires 110m³ of natural gas for one batch of 7 hours. The thermal energy calculations for the batch are as follows:

| Parameter | Value | Unit |
|---|---|---|
| **Fuel Consumption** | 110 | $m^3$ |
| **Fuel calorific value** | 12000 | $Kcal/m^3$ |
| **Total calorific output from fuel** | 1320000 | kilo calories |
| **Efficiency of boiler** | 85% | Percentage |
| **Total calorific output for process** | 1122000 | kilocalories |

The sample unit uses natural gas fired boiler system to heat water and generate steam to meet heating requirement in the distillation process. Solar thermal options are to be explored to satisfy the heat requirements for the reflux process described above.

## 2.2. Spray Drying

The thermal energy requirement in the process is fulfilled by use of diesel in the sample unit. In the process for a typical sample unit majority of steam is consumed in indirect heating of the air via the radiator. The air is heated to a temperature of 175°C @ 12 bar pressure via steam flowing through the jacketed vessel in the radiator. The thermal energy calculations for the batch are as follows:

| Parameter | Value | Unit |
|---|---|---|
| **Fuel Consumption** | 12 litres diesel/ hour for 12 hours per batch | litres |
| **Fuel calorific value** | 9500 | Kcal/litre |
| **Total calorific output from fuel per batch** | 1368000 | kilo calories |
| **Efficiency of boiler** | 70% | Percentage |
| **Total calorific output for process** | 957600 | kilo calories |
| **Batch Duration** | 12 | Hours |
| **Energy required for 7 hours** | = (957600/12)*7 = 558600 | kilocalories |

The sample unit uses diesel fired boiler system to heat water and generate steam to meet heating requirement in the spray drying process. Solar thermal options are to be explored to satisfy the heat requirements for the spray drying process described above.

## 2.3. Cleaning in place

The thermal energy requirement in the process is fulfilled by use of diesel in the sample unit. In the process for a typical sample unit the process is done by using hot water at 120°C. The water is heated through the existing boiler and used in the CIP process. The thermal energy calculations for the batch are as follows:

| Parameter | Value | Unit |
|---|---|---|
| **Fuel Consumption** | 90 litres diesel/batch | litres |

| | | |
|---|---|---|
| **Fuel calorific value** | 9500 | Kcal/litre |
| **Total calorific output from fuel** | 855000 | kilo calories |
| **Efficiency of boiler** | 70% | Percentage |
| **Total calorific output for process** | ~598500 | kilo calories |

Solar thermal options are to be explored to satisfy the heat requirements for the CIP process described above.

## 2.4. Boiler feed water pre-heating

The thermal energy requirement in the process is fulfilled by use of diesel in the sample unit. In the process for a typical sample unit the process is done by increasing the temperature of the input water from 25°C to 85°C. Currently in the sample unit there is no provisioning of pre heating of boiler feed water and water at ambient temperature is fed to the boiler and converted to steam/pressurized hot water as the case may be for use in various industrial processes. The unit has a requirement of 1700 litres / hour boiler feed water. The thermal energy calculations for the batch are as follows:

Heat input required for heating 1700 litres/hour water at 25°C to 90°C (ΔT=90-25=65°C)

= 1700*1*65 = 110500 kilo calories/hour

For a 7 hour shift the energy required will be

= 110500*7 = 773500 kilo calories

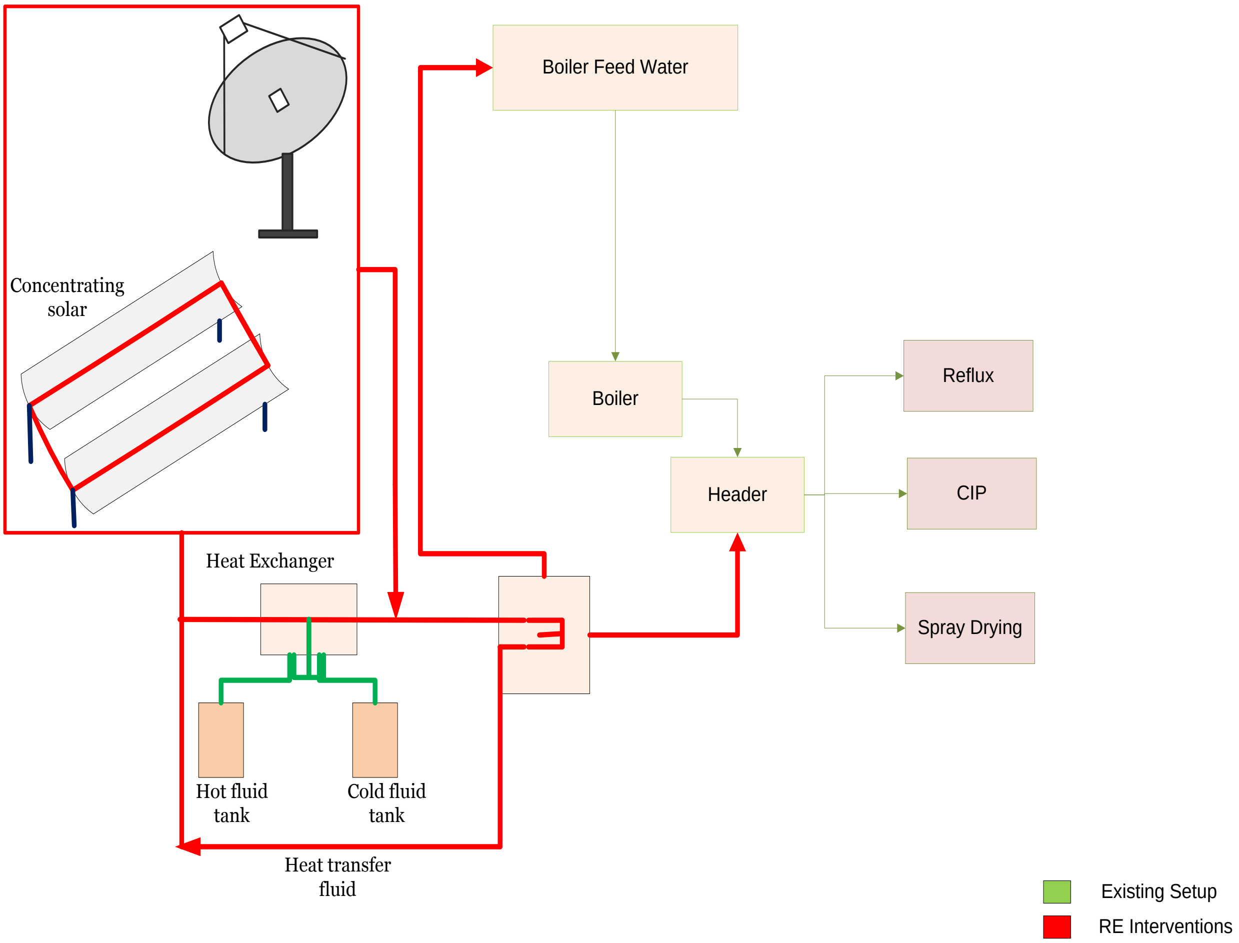
Solar thermal options are to be explored to satisfy the heat requirements for the boiler feed water pre heating process described above. Based on the process study, the new solar concentrator based system is proposed to be integrated with the existing boiler.

# 3 Solar sizing

For satisfying the heat requirements in the different sample units, solar thermal technologies could easily be integrated in their current setups. The thermal energy requirement in the various processes is continuous and is met through a fossil fuel based boiler (diesel/natural gas).

The size of the solar system has to be designed so as to optimize the thermal energy production and the current resources in hand. Solar thermal systems need to function so as to satisfy the process requirements of the industry in spite of variability of solar radiation over the days and seasons.

Further, the size of the system must also satisfy the cost constraints and more importantly the space requirements. Also, the system needs to be reliable within acceptable range. In order to overcome these hurdles, it is necessary to develop a design methodology and general integration approach that can be used for optimally sizing the solar concentrators. The different technologies applicable for such process requirement are parabolic trough, paraboloid dish and linear paraboloid fresnel dish. The indicative layout of the processes after the integration with solar thermal systems will be as follows:




## *3.1. Reflux*

The process requires ~1122000 kilo calories as illustrated in **Section 2.1** for replacement of 110m³ natural gas being currently utilised in the existing boilers. Assuming solar system efficiency of 95% the energy required from the system shall be

= 1122000/0.95 = ~1200000 kilo calories

Based on this energy assessment the system sizing for different technologies is illustrated as follows:

## *Parabolic Trough*

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per trough module per day** | ~75000 | Kcal/day |
| **Size of one trough module** | 35 | m² |
| **Shade free area for one module** | 50 | m² |
| **Calorific output required from process** | ~1200000 | Kcal/7 hours |
| **Modules of trough required** | = (1200000/75000) = 16 | Nos. |
| **Energy Displaced** | 75000*16*0.95 = 1122000 | Kilo calories |

| | | |
|---|---|---|
| **Fuel displaced** | 1122000/(12000*0.85) = 110 | $m^3$ of natural gas |
| **Total system size** | = 35*16 = 560 | $m^2$ |
| **Total system area required** | = 50*16 = 800 | $m^2$ |

## *Paraboloid Dish*

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per dish module per day** | ~300000 | Kcal/day |
| **Size of one trough module** | 90 | $m^2$ |
| **Shade free area for one module** | 100 | $m^2$ |
| **Calorific output required from process** | ~1200000 | Kcal/7 hours |
| **Modules of dish required** | = (1200000/300000) = 4 | Nos. |
| **Energy Displaced** | 300000*4*0.95 = 1122000 | Kilo calories |
| **Fuel displaced** | 1122000/(12000*0.85) = 110 | $m^3$ of natural gas |
| **Total system size** | = 90*4 = 360 | $m^2$ |
| **Total system area required** | = 100*4 = 400 | $m^2$ |

## *Linear fresnel paraboloid dish*

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per paraboloid dish module per day** | ~450000 | Kcal/day |
| **Size of one trough module** | 169 | $m^2$ |
| **Shade free area for one module** | 180 | $m^2$ |
| **Calorific output required from process** | ~1200000 | Kcal/7 hours |
| **Modules of paraboloid dish required** | = (1200000/450000) = 3 | Nos. |
| **Energy Displaced** | 450000*3*0.95 = 1282500 | Kilo calories |
| **Fuel displaced** | 1282500/(12000*0.85) ~= 125 | $m^3$ of natural gas |
| **Total system size** | = 169*3 = 507 | $m^2$ |
| **Total system area required** | = 180*3 = 540 | $m^2$ |

# *3.2. Spray Drying*

The process requires almost 558600 kilo calories as illustrated in **Section 2.2** for replacement of 84 litres of diesel (12litres/hour* 7 hours) being currently utilised in the existing boilers. Assuming solar system efficiency of 95% the energy required from the system shall be

= 558600/0.95 = ~600000 kilo calories

Based on this energy assessment the system sizing for different technologies is illustrated as follows:

## *Parabolic Trough*

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per trough module per day** | ~75000 | Kcal/day |
| **Size of one trough module** | 35 | $m^2$ |
| **Shade free area for one module** | 50 | $m^2$ |
| **Calorific output required from process** | ~600000 | Kcal/7 hours |
| **Modules of trough required** | = (600000/75000) = 8 | Nos. |
| **Energy Displaced** | 75000*8*0.95 = 558600 | Kilo calories |
| **Fuel displaced** | 558600/(9500*0.70) = 84 | litres of diesel |
| **Total system size** | = 35*8 = 280 | $m^2$ |
| **Total system area required** | = 50*8 = 400 | $m^2$ |

## *Paraboloid Dish*

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per dish module per day** | ~300000 | Kcal/day |
| **Size of one trough module** | 90 | $m^2$ |
| **Shade free area for one module** | 100 | $m^2$ |
| **Calorific output required from process** | ~600000 | Kcal/7 hours |
| **Modules of dish required** | = (600000/300000) = 2 | Nos. |
| **Energy Displaced** | 300000*2*0.95 = 558600 | Kilo calories |
| **Fuel displaced** | 558600/(9500*0.70) = 84 | litres of diesel |
| **Total system size** | = 90*2 = 180 | $m^2$ |
| **Total system area required** | = 100*2 = 200 | $m^2$ |

## *Linear fresnel paraboloid dish*

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per paraboloid dish module per day^** | ~450000 + ~300000 | Kcal/day |
| **Size of one trough module** | 169 + 104 | $m^2$ |
| **Shade free area for one module** | 273 | $m^2$ |
| **Calorific output required from process** | ~600000 | Kcal/7 hours |
| **Modules of paraboloid dish required** | 1 module of each size | Nos. |
| **Energy Displaced** | 750000*0.95 = 712500 | Kilo calories |
| **Fuel displaced** | 712500/(9500*0.70) ~= 107 | litres of diesel |
| **Total system size** | = 169 + 104 = 273 | $m^2$ |
| **Total system area required** | = 180+120 = 300 | $m^2$ |

## *3.3. Cleaning in place*

The process requires almost 598500 kilo calories as illustrated in **Section 2.3** for replacement of 90 litres of diesel being currently utilised in the existing boilers. Assuming solar system efficiency of 95% the energy required from the system shall be

= 5598500/0.95 = ~600000 kilo calories

Based on this energy assessment the system sizing for different technologies is illustrated as follows:

### *Parabolic Trough*

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per trough module per day** | ~75000 | Kcal/day |
| **Size of one trough module** | 35 | m² |
| **Shade free area for one module** | 50 | m² |
| **Calorific output required from process** | ~600000 | Kcal/7 hours |
| **Modules of trough required** | = (600000/75000) = 8 | Nos. |
| **Energy Displaced** | 75000*8*0.95 = 558600 | Kilo calories |
| **Fuel displaced** | 558600/(9500*0.70) = 84 | litres of diesel |
| **Total system size** | = 35*8 = 280 | m² |
| **Total system area required** | = 50*8 = 400 | m² |

### *Paraboloid Dish*

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per dish module per day** | ~300000 | Kcal/day |
| **Size of one trough module** | 90 | m² |
| **Shade free area for one module** | 100 | m² |
| **Calorific output required from process** | ~600000 | Kcal/7 hours |
| **Modules of dish required** | = (600000/300000) = 2 | Nos. |
| **Energy Displaced** | 300000*2*0.95 = 558600 | Kilo calories |
| **Fuel displaced** | 558600/(9500*0.70) = 84 | litres of diesel |
| **Total system size** | = 90*2 = 180 | m² |
| **Total system area required** | = 100*2 = 200 | m² |

### *Linear fresnel paraboloid dish*

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per paraboloid dish module per day^** | ~450000 + ~300000 | Kcal/day |

| | | |
|---|---|---|
| **Size of one trough module** | 169 + 104 | m² |
| **Shade free area for one module** | 273 | m² |
| **Calorific output required from process** | ~600000 | Kcal/7 hours |
| **Modules of paraboloid dish required** | 1 module of each size | Nos. |
| **Energy Displaced** | 750000*0.95 = 712500 | Kilo calories |
| **Fuel displaced** | 712500/(9500*0.70) ~= 107 | litres of diesel |
| **Total system size** | = 169 + 104 = 273 | m² |
| **Total system area required** | = 180+120 = 300 | m² |

## 3.4. Boiler feed water pre-heating

The process requires almost 773500 kilo calories as illustrated in **Section 2.4** for boiler feed water preparation process. Assuming solar system efficiency of 95% the energy required from the system shall be

= 773500/0.95 = ~800000 kilo calories

Based on this energy assessment the system sizing for different technologies is illustrated as follows:

### Parabolic Trough

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per trough module per day** | ~75000 | Kcal/day |
| **Size of one trough module** | 35 | m² |
| **Shade free area for one module** | 50 | m² |
| **Calorific output required from process** | ~600000 | Kcal/7 hours |
| **Modules of trough required** | = (800000/75000) ~= 11 | Nos. |
| **Energy Displaced** | 75000*11*0.95 = 783750 | Kilo calories |
| **Fuel displaced** | 783750/(9500*0.70) ~= 118 | litres of diesel |
| **Total system size** | = 35*11 = 385 | m² |
| **Total system area required** | = 50*11 = 550 | m² |

### Paraboloid Dish

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per dish module per day** | ~300000 | Kcal/day |
| **Size of one trough module** | 90 | m² |
| **Shade free area for one module** | 100 | m² |
| **Calorific output required from process** | ~800000 | Kcal/7 hours |
| **Modules of dish required** | = (800000/300000) = 3 | Nos. |

| | | |
|---|---|---|
| **Energy Displaced** | 300000*3*0.95 = 855000 | Kilo calories |
| **Fuel displaced** | 855000/(9500*0.70) ~= 128 | litres of diesel |
| **Total system size** | = 90*3 = 270 | m² |
| **Total system area required** | = 100*3 = 300 | m² |

### *Linear fresnel paraboloid dish*

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per paraboloid dish module per/ day** | ~450000 + ~300000 | Kcal/day |
| **Size of one trough module** | 169 + 104 | m² |
| **Shade free area for one module** | 273 | m² |
| **Calorific output required from process** | ~600000 | Kcal/7 hours |
| **Modules of paraboloid dish required** | 1 module of each size | Nos. |
| **Energy Displaced** | 750000*0.95 = 712500 | Kilo calories |
| **Fuel displaced** | 712500/(9500*0.70) ~= 107 | litres of diesel |
| **Total system size** | = 169 + 104 = 273 | m² |
| **Total system area required** | = 180+120 = 300 | m² |

# *4 Financial Analysis*

For satisfying the heat requirements in the various units, solar thermal technologies could easily be integrated in the current setup of the sample units. Following the decision on the size of the system to be installed, this exercise has been carried out to assess the indicative financial feasibility of the project, considering all the three technology options. Based on the costs of the systems and the MNRE Benchmarks for subsidy and additional UNDP support, the overall project cost is calculated.

Financial modelling has been done so as to estimate the payback period of the three technologies for the various processes. The results of the model will be instrumental in the capital investment decision. The overall cost (Cost of system-MNRE subsidy-UNDP support) of the system is the upfront investment which brings about significant savings in terms of the fuel saved. Current dependence on fossil fuel for thermal energy production in the four processes, MNRE subsidy of 30%, additional support from UNDP and year around operation of the unit leading to increased utilization will ensure that the payback periods are less. List of assumptions made for preparing the financial models is tabulated below.

| Assumptions | |
|---|---|
| **Annual escalation in fuel price** | 10 % |
| **Debt : Equity for beneficiary's contribution** | 70:30 |
| **Cost of Equity** | 16 % |
| **O & M as a % of project cost** | 2 % |
| **Inflation in O&M** | 1 % |

| | |
|---|---|
| **Deration** | 1 % |
| **Life of Project** | 20 years |
| **Days of operation per annum** | 300 |

Based on this financial modelling exercise, the financial performance indicators of all the three technology options for the four processes are obtained.

## 4.1. Reflux

In this process the unit is using natural gas (@Rs 48/m3) and the solar thermal intervention is able to bring about savings in the current dependence as described in **Section 3.1**. Based on the financial modelling a summary of the results for the three technologies is tabulated below:

| Technology/ Parameters | Parabolic Trough | Paraboloid Dish | Linear Fresnel Paraboloid dish |
|---|---|---|---|
| **System size proposed** | 16 | 4 | 3 |
| **Surface Area (A)** | 560 $m^2$ | 360 $m^2$ | 507 $m^2$ |
| **Footprint** | 800 $m^2$ | 400 $m^2$ | 540 $m^2$ |
| **Tracking** | Single Axis | Double axis | Double Axis |
| **Total indicative cost of system (B)#** | ₹ 1,20,00,000 | ₹ 1,20,00,000 | ₹ 1,12,50,000 |
| **MNRE benchmark for subsidy (C)** | ₹ 5,400/ $m^2$ | ₹ 6,000/ $m^2$ | ₹ 6,000/ $m^2$ |
| **Total MNRE Subsidy (D=A x C) or (30% of B)** | ₹ 30,24,000 | ₹ 21,60,000 | ₹ 30,42,000 |
| **UNDP Grant For Demonstration*** | ₹ 15,12,000 | ₹ 10,80,000 | ₹ 15,21,000 |
| **Overall cost (E= B-D)** | **₹74,64,000** | **₹87,60,000** | **₹66,87,000** |
| **Fuel Savings per day (7hrs)** | 110 $m^3$ | 110 $m^3$ | 125 $m^3$ |
| **Project IRR** | 30.30% | 26.97% | 34.71% |
| **Equity IRR** | 68.09% | 55.76% | 83.91% |
| **Payback (Years)** | 3.47 | 3.98 | 2.98 |

## 4.2. Spray Drying

In this process the unit is using diesel (@Rs 65/litre) and the solar thermal intervention is able to bring about savings in the current dependence as described in **Section 3.2**. Based on the financial modelling a summary of the results for the three technologies is tabulated below:

| Technology/ Parameters | Parabolic Trough | Paraboloid Dish | Linear Fresnel Paraboloid dish |
|---|---|---|---|
| **System size proposed** | 8 | 2 | 1 each of 169 & 104 $m^2$ |

| | | | |
|---|---|---|---|
| **Surface Area (A)** | 280 $m^2$ | 180 $m^2$ | 273 $m^2$ |
| **Footprint** | 400 $m^2$ | 200 $m^2$ | 300 $m^2$ |
| **Tracking** | Single Axis | Double axis | Double Axis |
| **Total indicative cost of system (B)#** | ₹ 60,00,000 | ₹ 60,00,000 | ₹ 61,50,000 |
| **MNRE benchmark for subsidy (C)** | ₹ 5,400/ $m^2$ | ₹ 6,000/ $m^2$ | ₹ 6,000/ $m^2$ |
| **Total MNRE Subsidy (D=A x C) or (30% of B)** | ₹ 15,12,000 | ₹ 10,80,000 | ₹ 16,38,000 |
| **UNDP Grant For Demonstration*** | ₹ 7,56,000 | ₹ 2,00,000 | ₹ 7,60,500 |
| **Overall cost (E= B-D)** | **₹37,32,000** | **₹47,20,000** | **₹37,55,500** |
| **Fuel Savings per day (7hrs)** | 84 litres | 84 litres | 107 litres |
| **Project IRR** | 49.39% | 41.71% | 57.03% |
| **Equity IRR** | 134.94% | 108.49% | 160.97% |
| **Payback (Years)** | 2 | 2.42 | 1.72 |

## *4.3. Cleaning in Place*

In this process the unit is using diesel (@Rs 65/litre) and the solar thermal intervention is able to bring about savings in the current dependence as described in **Section 3.3**. Based on the financial modelling a summary of the results for the three technologies is tabulated below:

| Technology/ Parameters | Parabolic Trough | Paraboloid Dish | Linear Fresnel Paraboloid dish |
|---|---|---|---|
| **System size proposed** | 8 | 2 | 1 each of 169 & 104 $m^2$ |
| **Surface Area (A)** | 280 $m^2$ | 180 $m^2$ | 273 $m^2$ |
| **Footprint** | 400 $m^2$ | 200 $m^2$ | 300 $m^2$ |
| **Tracking** | Single Axis | Double axis | Double Axis |
| **Total indicative cost of system (B)#** | ₹ 60,00,000 | ₹ 60,00,000 | ₹ 61,50,000 |
| **MNRE benchmark for subsidy (C)** | ₹ 5,400/ $m^2$ | ₹ 6,000/ $m^2$ | ₹ 6,000/ $m^2$ |
| **Total MNRE Subsidy (D=A x C) or (30% of B)** | ₹ 15,12,000 | ₹ 10,80,000 | ₹ 16,38,000 |
| **UNDP Grant For Demonstration*** | ₹ 7,56,000 | ₹ 2,00,000 | ₹ 7,60,500 |
| **Overall cost (E= B-D)** | **₹37,32,000** | **₹47,20,000** | **₹37,55,500** |
| **Fuel Savings per day (7hrs)** | 84 litres | 84 litres | 107 litres |
| **Project IRR** | 49.39% | 41.71% | 57.03% |

| | | | |
|---|---|---|---|
| **Equity IRR** | 134.94% | 108.49% | 160.97% |
| **Payback (Years)** | 2 | 2.42 | 1.72 |

## 4.4. Boiler Feed Water pre heating

In this process the unit is assumed to be using diesel (@Rs 65/litre) and the solar thermal intervention is able to bring about savings in the current dependence as described in **Section 3.4**. Based on the financial modelling a summary of the results for the three technologies is tabulated below:

| Technology/ Parameters | Parabolic Trough | Paraboloid Dish | Linear Fresnel Paraboloid dish |
|---|---|---|---|
| **System size proposed** | 11 | 3 | 1 each of 169 & 104 $m^2$ |
| **Surface Area (A)** | 385 $m^2$ | 270 $m^2$ | 273 $m^2$ |
| **Footprint** | 550 $m^2$ | 300 $m^2$ | 300 $m^2$ |
| **Tracking** | Single Axis | Double axis | Double Axis |
| **Total indicative cost of system (B)#** | ₹ 82,50,000 | ₹ 90,00,000 | ₹ 61,50,000 |
| **MNRE benchmark for subsidy (C)** | ₹ 5,400/ $m^2$ | ₹ 6,000/ $m^2$ | ₹ 6,000/ $m^2$ |
| **Total MNRE Subsidy (D=A x C) or (30% of B)** | ₹ 20,79,000 | ₹ 16,20,000 | ₹ 16,38,000 |
| **UNDP Grant For Demonstration*** | ₹ 10,39,500 | ₹ 8,10,000 | ₹ 7,60,500 |
| **Overall cost (E= B-D)** | **₹51,31,500** | **₹65,70,000** | **₹37,55,500** |
| **Fuel Savings per day (7hrs)** | ~118 litres | ~128 litres | ~107 litres |
| **Project IRR** | 49.12% | 43.56% | 57.99% |
| **Equity IRR** | 134.50% | 115.39% | 164.55% |
| **Payback (Years)** | 2.01 | 2.29 | 1.69 |

# 5 Case Studies

In this section we are analysing sample case studies which are a combination of two or more processes defined in the previous sections. This task is done to give the readers a better understanding of the technology and the financial feasibility.

## 5.1. Case Study A

In this sample case study we have assumed that the unit has 1.4 times the requirement of the reflux process as mentioned in Section 2.1 and half the spray drying and CIP requirement as described in Section 2.2 and Section 2.3. Thus the overall energy requirement of the industry shall be:

1.4*1122000 + 0.5*558600 + 0.5*598500 kilocalories = 1700000 kilocalories

### 5.1.1. Solar sizing

The process requires ~1700000 kilo calories as illustrated above for replacement of current natural gas dependence. Assuming solar system efficiency of 95% the energy required from the system shall be

= 1700000/0.95 = ~1800000 kilo calories

Based on this energy assessment the system sizing for different technologies is illustrated as follows:

#### 5.1.1.1. Parabolic Trough

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per trough module per day** | ~75000 | Kcal/day |
| **Size of one trough module** | 35 | $m^2$ |
| **Shade free area for one module** | 50 | $m^2$ |
| **Calorific output required from process** | ~1800000 | Kcal/7 hours |
| **Modules of trough required** | = (1800000/75000) = 24 | Nos. |
| **Energy Displaced** | 75000*24*0.95 = 1710000 | Kilo calories |
| **Fuel displaced** | 1710000/(12000*0.85) ~= 167 | $m^3$ of natural gas |
| **Total system size** | = 35*24 = 840 | $m^2$ |
| **Total system area required** | = 50*24 = 1200 | $m^2$ |

#### 5.1.1.2. Paraboloid Dish

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per dish module per day** | ~300000 | Kcal/day |
| **Size of one trough module** | 90 | $m^2$ |
| **Shade free area for one module** | 100 | $m^2$ |
| **Calorific output required from process** | ~1800000 | Kcal/7 hours |
| **Modules of dish required** | = (1800000/300000) = 6 | Nos. |
| **Energy Displaced** | 300000*6*0.95 = 1710000 | Kilo calories |
| **Fuel displaced** | 1710000/(12000*0.85) ~= 167 | $m^3$ of natural gas |
| **Total system size** | = 90*6 = 540 | $m^2$ |
| **Total system area required** | = 100*6 = 600 | $m^2$ |

#### 5.1.1.3. Linear fresnel paraboloid dish

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per paraboloid dish module per day** | ~300000 | Kcal/day |
| **Size of one trough module** | 104 | $m^2$ |

| | | |
|---|---|---|
| **Shade free area for one module** | 110 | $m^2$ |
| **Calorific output required from process** | ~1800000 | Kcal/7 hours |
| **Modules of paraboloid dish required** | = (1800000/300000) = 6 | Nos. |
| **Energy Displaced** | 300000*6*0.95 = 1710000 | Kilo calories |
| **Fuel displaced** | 1710000/(12000*0.85) ~= 167 | $m^3$ of natural gas |
| **Total system size** | = 104*6 = 624 | $m^2$ |
| **Total system area required** | = 110*6 = 660 | $m^2$ |

## 5.1.2. Financial Analysis

Financial modelling has been done so as to estimate the payback period of the three technologies for the combination of the two processes. In this process the unit is assumed to be using natural gas (@Rs 48/$m^3$) and the solar thermal intervention is able to bring about savings in the current dependence as described above. Based on the financial modelling a summary of the results for the three technologies is tabulated below:

| Technology/ Parameters | Parabolic Trough | Paraboloid Dish | Linear Fresnel Paraboloid dish |
|---|---|---|---|
| **System size proposed** | 24 | 6 | 6 |
| **Surface Area (A)** | 840 $m^2$ | 540 $m^2$ | 624 $m^2$ |
| **Footprint** | 1200 $m^2$ | 600 $m^2$ | 660 $m^2$ |
| **Tracking** | Single Axis | Double axis | Double Axis |
| **Total indicative cost of system (B)#** | ₹ 1,80,00,000 | ₹ 1,80,00,000 | ₹ 1,44,00,000 |
| **MNRE benchmark for subsidy (C)** | ₹ 5,400/ $m^2$ | ₹ 6,000/ $m^2$ | ₹ 6,000/ $m^2$ |
| **Total MNRE Subsidy (D=A x C) or (30% of B)** | ₹ 45,36,000 | ₹ 32,40,000 | ₹ 37,44,000 |
| **UNDP Grant For Demonstration*** | ₹ 22,68,000 | ₹ 16,20,000 | ₹ 18,72,000 |
| **Overall cost (E= B-D)** | **₹111,96,000** | **₹1,31,40,000** | **₹87,84,000** |
| **Fuel Savings per day (7hrs)** | 167 $m^3$ | 167 $m^3$ | 167 $m^3$ |
| **Project IRR** | 19.87% | 17.12% | 24.69% |
| **Equity IRR** | 38.80% | 28.19% | 58.48% |
| **Payback (Years)** | 4.69 | 5.40 | 3.76 |

# 5.2. Case Study B

In this sample case study we have assumed that the unit has a requirement of all the four processes as mentioned in Section 2.1; Section 2.2; Section 2.3 and Section 2.4. Thus the energy requirement of the industry shall be:

1122000 + 558600 + 598500 + 773500 kilocalories = 3052600 kilocalories

## 5.2.1. Solar sizing

The process requires ~2931500 kilo calories as illustrated above for replacement of current diesel dependence. Assuming solar system efficiency of 95% the energy required from the system shall be

= 3052600/0.95 = ~3000000 kilo calories

Based on this energy assessment the system sizing for different technologies is illustrated as follows:

### 5.2.1.1. Parabolic Trough

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per trough module per day** | ~75000 | Kcal/day |
| **Size of one trough module** | 35 | $m^2$ |
| **Shade free area for one module** | 50 | $m^2$ |
| **Calorific output required from process** | ~3000000 | Kcal/7 hours |
| **Modules of trough required** | = (3000000 /75000) ~= 40 | Nos. |
| **Energy Displaced** | 75000*40*0.95 = 2850000 | Kilo calories |
| **Fuel displaced** | 2850000/(9500*0.85) ~= 353 | Litres of diesel |
| **Total system size** | = 35*40 = 1400 | $m^2$ |
| **Total system area required** | = 50*40 = 2000 | $m^2$ |

### 5.2.1.2. Paraboloid Dish

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per dish module per day** | ~300000 | Kcal/day |
| **Size of one trough module** | 90 | $m^2$ |
| **Shade free area for one module** | 100 | $m^2$ |
| **Calorific output required from process** | ~3000000 | Kcal/7 hours |
| **Modules of dish required** | = (3000000/300000) =10 | Nos. |
| **Energy Displaced** | 75000*40*0.95 = 2850000 | Kilo calories |
| **Fuel displaced** | 2850000/(9500*0.85) ~= 353 | Litres of diesel |
| **Total system size** | = 90*10 = 900 | $m^2$ |
| **Total system area required** | = 100*10 = 1000 | $m^2$ |

### 5.2.1.3. Linear fresnel paraboloid dish

| Parameter | Value | Unit |
|---|---|---|
| **Calorific output per paraboloid dish module per day** | ~300000 | Kcal/day |
| **Size of one trough module** | 104 | $m^2$ |

| | | |
|---|---|---|
| **Shade free area for one module** | 110 | $m^2$ |
| **Calorific output required from process** | ~3000000 | Kcal/7 hours |
| **Modules of paraboloid dish required** | = (3000000/300000) =10 | Nos. |
| **Energy Displaced** | 75000*40*0.95 = 2850000 | Kilo calories |
| **Fuel displaced** | 2850000/(9500*0.85) ~= 353 | Litres of diesel |
| **Total system size** | = 104*10 = 1040 | $m^2$ |
| **Total system area required** | = 110*10 = 1100 | $m^2$ |

## *5.2.2. Financial Analysis*

Financial modelling has been done so as to estimate the payback period of the three technologies for the combination of the two processes. In this process the unit is assumed to be using diesel (@Rs 65/litres) and the solar thermal intervention is able to bring about savings in the current dependence as described above. Based on the financial modelling a summary of the results for the three technologies is tabulated below:

| Technology/ Parameters | Parabolic Trough | Paraboloid Dish | Linear Fresnel Paraboloid dish |
|---|---|---|---|
| **System size proposed** | 40 | 10 | 10 |
| **Surface Area (A)** | 1400 $m^2$ | 900 $m^2$ | 1040 $m^2$ |
| **Footprint** | 2000 $m^2$ | 1000 $m^2$ | 1100 $m^2$ |
| **Tracking** | Single Axis | Double axis | Double Axis |
| **Total indicative cost of system (B)#** | ₹ 3,00,00,000 | ₹ 3,00,00,000 | ₹ 2,40,00,000 |
| **MNRE benchmark for subsidy (C)** | ₹ 5,400/ $m^2$ | ₹ 6,000/ $m^2$ | ₹ 6,000/ $m^2$ |
| **Total MNRE Subsidy (D=A x C) or (30% of B)** | ₹ 75,60,000 | ₹ 54,00,000 | ₹ 62,40,000 |
| **UNDP Grant For Demonstration*** | ₹ 37,80,000 | ₹ 27,00,000 | ₹ 31,20,000 |
| **Overall cost (E= B-D)** | **₹186,60,000** | **₹219,00,000** | **₹146,40,000** |
| **Fuel Savings per day (7hrs)** | 353 litres | 353 litres | 353 litres |
| **Project IRR** | 33.39% | 29.31% | 40.69% |
| **Equity IRR** | 91.70% | 76.63% | 117.70% |
| **Payback (Years)** | 2.74 | 3.13 | 2.23 |

**The above results for different processes/cases are only an indicative assessment based on public information and shall be different for different sites and subject to variation by different manufacturers. Also the UNDP support is subject to certain terms and conditions which may result in lowering of the overall support for hard capital investment.**

# *Disclaimer*



The referred data in the report have been made available by industry respondents and technology suppliers for use in the report for the task allotted by UNDP-MNRE-GEF PMU on CSH to PricewaterhouseCoopers India Pvt. Ltd. [hereinafter referred as PwC]. PwC does not take responsibility of the authenticity and accuracy of the data and in no case will be held accountable for the incorrect data. Also, the analysis in the report is based on the data provided, hence the accuracy and its utility is dependent upon the quality of data provided.

This report is in accordance with the scope of work assigned to PwC by UNDP-MNRE-GEF PMU on CSH. It will be sole discretion of UNDP to share the report with any other agency and to answer any query raised thereof.