Technology Compendium for Energy Efficiency and Renewable Energy Opportunities in Dairy Sector

Gujarat Dairy Cluster

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

September 2020

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Promoting Energy Efficiency and Renewable Energy in Selected MSME Clusters in India

(A GEF funded project being jointly implemented by UNIDO & BEE)

UNIDO UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Compendium of

Energy Efficiency and Renewable Energy Technologies for Gujarat Dairy Cluster

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Developed under the assignment

Scaling up and expanding of project activities in MSME Clusters

Prepared by

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Confederation of Indian Industry
125 Years - Since 1895

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Acknowledgement

Acknowledgement

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AHU	Air Handling Unit
APFC	Automatic Power Factor Controller
AC	Alternating Current
BEE	Bureau of Energy Efficiency
BEP	Best Efficiency Point
BLDC	Brushless Direct Current
BMC	Bulk Milk Cooler
BOD	Biological Oxygen Demand
CAGR	Compound Annual Growth Rate
CFD	Computational Fluid Dynamics
CHW	Chilled Water
CII	Confederation of Indian Industry
CIP	Cleaning in Place
COD	Chemical Oxygen Demand
COP	Coefficient of Performance
DAHD	Department of Animal Husbandry and Dairying
DC	Direct Current
DG	Diesel Generator
EHP	Electric Heat Pump
ETP	Effluent Treatment Plant
FAO	Food and Agricultural Organization
FCU	Fan Coil Unit
FFC	Falling Film Chiller
FO	Furnace Oil
GCMMF	Gujarat Cooperative Milk Marketing Federation
GCV	Gross Calorific Value
GDP	Gross Domestic Product
GEF	Global Environment Facility
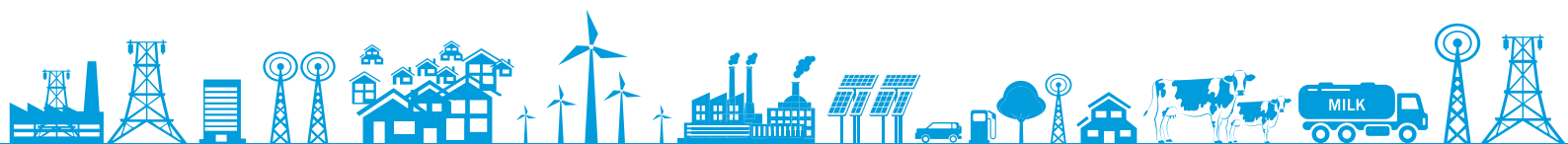
GHG	Greenhouse Gas
GLPCL	Gujarat Livelihood Promotion Company Limited
HSD	High Speed Diesel
HTST	High Temperature Short Time
HVAC	Heating Ventilation and Air Conditioning
IBT	Ice Bank Tank
IFC	Intelligent Flow Controller
IoT	Internet of Things
IRR	Internal Rate of Return
ISO	International Standard Organization
LED	Light Emitting Diode
LP	Low Pressure
LSP	Local Service Provider
MBR	Membrane Bio Reactor
MBRT	Methylene Blue Dye Reduction Test
MCC	Milk Chilling Center
MPPT	Maximum Power Point Tracker
MSME	Micro, Small and Medium Enterprises
NB	Nominal Bore
NDDB	National Dairy Development Board
NG	Natural Gas
NPV	Net Present Value
OEM	Original Equipment Manufacturer
PCU	Power Conditioning Unit
PF	Power Factor
PHE	Plate Heat Exchanger
PID	Proportional Integral Derivative
PNG	Piped Natural Gas
PRV	Pressure Reducing Valve
PV	Photovoltaic
RE	Renewable Energy
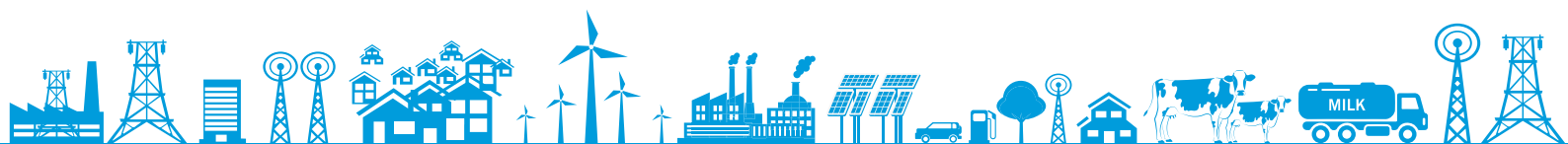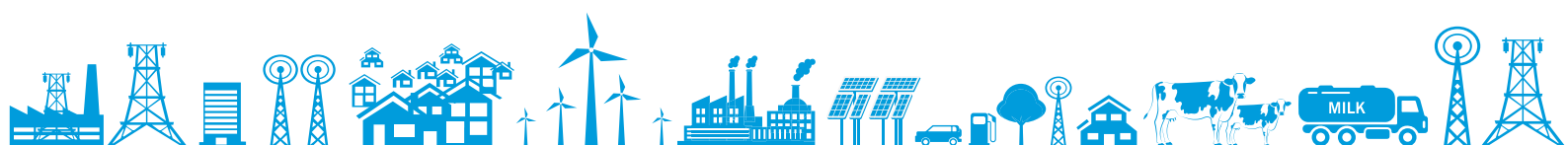
SEC	Specific Energy Consumption
SNF	Solid Not Fat
SOPT	Steam Operated Pumping Trap
TCV	Temperature Control Valve
TDS	Total Dissolved Solids
TOE	Tons of Oil Equivalent
UASB	Up flow Anaerobic Sludge Blanket
UHT	Ultra-High Temperature
UNIDO	United Nations Industrial Development Organization
UOM	Unit of Measurement
VFD	Variable Frequency Drive
WHR	Waste Heat Recovery
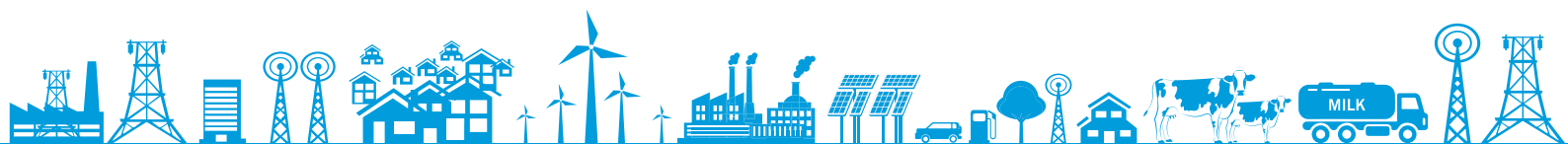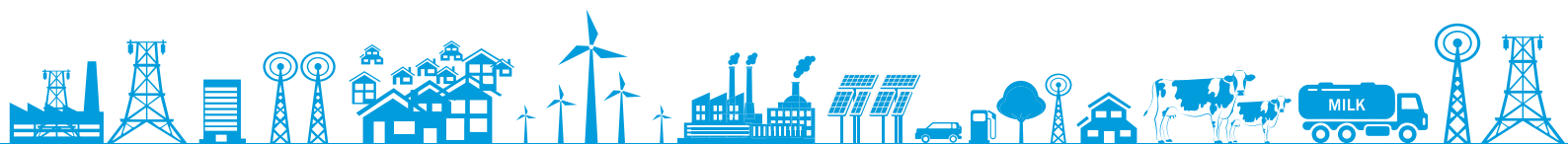
Unit of Measurements

cfm	Cubic Feet per Minute
gm	Grams
HP	Horse Power
kg	Kilogram
kg/cm²	kilo gram per area
kJ	Kilo Joule
kl	Kilo Litre
kl/hr	Kilo Litre per Hour
km	Kilometre
kVAr	Reactive Power
kW	Kilo Watt
kWh	Kilo Watt Hour
kWp	Kilowatt Peak
LLPD	Lakh Litre per Day
^{o}C	Degree Celsius
ppm	parts per million
psi	Pounds per Square Inch
INR	Indian Rupees
TCO_2	Tons of Carbon dioxide
TDS	Total Dissolved Solids
THD	Total Harmonic Distortion
TOE	Tons of Oil Equivalent
TPD	Tons Per Day
TPH	Tons per Hour
TR	Tons of Refrigeration

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About Project & Technology Compendium

About the Project

The United Nations Industrial Development Organization (UNIDO), in collaboration with the Bureau of Energy Efficiency (BEE), a statutory body under the Ministry of Power, Government of India, is executing a Global Environment Facility (GEF) funded national project titled 'Promoting energy efficiency and renewable energy in selected MSME clusters in India'. The project was operational in 12 MSME clusters across India in five sectors, respectively: Brass (Jamnagar); Ceramics (Khurja, Thangadh and Morbi); Dairy (Gujarat, Sikkim and Kerala); Foundry (Belgaum, Coimbatore and Indore); Hand Tools (Jalandhar and Nagaur). The Project has now scaled-up and expanded its activities to 11 new clusters, namely in Dairy (Tamil Nadu, Odisha, Madhya Pradesh, Andhra Pradesh & Telangana, Haryana, Maharashtra & Punjab), Foundry (Ahmedabad & Howrah), Ceramic (Himmatnagar) Mixed Cluster (Indore & Sikkim) in order to reach out to MSME's at national level.

This project so far has supported 303 MSME units in implementing 603 Energy conservation Measures and thus resulted in reduction of about 10,850 TOE energy consumption and avoided 62,868 metric tons of CO_2 emissions as on date.

Jalandhar – Handtools Cluster

Punjab – Dairy Cluster

Thangadh – Ceramic Cluster

Nagaur – Handtools Cluster

Jamnagar – Brass Cluster

Ahmedabad – Foundry Cluster

Gujarat –Dairy Cluster

Morbi – Ceramic Cluster

Belgaum – Foundry Cluster

Kerala – Dairy Cluster

Maharashtra – Dairy Cluster

Himmatnagar - Ceramic Cluster

Khurja –Ceramic Cluster

Haryana – Dairy Cluster

Howrah – Foundry Cluster

Sikkim – Dairy Cluster, Mixed Cluster

Madhya Pradesh – Dairy Cluster

Indore – Foundry Cluster, Mixed Cluster

Odisha –Dairy Cluster

Telangana –Dairy Cluster

Andhra Pradesh –Dairy Cluster

Coimbatore –Foundry Cluster

Tamil Nadu –Dairy Cluster

The key components of the project include:

❖ Increasing capacity of suppliers of EE/RE product suppliers / service providers / finance providers

❖ Increasing the level of end user demand and implementation of EE and RE technologies and practices by MSMEs.

❖ Scaling up of the project to more clusters across India.

❖ Strengthening policy, institutional and decision-making frameworks.

❖ Significant progress has been made in the project and it is now proposed to scale up and expand. The activities envisaged under the scaling up phase of the project include:

⬦ Establishment of field level Project Management Cell (PMC)

⬦ Organizing cluster level awareness program and identification of potential MSME enterprises

⬦ Development of cluster specific EE and RE based technology compendiums

⬦ Providing implementation support and other related activities to the identified enterprises
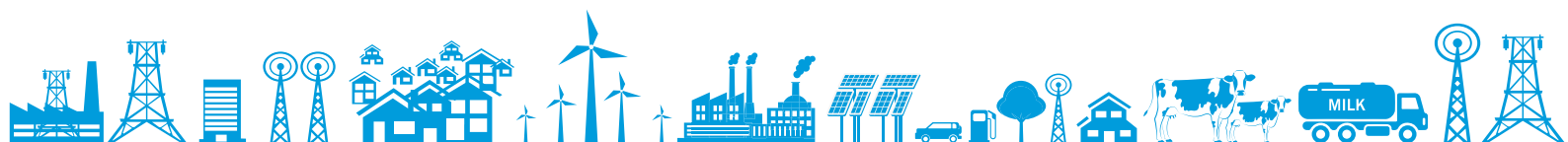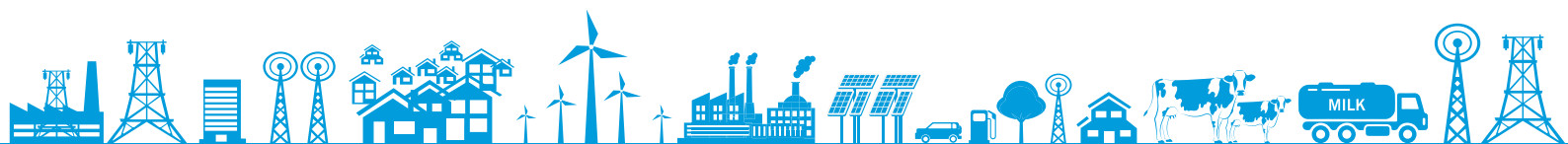
About the Technology Compendium

The dairy industry in India today faces challenges and opportunities resulting from rising energy costs, environmental concerns and competitiveness. Dairy processing in dairy value chain consumes more energy than any other operation across the value chain. The dairy uses energy for cooling, heating and in operation of various equipment such as refrigeration, boilers, compressors, etc. Over the years, there has been significant technology improvement in process and utilities area and dairies have been able to improve the energy efficiency in their operations. However, various opportunities still exist for dairies to improve their energy efficiency. To be competitive and have environment friendly operations, energy efficiency is crucial.

The technology compendium is prepared with the objective of accelerating the adoption of energy efficient technologies and practices in the dairy industry and it focuses on dairy equipment upgrades, new technologies and practices for improving energy efficiency. The technology case studies included in the compendium provide all the necessary information to enable dairies to refer and implement it in their operations. The case studies are supported by technology background, baseline scenario, merits, challenges, technical feasibility, financial feasibility and technology provider details. The opportunities presented in this compendium are developed for dairy processing units but may be applicable across the daily value chain. The energy efficiency measures included in the report cover more than 90% of energy consumption in a dairy unit.

- ❖ The objective of this compendium is to act as a catalyst to facilitate dairies towards continuously improving their energy performance, thereby achieving world class levels (with a thrust on energy & environment management).

- ❖ The compendium includes general energy efficiency options as well as specific case studies on applicable technology upgradation projects which can result in significant energy efficiency improvements.

- ❖ The suggested best practices may be considered for implementation only after detailed evaluation and fine-tuning requirements of existing units.

- ❖ In the wide spectrum of technologies and equipment applicable for dairy sector for energy efficiency, it is difficult to include all the energy conservation aspects in this manual. However, an attempt has been made to include the more common implementable technologies across all the dairy units.

- ❖ The user of the compendium has to fine-tune the energy efficiency measures suggested in the compendium to their specific plant requirements, to achieve maximum benefits.

- ❖ The technologies collated in the compendium may not necessarily be the ultimate solution as the energy efficiency through technology upgradation is a continuous process and will eventually move towards better efficiency with advancement in technology.

- ❖ The Gujarat dairy industry should therefore view this manual positively and utilise this opportunity to implement the best operating practices and energy saving ideas during design and operations, to facilitate achieving world class energy efficiency standards.

Executive Summary

Executive Summary

The United Nations Industrial Development Organization (UNIDO), in collaboration with the Bureau of Energy Efficiency (BEE), a statutory body under the Ministry of Power, Government of India, is executing a Global Environment Facility (GEF) funded national project called 'Promoting energy efficiency and renewable energy in selected MSME clusters in India'. The project execution is planned in multiple phases.

The aim of the Phase-I of the project was to develop and promote a market environment for introducing energy efficiency and enhanced use of renewable energy technologies in process applications in the selected (12) energy-intensive MSME clusters in India, with feasibility for expansion to more clusters. Phase-II of the project is to scale up and expand the project activities to a greater number of enterprises in existing clusters, as well as 11 new clusters, for better implementation of energy efficiency technologies and practices.

Efficient use of energy in any facility is invariably the most important strategic area for manageability of cost or potential cost savings. Awareness of the personnel, especially operators in the facility becomes a significant factor for the proper implementation of energy conservation initiatives. With this context, this Technology Compendium has been prepared, which comprises of various technologies and best practices to save energy.

The information in this compendium is intended to help the dairy managers in the Gujrat Dairy industry to reduce energy consumption in a cost-effective manner while maintaining the quality of products manufactured. Further analysis on the economics of all measures—as well as on their applicability to different production practices—is needed to assess their cost effectiveness at individual dairy units. Additionally, this compendium shall also serve the purpose of tapping the opportunities to significantly reduce energy consumption. Further, this shall also serve as a guide for estimating the feasibility of energy saving project at the first place and ensure accelerated implementation.

Chapter 1 of the compendium provides an overview of Indian Dairy and Gujarat Dairy Cluster. Chapter 2 focuses on a brief overview of dairy process and energy consumption in dairy units and also includes technology status/mapping of the dairy cluster.

Chapter 3 focuses on importance of energy efficiency in dairy industry and some of the common measures applicable in different sections of the dairy unit. The energy efficiency measures are included for more than 90% of energy consumption areas in a dairy plant, such as refrigeration, steam systems, process, utilities and utilization of renewable energy. The chapter also includes some of the best practices and key indicators that the plant should follow and monitor to maintain the energy efficiency levels in different energy consuming areas.

Chapter 4 provides detailed case studies for some of high impact and implementable energy efficient technologies in dairy units. In this chapter, 21 case studies have been included in areas such as refrigeration, steam systems, utilities, renewable energy, etc. These technologies are described in detail, such as baseline scenario, proposed scenario, merits, demerits, etc.,
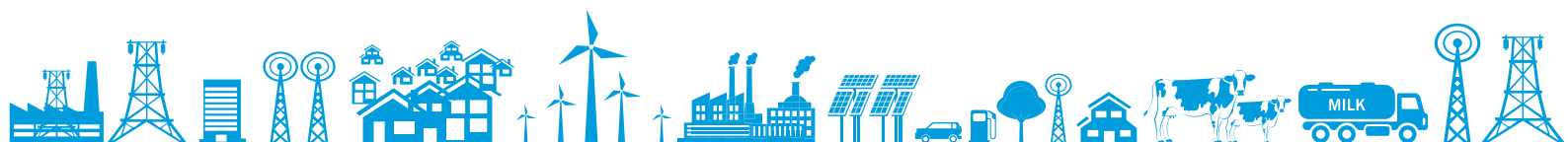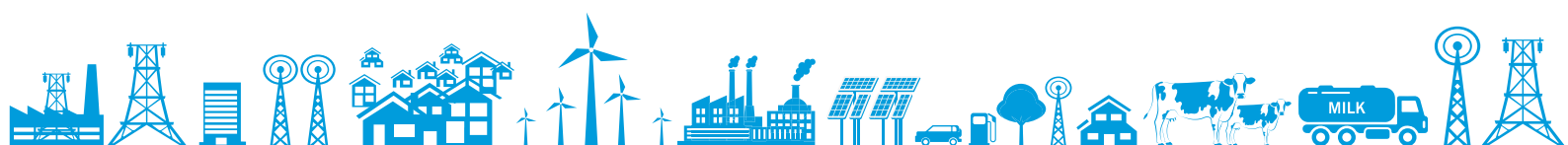
wherever possible, a case reference from a dairy unit that has implemented the technology has been included. In most of the examples, typical energy saving data, GHG emission reduction, investments, payback period, etc., have been highlighted. Energy saving potential in this sector is estimated to be about 10-15% without (or with marginal) investment and an additional 15% with investment. High potential for improving energy efficiency in dairies exists in the areas of heating and cooling via adoption of technologies such as co-generation, de-super heater, evaporative cooling systems, utilization of renewable energy, biomass fired boilers and increased automation.

The following table summarizes list of technologies included in the compendium:

Table 1: Energy Efficiency Technologies – Attractiveness and Investment

Sr. No	Technologies	Internal Rate of Return (IRR %)	Payback (months)	Unit Abatement Cost (INR Lakh/ TOE)
	Steam Generation and Distribution			
1	Conversion of Furnace Oil Fired Boiler to Fully Automated Biomass Fired Boiler	32.23	42	0.62
2	Condensate Recovery System	143.60	10	0.13
3	Steam Operated Pumping Traps	128.76	12	0.37
4	Installation of Microturbine	100.81	16	1.20
	Refrigeration Systems			
5	Installation of Screw Refrigeration Compressor	44.00	41	2.20
6	Variable Frequency Drive (VFD) in Chiller Compressor	73.04	23	1.23
7	Evaporative Condenser	63.79	27	1.73
8	Falling Film Chiller	121.28	13	0.92
9	Direct Cooling Method – Ice Bank Tank (IBT)	56.63	31	2.53
	Waste Heat Recovery (WHR)			
10	Desuperheater for Compressors	52.98	34	0.43
11	Heat Pump	153.17	10	0.47
12	Thermal Energy Storage for Bulk Milk Coolers (BMC)	246.13	06	1.34
	Utilities			
13	VFD for Air Compressor	142.02	11	0.57
14	Demand Side Controller for Compressed Air	175.26	08	0.63

Sr. No	Technologies	Internal Rate of Return (IRR %)	Payback (months)	Unit Abatement Cost (INR Lakh/ TOE)
15	Energy Efficient Pumps	66.74	17	0.65
16	Package Type Biogas Reactor	62.31	27	1.05
17	Methane Capture from dairy effluents	71.44	24	1.47
18	IoT based Water Management System	181.12	08	-
Renewable Energy				
19	Solar Rooftop system	19.81	84	5.54
20	Solar Thermal System	48.24	37	0.12
21	Solar Wind Hybrid system	20.88	84	5.50

The Gujarat dairy industry should view this manual positively and utilize this opportunity to implement the best operating practices and energy saving ideas during design and operations stages and thus work towards achieving world class energy efficiency.
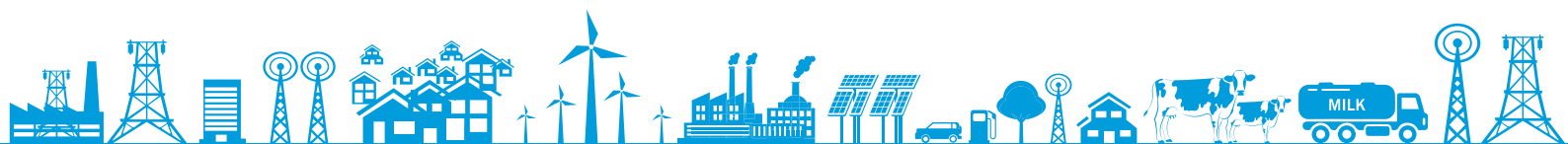
1. Indian Dairy Industry

1. Indian Dairy Industry

1.1 Background

India is the world's largest milk producer and is responsible for 21% of global milk production (FAO, 2019). The dairy sector in India has grown exponentially in the last five decades and the 'White Revolution' has helped India transform from a milk deficit nation to a milk surplus country. In the year 1950, India's milk production was a mere 17 million tons per year and it has increased to 176.5 million tons in 2017-18 (NDDB, 2019). The dairy sector has grown at a CAGR of 4.18% every year since 1990 and in the same duration, the per capita milk availability has improved from 178 grams/day to 375 grams/day, as of 2017-18 (NDDB, 2019). The following graph highlight the growth in milk production and per capita milk availability in the country:

Milk Production and Per Capita Availability
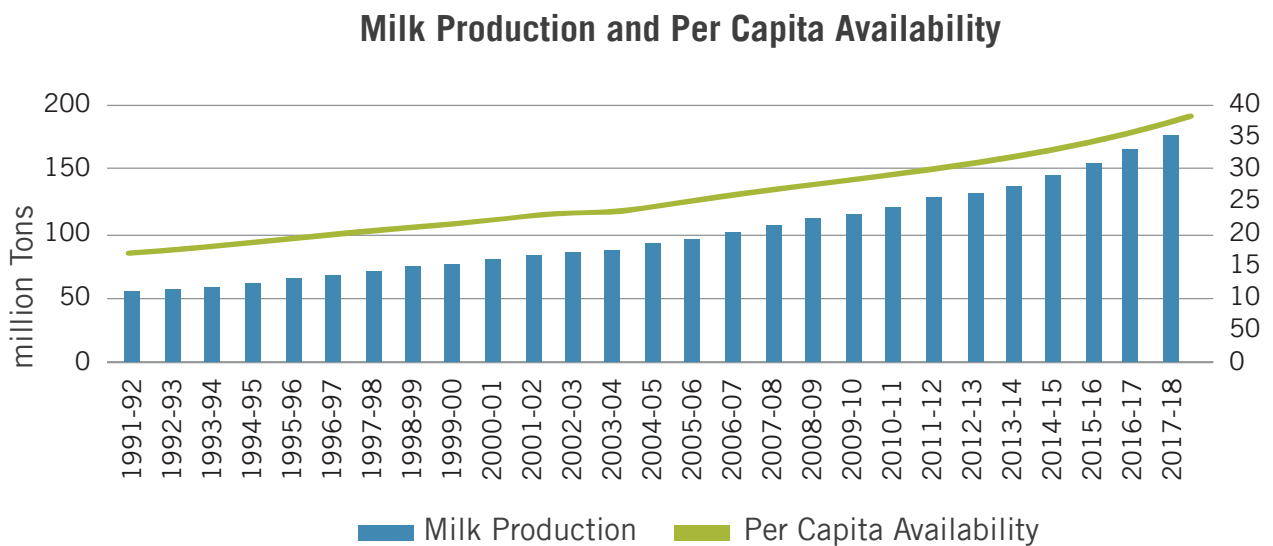
Figure 1: Milk Production and Per Capita Availability in Country (NDDB, 2019)

Among the various states in India, the five largest milk producers are Uttar Pradesh, Rajasthan, Madhya Pradesh, Andhra Pradesh, Gujarat and these states make up for 53% of milk production in India in 2017-18.

Milk Production - State wise (2017-18)
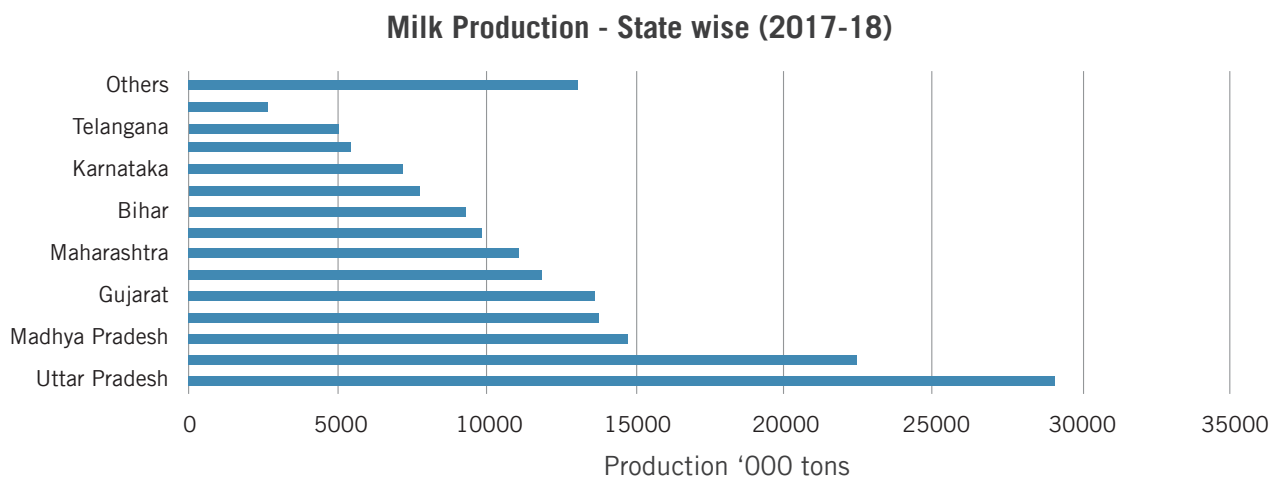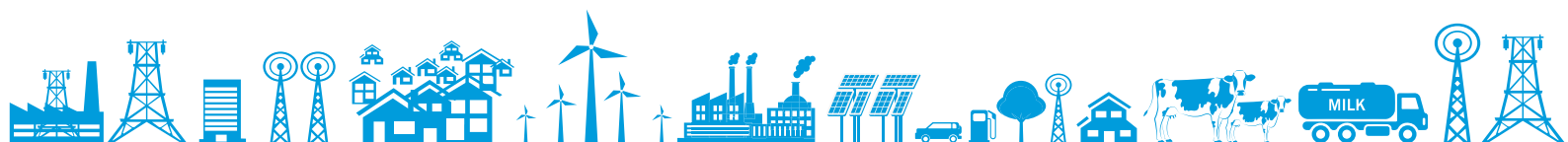
Figure 2: Milk Production – state wise

1.2 Dairy Sector Growth Prospects

The dairy sector has also played a critical role in socio-economic development of the country, as it provides employment and entrepreneurship opportunities to millions of households in the country. The livestock, which is an important constituent within the dairy sector, is also important as it contributes to 67% of the output value of the livestock sub-sector under the agriculture sector (DAHD, 2018).

The key growth drivers for dairy sector are population growth, income growth and urbanization and it is expected that these factors will drive India's milk consumption to 300 million tons by 2023-24 and will also result in increased per capita availability of milk to 592 grams/day (DAHD, 2018). Thus, there is a significant growth potential in the dairy sector for the coming years. The Government of India in 2018 announced the National Action for Dairy Development to tap the growth opportunity by addressing the gaps in infrastructure required to handle and process the milk to not only meet the growing demand but also for doubling the famers' income.

To tap the growth opportunity, it is important to have sufficient dairy infrastructure, such as chilling centers, milk processing facilities, as well as value-added products. As highlighted in the National Action Plan for Dairy Development, there is an urgent need to modernize the existing infrastructure and to develop new infrastructure in the dairy sector, in order to achieve the target of 300 million tons of production and processing in the country by 2023-24. The following table highlights the existing capacity of dairy infrastructure and targets envisaged as per the plan for 2023-24.

Table 2: Dairy Infrastructure Growth

Dairy Infrastructure Growth				
Sr. No	Particulars	UOM	2015-16	2023-24
1	Processing Capacity	LLPD	1,420	5,345
2	Chilling Capacity	LLPD	767	4,260
3	Value added products	TPD	7,918	20,534
4	Milk powder	TPD	2,961	8,401
5	Cattle feed plant	TPD	15,562	21,300

To meet the gap in the infrastructure, it is estimated that INR 1,27,455 crore of investment is required by cooperatives, producers and the private sector. Among these, the major investment would be driven by milk processing and milk chilling infrastructures. (DAHD, 2018).

Thus, the dairy sector is bound to have an accelerated growth in the coming years and would contribute significantly in socio-economic development of the country and most importantly, in the development of rural India.
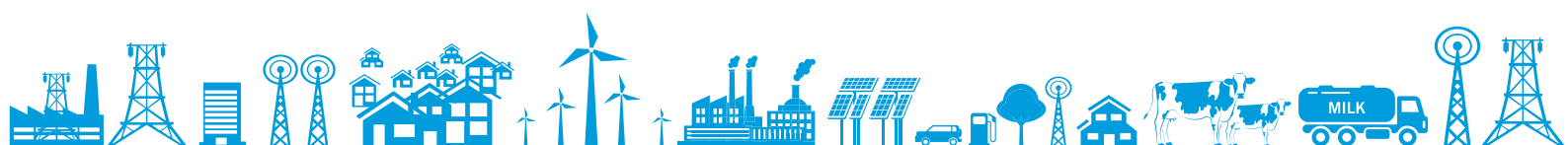
1.3 Gujarat Dairy Cluster

Gujarat is among the largest milk producer in the country. In 2017-18, the state produced 13.56 million tons of milk and was responsible for 7.52% of the country's total production (NDDB, 2019). Gujarat has played an important role in making the country one of the largest milk producers in the world, resulting from the movement started on the eve of independence in 1947, when the rural milk producers of Gujarat stood against their exploitation and formed a cooperative to take over the control of producing, processing and marketing of milk and milk products. This cooperative movement was later institutionalized in the form of 'Operation Flood' and it helped transform India from a milk deficit nation to one of the largest milk producers in the world.

In Gujarat, most districts have cooperatives and their milk processing capacity ranges from 1 lakh litre per day to 35 lakh litre per day. All these cooperatives are members of Gujarat Cooperative Milk Marketing Federation (GCMMF) and GCCMMF markets the products under the brand name 'Amul'. The Gujarat Model, established under Kaira Milk Union Limited, was subsequently extended to the whole country.

Gujarat Cooperative Milk Marketing Federation Ltd (GCMMF) is India's largest food product marketing organization, with annual turnover (2018-19) of USD 4.8 billion. Its daily milk procurement is 23 million litre, from 18,700 village milk cooperative societies, 18 member unions covering 33 districts and 3.6 million milk producer members (GCMMF, 2019). The following table highlights the key performance indicators for GCMMF:

Table 3: GCMMF – Key Indicators

GCMMF – Key Indicators		
Sr. No	**Particulars**	**Value**
1	Year of Establishment	1973
2	Member Cooperatives	3.6 million
3	Village Societies	18,554
4	Milk Handling Capacity	35 million LPD
5	Daily Average Milk Collection	23 million LPD
6	Cattle Feed Capacity	9200 tons per day
7	Sales Turnover	INR 33,150 Crores (USD 4.8 billion)

The dairy sector is also an important contributor to the state's GDP and milk contributes to 22% of the Agricultural GDP of Gujarat. It is also one of the biggest sectors for supporting livelihood in the state, as more than 40% of households in Gujarat are engaged in the dairy and animal husbandry sector. (GLPCL, 2019).
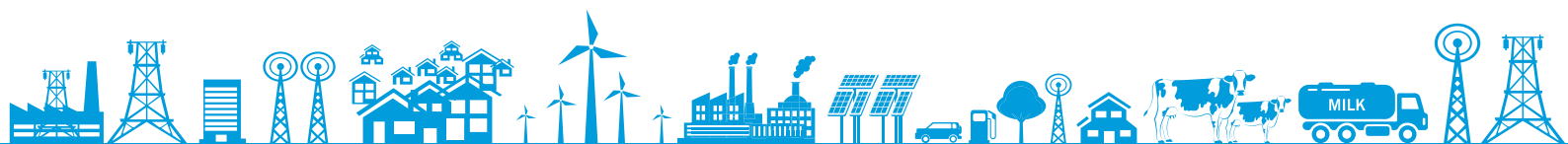
The Amul Model for dairy is a three-tiered structure, with the dairy cooperative societies at the village level, federated under a milk union at district level and a federation of member unions at state level. It is highlighted in the following figure:

Milk Producers   Village Dairy Cooperative   District Milk Cooperative Union   State Cooperative Milk Marketing Federation
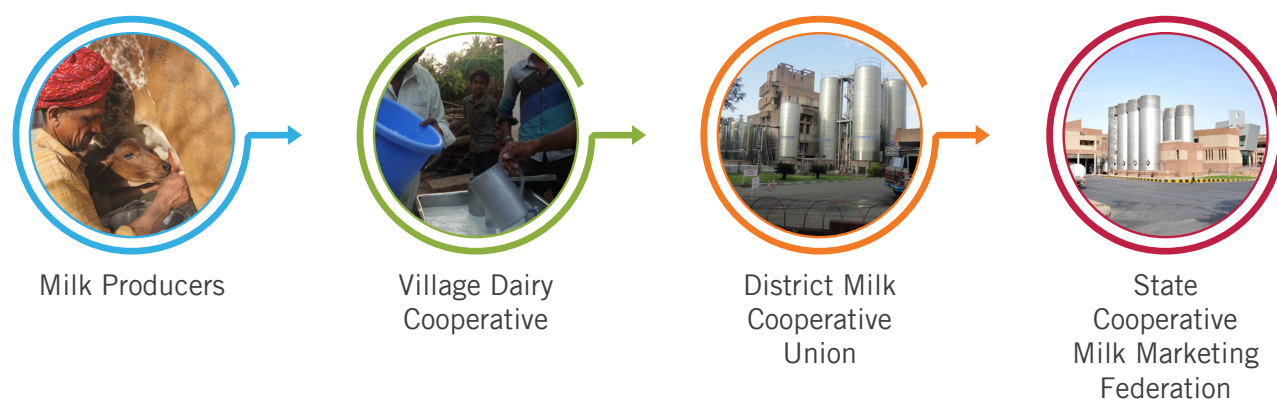
Figure 3: Dairy Institutional Structure – Gujarat

There are 18 milk unions in Gujarat and they produce various milk and value-added products, which are marketed across India and several foreign countries. The following are the 18 milk unions in Gujarat:

Table 4: District Milk Unions in Gujarat

Sr. No	Dairy Cooperatives
1	Kaira District Cooperative Milk Producers' Union Ltd., Anand
2	Mehsana District Cooperative Milk Producers' Union Ltd, Mehsana
3	Sabarkantha District Cooperative Milk Producers' Union Ltd., Himatnagar
4	Banaskantha District Cooperative Milk Producers' Union Ltd., Palanpur
5	Surat District Cooperative Milk Producers' Union Ltd., Surat
6	Baroda District Cooperative Milk Producers' Union Ltd., Vadodara
7	Panchmahal District Cooperative Milk Producers' Union Ltd., Godhra
8	Valsad District Cooperative Milk Producers' Union Ltd., Valsad
9	Bharuch District Cooperative Milk Producers' Union Ltd., Bharuch
10	Ahmedabad District Cooperative Milk Producers' Union Ltd., Ahmedabad
11	Rajkot District Cooperative Milk Producers' Union Ltd., Rajkot
12	Gandhinagar District Cooperative Milk Producers' Union Ltd., Gandhinagar
13	Surendranagar District Cooperative Milk Producers' Union Ltd., Surendranagar
14	Amreli District Cooperative Milk Producers Union Ltd., Amreli
15	Bhavnagar District Cooperative Milk Producers Union Ltd., Bhavnagar
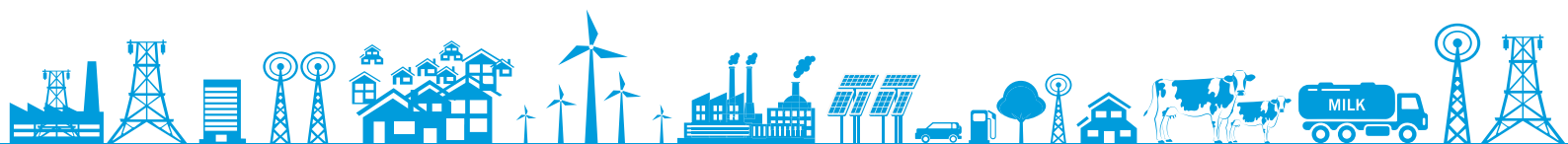
Sr. No	Dairy Cooperatives
16	Kutch District Cooperative Milk Producers' Union Ltd., Anjar
17	Junagadh District Cooperative Milk Producers' Union Limited, Junagadh
18	Porbandar District Cooperative Milk Producers' Union Ltd, Porbandar

These milk unions produce more than 30 brand products for Amul, such as processed milk, butter, cheese, curd, ghee, paneer (cottage cheese), milk powders, ice cream, flavored milk, shrikhand, butter milk, sweets, etc.
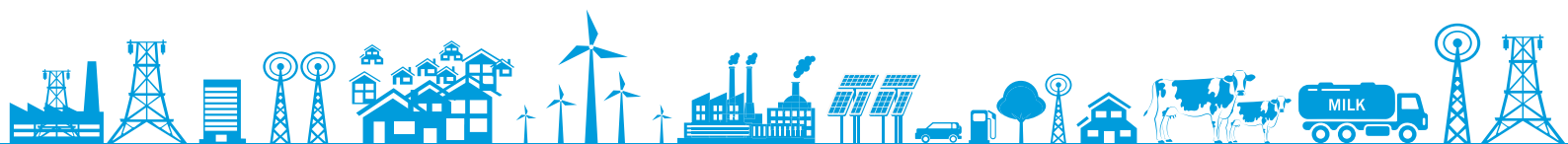
2. Dairy Process

2. Dairy Process

2.1 Dairy Sector Overview

Milk is one of the staple foods in India and it is highly nutritious but also has a short shelf life and thus requires special handling and processing for delivery to end consumers. As milk is an excellent medium for the growth of microorganisms and sine that can cause spoilage and health impact on consumers, special treatment and processing measures are undertaken to preserve it nutritious value while extending its shelf life. The following figure indicates the value chain of the dairy industry, from raw milk to the final products delivered to consumers.
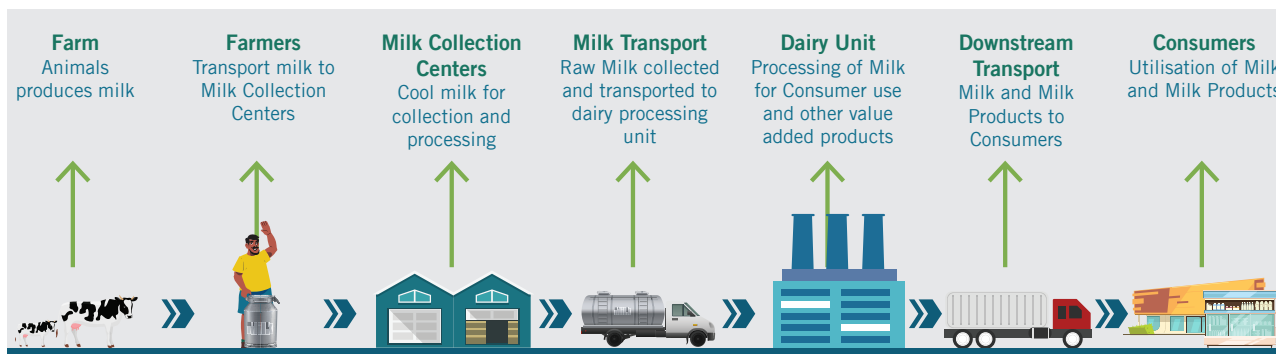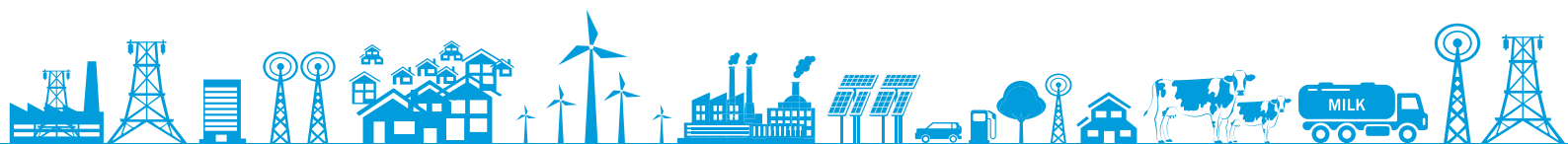
Figure 4: Milk Processing Value Chain

There are two major operations in milk processing: (i) Milk Chilling Centers (ii) Dairies.

I) Farming: The milk is produced from milch animals and is taken care of by the farming community. These farming communities will collect milk and take it to the milk collection centers.

II) Milk Chilling Centers (MCC)/Bulk Milk Coolers (BMC): The milk collected from different locations is first chilled in MCCs/BMCs. The milk is stored at lower temperatures so that it does not spoil and can be further transported to processing. Chilled milk is graded, weighed, sampled and dispatched in tankers for further processing.

III) Dairies: The dairies are the critical link in this value chain, as they connect farmers and consumers. At the dairies, the milk is collected and processed to prevent microorganism growth and also converted into value-added products, such as curd, cream, paneer, cheese, butter, etc. The dairy process mainly involves heating and cooling, which is used in processes like pasteurization, homogenizing, CIP, etc.

IV) Downstream Transport: Once milk is processed, the products are packed and transported to the retail outlets or to the consumers for further value addition or final consumption.

V) Consumers: The consumers utilize the milk and milk products as nutritious products.

2.2 Overview: Process Flow in Dairy Plant

The processing techniques that are employed by dairy plants are as diverse as the variety of products manufactured by the industry. The choice of individual processes and process sequence depends heavily on the end product being manufactured. In addition, for any given product, the choice of processes and process sequence can vary from facility to facility. There are many unit processes (i.e., discrete processing steps) that are common across the industry. Raw material specific processes such as pasteurization, homogenization and cold storage can be found in nearly every dairy processing facility. Furthermore, there are many end-product specific processes such as cream, butter, condensed and evaporated dairy products. Thus, while there is a diversity of processing techniques employed across the industry, a core group of unit processes exists to provide the basic building blocks for process sequences employed in nearly every dairy processing facility, as shown in the figure below:
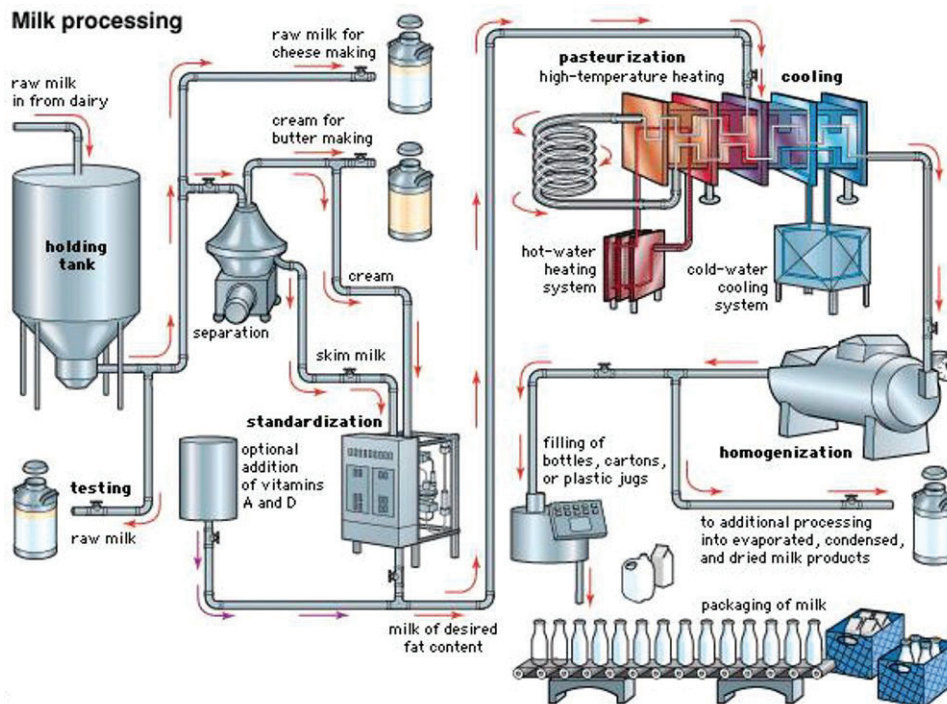
Figure 5: Milk Processing Flow

Receiving Milk at Dairy

All dairy products start with receiving raw milk from the farm. The raw milk generally is transported by way of tanker trucks and is typically already refrigerated to 7 degree celsius (°C). When the raw milk is unloaded into the processing facility, it is sometimes also sent through a centrifuge to remove particulates, a process known as clarification and cooled to 4°C via a heat exchanger on its way to a refrigerated storage tank. Stored raw milk is kept at 4°C prior to processing, usually by way of a jacketed storage tank.
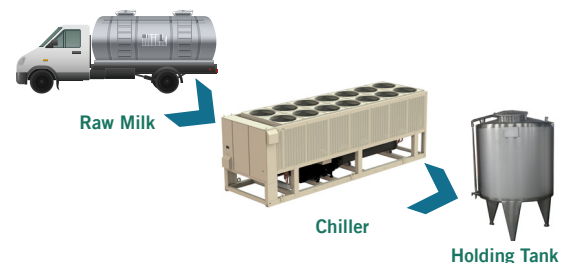
Figure 6: Milk Receiving
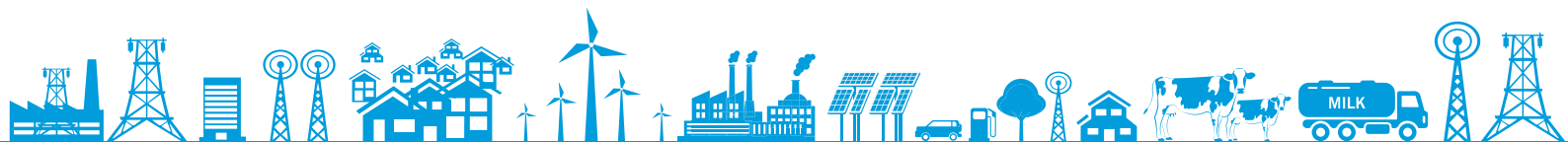
Pasteurization, sterilization and other **heat treatments** are occasionally done via a batch process, where a tank of the milk is heated to a specific temperature and held for a specific length of time. However, by far the most common method used is a continuous process.
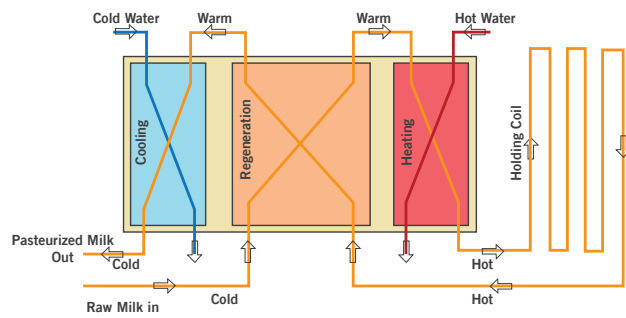
Figure 7: Pasteurization process

In a continuous process, a gear pump or a flow regulator is used to deliver a constant and accurate flow rate to the pasteurization process. The stream is passed through a heat exchanger, which heats the milk to the desired temperature. It is then pumped through a specific length of piping to hold it at this temperature for a specified period of time and then it is cooled back down. Most dairy processors use a process called regeneration to cut down on energy costs. Regeneration cools the outlet stream by using it to heat the incoming stream, recovering approximately 85% - 90% of the thermal energy. A small amount of steam or hot water is used to finish heating the inlet stream and a small amount of cooling is used to finish cooling the outlet stream. This heat treatment process serves to kill all the micro-organisms capable of causing diseases. Time and temperature combination is important for the determination of heat treatment.

Standardization is the process to ensure the proper fat content and Solids Not Fat (SNF) content for the desired finished product. Ensuring the proper fat content can be done in one of two ways. Both processes use a centrifuge to separate the very low-fat content and dense skim portion from the high fat content and less dense cream portion. One process involves analyzing the raw milk's fat content prior to processing and calculating the proportion of fat to remove during centrifugation. The other process involves completely separating raw milk as it is unloaded from the tanker truck and individually storing the two phases. These two streams are then recombined in the proportions required by the specific product as the first step of processing.

The latter method is used primarily by larger operations with diverse products, giving them the flexibility to quickly switch the product being produced without having to retest the milk and recalculate the degree of separation. The figure in the illustration is based on treatment of 100 kg whole milk with 4% fat. The requirement is to produce an optimal amount of 3% standardized milk and surplus cream containing 40% fat.
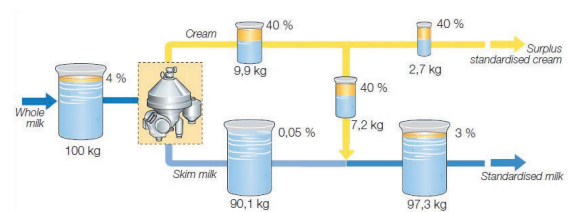
Figure 8: Milk Standardization Process

Separation of 100 kg of whole milk yields 90.35 kg of skim milk with 0.05% fat and 9.65 kg of cream with 40% fat. The amount of 40% cream that must be added to the skim milk is 7.2 kg. This gives a total of 97.55 kg of 3% market milk, leaving 9.65 − 7.2 = 2.45 kg of a surplus of 40% cream.

Homogenization: Milk is normally homogenized between the regeneration and heating cycles of the pasteurization process. The purpose of homogenization is to break up the fat globules into smaller sizes and disperse them in the water-soluble component, which prevents them from coalescing and forming the separate layer. Milk fat is what gives milk its rich and creamy taste.

1. Main drive motor
2. V-belt transmission
3. Pressure indication
4. Crankcase
5. Piston
6. Piston seal cartridge
7. Solid stainless steel pump block
8. Valves
9. Homogenising device
10. Hydraulic pressure setting system
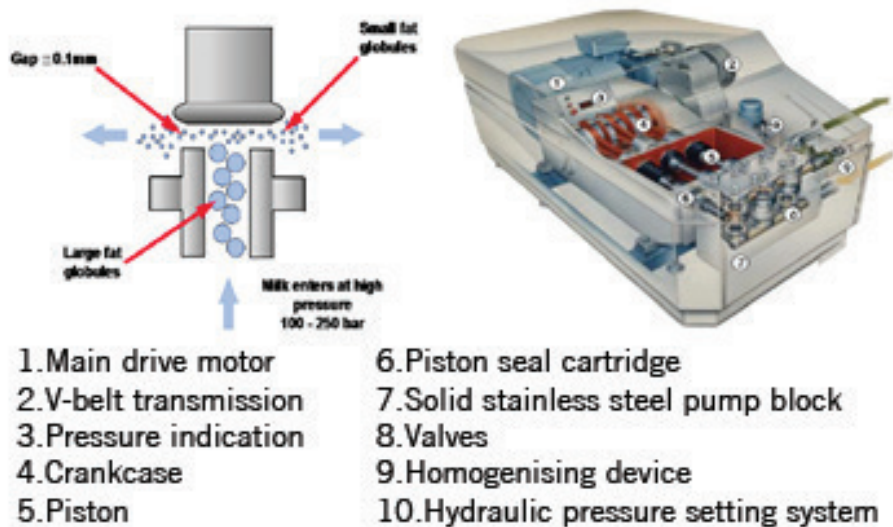
Figure 9: Homogenization Process

Homogenization makes sure that the fat is spread out evenly in the milk. Milk is transferred to an equipment called homogenizer. In this machine, the milk fat is forced, under high pressure, through tiny holes that break the fat cells up into tiny particles, 1/8 their original size. Protein, contained in the milk quickly forms around each particle and this prevents the fat from rejoining. The milk fat cells then stay suspended evenly throughout the milk.

CIP – Clean in Place is a method of cleaning the interior surfaces of pipes, vessels, process equipment, filters and associated fittings, without disassembly. Hygiene is an essential factor in the processing of food products. This requires a good and controlled cleaning or/and sterilization of the processing equipment.
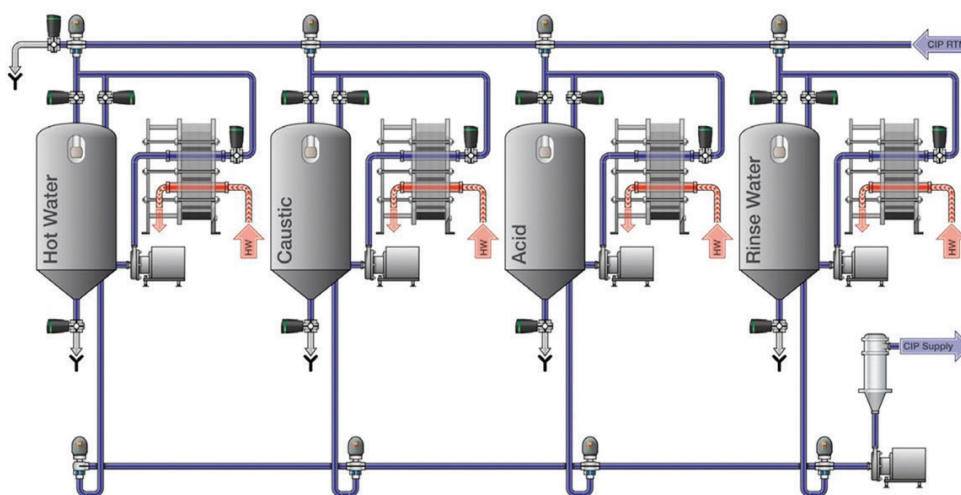
Figure 10: Auto CIP – (Source Alfa Laval)
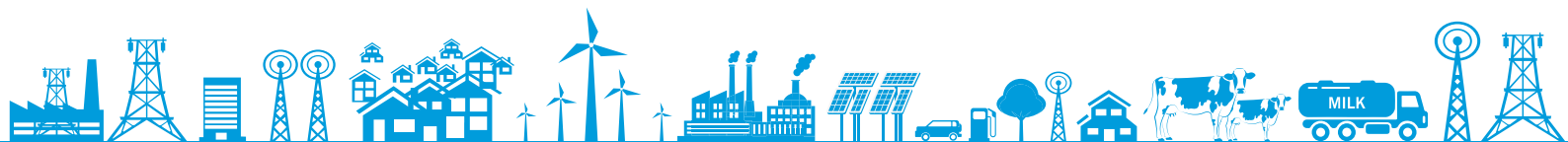
Packaging and storage: Milk is then pumped through automatic filling machines directly into bags, cartons and jugs. The machines are carefully sanitized and packages are filled and sealed with automated machines. This keeps outside bacteria out of the milk, which helps keep the milk stay fresh. During the entire time that the milk is at the dairy, it is kept at 1°-2°C. This prevents the development of extra bacteria and keeps the milk fresh.

In addition to the fluid milk, the dairy produces various other value-added products and unit operations and processes vary from product to product. Depending on the market demand, the dairies produce the value-added product. Some of the value-added products by dairies across India are butter, cheese, buttermilk, ghee, paneer, curd, milk powder, etc.

Figure 11: Milk Packaging

2.3 Energy Consumption in Dairy Plants

The dairy industry uses energy in the form of steam, hot water and electricity for processing milk and milk products. The cost of energy sources used in the industry is increasing continuously, which in turn increases the processing expenses and, therefore, the product cost. Energy costs typically constitute 10%-20% of the overall manufacturing cost. The following table provides an overview of major energy consuming areas within a dairy plant:

Table 5: Energy Consumption Overview for Dairy Plant

Sr. No	Equipment	Process Requirement	Primary Energy	Secondary Energy
1	Pre Chiller	Cooling	Electricity	Chilling Media
2	Pasteurization	Heating	Natural gas (NG)/Briquette/Furnace oil/High Speed Diesel (HSD)	Steam
		Cooling	Electricity	Chilling Media
3	Cold Rooms	Cooling	Electricity	Chilling Media
4	CIP	Heating	NG/Briquette/FO/HSD	Steam
5	Milk Powder	Heating	Steam	
6	Value Added Products	Heating	NG/Briquette/FO/HSD	Steam
		Cooling	Electricity	Chilling Media

Energy consumption of different processing plants varies widely, depending on capacity utilization, availability of milk, scale of the plant, technology used, level of automation and product mix. The share of primary energy (thermal and electrical) in a typical dairy plant is depicted in Figure 12 and is primarily dominated by electrical energy.

Energy Cost - Share (Dairy Plant)

60% Electrical
40% Thermal
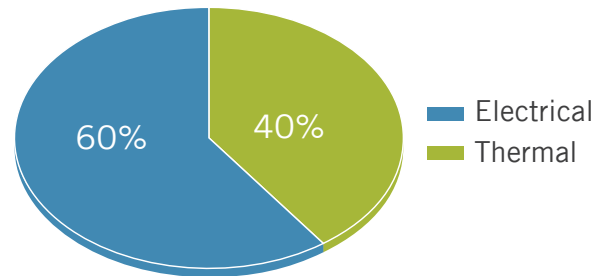
Figure 12: Energy Cost – Breakup (Dairy Plant)

Energy Balance of a Dairy Plant

20% Milk Processing
35% Refrigeration and Cold Storage
15% Utilities and Lighting
20% CIP, Washing and Others
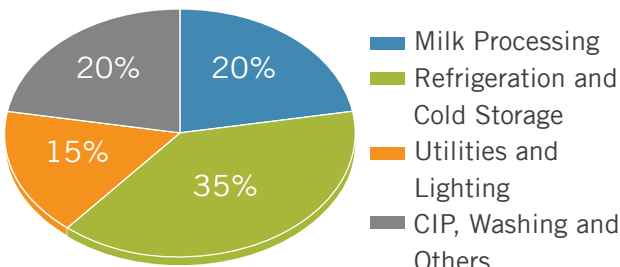
Figure 13: Energy Balance of a Dairy Plant

The major portion of energy consumption in a typical dairy goes to refrigeration, general utility and services, which include heating and steam generation. A certain portion of energy consumption goes to the cleaning operation and the processing activity. The major energy consuming equipment includes refrigeration system, air compressors, lightings, pumps, motors, homogenizers, evaporating plants, separator and clarifiers,
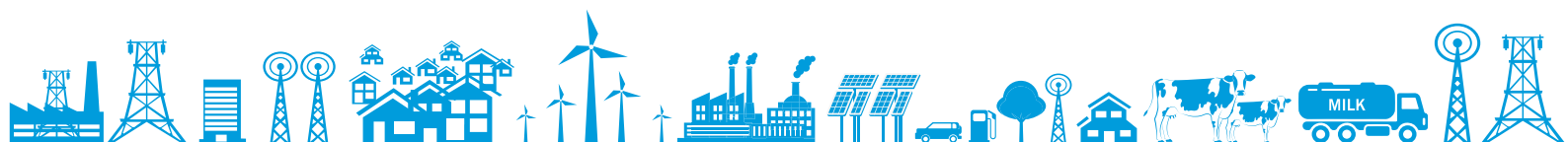
effluent treatment plant, CIP and boilers. Figure 13 highlights the overall energy balance of a plant. More than 35% of the total energy consumption is consumed in refrigeration and cold storage and 30% is consumed in milk processing, which includes heating and cooling, while the remaining energy is consumed in other supporting activities such as cleaning, utilities and packing.

Dairy plants in India have seen significant improvement in energy and productivity in the last few years due to increased levels of automation and technology development. This has helped in improving product quality and operating conditions while reducing product losses, maintenance time, manpower requirement and energy consumption. Innovations like cooling of hot cream with chilled raw milk have been adopted to improve regeneration efficiency and, thereby, reduce energy consumption. The new, dairy plants have implemented new energy efficient process equipment like plate heat exchangers, cream separators, homogenizers, etc. Building designs now provide more natural light coupled with a natural ventilation system, which has led to conservation of energy as well as improvements in operating conditions.
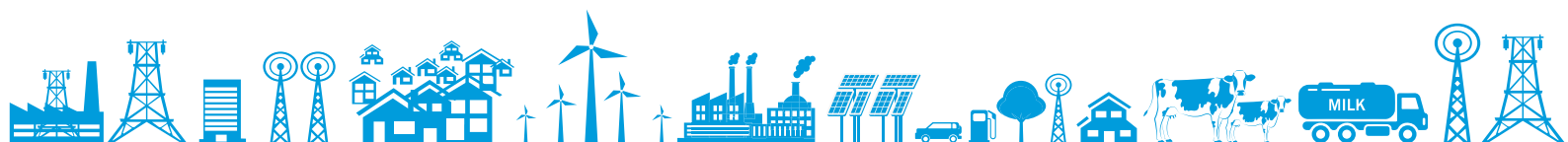
2.4 Technology Status in Gujarat Dairy Cluster

The dairies in Gujarat were mostly established during the period of 1950-1970, and have expanded over time with upgradation of equipment and technologies, expansion, automation, and process control. Many of the dairies have also adopted latest technologies in processing and other important areas of the dairy processing plant. Following is the technology status for the dairies in Gujarat:

Table 6: Technology Status – Gujarat Dairy Cluster

Sr. No	Area	Current Status
1	Energy Sources	Electrical and thermal energy are the major energy consumed in the dairy plant. Electrical Energy – The dairy units procure electricity from distribution companies in Gujarat (depending on region) and pay in the range of INR 6- 8/kWh. Power procurement through open access is also practiced at one of the units. For thermal energy it is mostly met through natural gas. In Gujarat, the natural gas is available through City/Industrial Gas Distribution Network and is made available for the units to use for their requirement. Natural gas fired boilers are used across various dairies, and in addition, depending on availability of biomass, the biomass briquette is also used in boilers. In addition to these, High-Speed Diesel, Furnace Oil and coal is also used in dairy units for meeting their thermal energy requirement. In addition to the above, many of the dairy units also use biogas generated from their Effluent Treatment Plant (ETP) in boilers or other applications.
2	Steam Generation	The dairy units in Gujarat use boilers for meeting their steam requirement. It is generated in range of 15-22 kg/cm² in the plants and is used in various processes, such as pasteurizers, powder plant and other process areas. Many of the units have upgraded their boilers with energy efficient boilers and have incorporated various energy conservation measures such as excess air control, automation, flue gas heat recovery, etc. However, not all the units use condensing economizers, and this presents good opportunity for upgradation from conventional economizers.
3	Steam Distribution	On the steam distribution side, the dairies reduce the pressure of steam through Pressure Reducing Valve (PRV) and send it to various process/section for use. On the condensate recovery, not many units have the systems in place for maximum recovery and this is still a potential area to be targeted. In addition to that, the steam trap monitoring and maintenance is also an important area for dairies to focus on. In addition to the above, one important area that large dairies (more than 10 Lakh litre/day capacity) can explore is the option of using micro turbine instead of PRV.

Sr. No	Area	Current Status
4	Refrigeration Compressors	The refrigeration system is a critical area for any dairy, as faster and appropriate cooling is a necessity. Many of the dairy units are using screw compressors (equipped with VFD) and evaporative condensers. However, a few of the units have reciprocating compressors and this is a potential area for improvement. In addition to the technology upgradation, other areas where improvement is possible include: waste heat recovery from compressors, ammonia overhead feed systems, VFD for compressors, etc.
5	Condensers	In Gujarat cluster, many dairies have upgraded their condenser cooling systems from conventional shell & tube to evaporative condensers, and this has helped to improve energy efficiency in refrigeration systems. For units using the conventional systems, the use of evaporative condenser is an attractive option to improve energy efficiency.
6	Process Area	Most of units in the cluster have been using high regenerative pasteurizers for High Temperature Short Time (HTST) processing, and some of the latest technologies in Ultra High Temperature (UHT) Processing. In addition to the above, some opportunity still exists in terms of technology upgradation as well as in process automation and control. In addition to that, most of the dairies in Gujarat have milk powder plant, and use steam radiators for heating and multi effect systems for evaporation to produce milk powder.
7	Renewable Energy	A few of the dairy units in Gujarat have utilized the option of renewable energy for electrical and thermal energy. Some units have installed rooftop systems (kW scale), but there's good potential for Solar Photo Voltaic (PV) installation in various other diaries. Some units have also installed Solar Thermal Systems for boiler feed water heating or hot water for CIP.
8	Others	The other equipment and technologies to support dairy processing are Pumping, electrical distribution, compressed air systems, etc.
8a	Pumping	The pumping systems are used extensively in dairy processing for pumping milk and water. The efficiency of these pumpsets needs to evaluated, as some pumps are old and when expansion is undertaken, new pumpsets are installed, but often there is good scope for improvement by avoiding throttling (installation of VFD, trimming of impeller) or installation of high efficiency pumpsets (more than 75% efficiency).
8b	Electrical Distribution	Power Factor: Most of the units have installed Automatic Power Factor Controller (APFC) for power factor improvement. For harmonics control, the units have also installed harmonic filters. However, there are certain opportunities which dairies can tap in electrical distribution, such as installation of energy efficient transformers, optimal loading of transformers, installation of energy efficient motors, installation of VFD, soft starters, auto star delta conversion, etc.
8c	Compressed Air	Compressed air in dairy units is used as instrument air and also in packing machines. The units use either screw compressors or reciprocating compressor to meet their compressed air requirements.

3. Energy Efficiency Opportunities

3. Energy Efficiency Opportunities

3.1 Energy Efficiency in Dairy

The dairy operations are highly energy intensive as the milk and value-added products are to be heated and cooled in various cycles to ensure that they are not spoilt and have a long shelf life. The refrigeration and steam systems are necessary and energy consuming for any dairy and improving energy efficiency in these areas are critical.

Over the years, there has been significant technology improvement in process and utilities area and dairies have been able to improve energy efficiency in their operations. However, opportunities still exist for dairies to improve their energy efficiency and to become more competitive. For environment friendly operation, energy efficiency is indispensable.

The dairies have been implementing various energy conservation measures across various production processes. Energy efficiency at a dairy industry can be viewed at two levels – equipment & component level and process level. The energy efficiency at equipment or component level can be achieved by adopting various new technologies, preventive maintenance, optimum utilization, or replacement of old equipment with new and energy efficiency equipment. In addition to improving energy efficiency at equipment or component level, the dairy industry in India has made significant improvements in process level efficiency through various energy conservation measures such as automation, process control & optimization, process integration or implementation of new and efficient processes.

Often, energy efficiency measures when implemented at the dairy operations not only result in improvement in energy efficiency but also in productivity and quality. To summarize, the energy efficiency strategy for dairy industry can be focused at three levels:
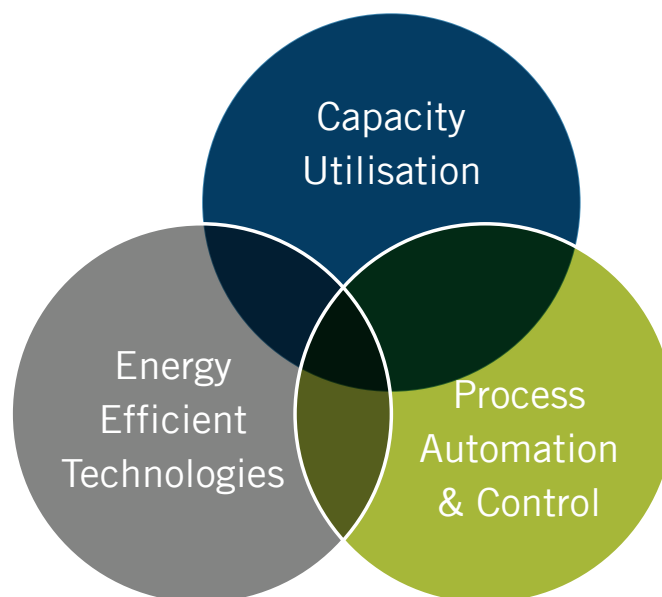
Figure 14: Energy Efficiency Approach – Dairy Industry

3.2 Energy Efficiency Measures

There are various energy consuming areas within a dairy plant which can be classified as primary energy consuming areas, such as steam systems and the refrigeration plant. The following figure provides an overview of energy usage in a dairy plant:
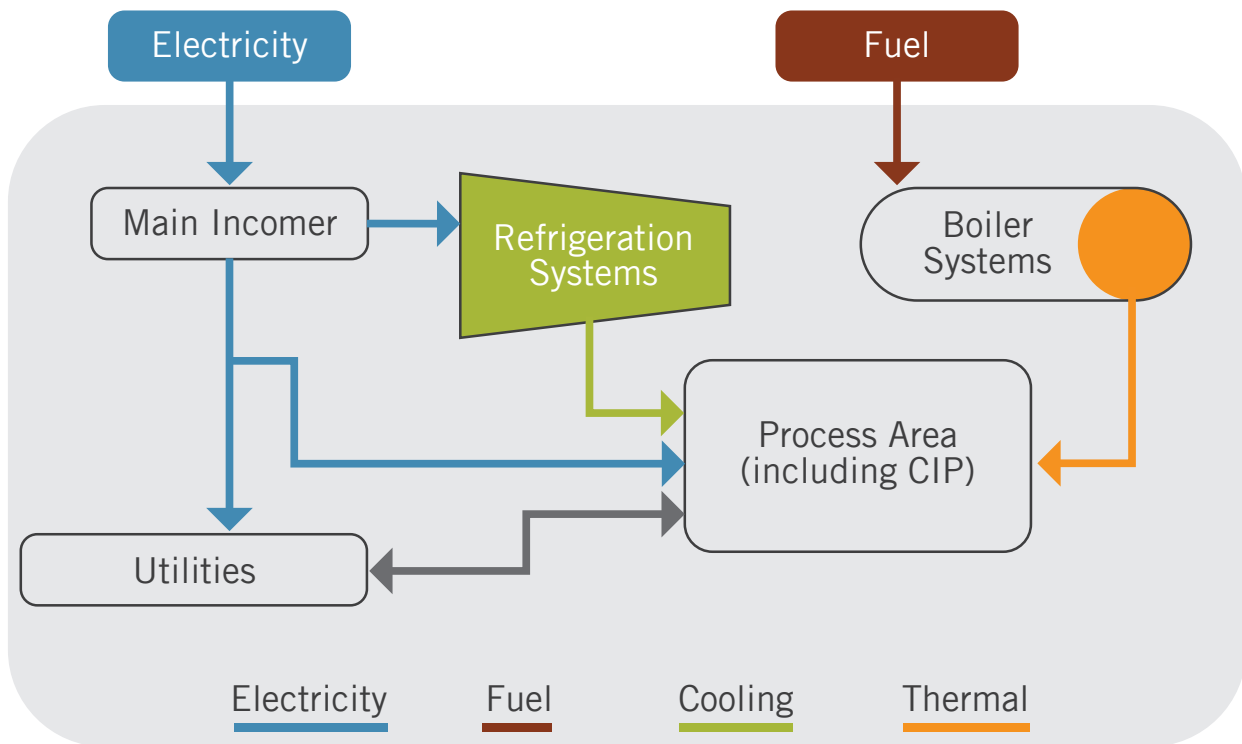
Figure 15: Dairy - Energy Consumption Overview

The following section provides an overview of some of the key energy efficiency measures in major energy consuming areas in a dairy unit. In further sections, some of the latest applicable technologies are covered.
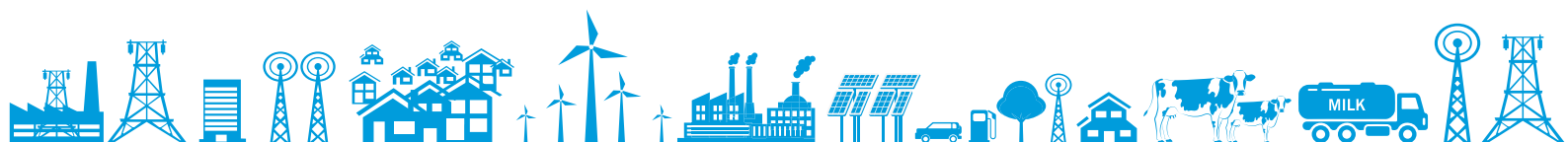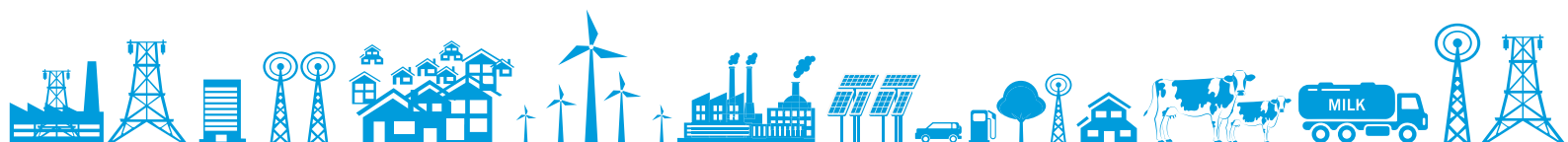
3.2.1 Energy Efficiency in Steam Systems

The steam or steam generation is an important utility area for dairy, as many of the processes in a dairy unit require heating of raw milk or products for various process requirements. The steam is generated in a fuel-fired boiler and is further distributed into process through steam distribution systems. The energy efficiency in steam generation and steam distribution is an important area as it accounts for approximately 25-30% of the energy cost. Following are some of the key energy conservation measures in steam generation and steam distribution systems:

Table 7: Energy Efficiency Measures in Steam Generation and Distribution Systems

Energy Efficiency in Steam Generation and Distribution Systems	
Steam Generation – Boilers	
Use of Energy Efficient Boilers	Fuel Switch (Coal to Natural Gas (NG))
Excess Air Control	Boiler Process Automation & Control
Improved Insulation	High Efficiency Burners (for NG)
Proper Boiler Maintenance	Automatic Blowdown
Condensing Economizers	Condensate Recovery
Steam Distribution	
Appropriate Selection of Steam Trap	Improved Insulation
Reduced Pressure drop in pipelines	Steam Trap monitoring and maintenance
Recovery of Condensate	Flash Steam Recovery
Monitoring and addressing steam leaks	Proper Design of Distribution Systems
Management Systems	
Effective monitoring of Key Parameters	Root Cause Analysis
Others	
Use of Micro Turbine	Briquette Fired Boiler

3.2.2 Energy Efficiency in Refrigeration Systems

Refrigeration system is the heart of any dairy value chain. From procurement to consumption of milk, it is stored in low temperatures. For a dairy unit, the refrigeration load can be in the range of 30-40% of the overall electrical load and is hence a significant contributor to overall energy expenses. Thus, energy efficiency at refrigeration can significantly impact the energy consumption and energy cost for a dairy unit. For chilling applications, most dairies use ammonia-based compressors, as they are reliable and efficient for refrigeration effect. The concentrated ammonia is much colder than typical room temperature, which makes it an excellent choice for dairy units. Over the years, there have been many technology developments in the refrigeration systems in compressors, condensers, pump sets, controls, etc. Some of the energy efficiency measures in the refrigeration system are as follows:

Table 8: Energy Efficiency in Refrigeration Systems

Energy Efficiency in Refrigeration Systems	
Compressors	
Use of Screw Compressors	Installation of Variable Frequency Drive (VFD)
Appropriate Refrigeration Charge	Compressor Control and Scheduling
Optimum Suction Pressure	Monitoring key parameters
Preventive maintenance	Ammonia Overhead feeding systems
Two-Stage Compression	Process Automation & Control
Condensers and Evaporators	
Use of Evaporative Condensers	Preventive maintenance of Condensers
Automatic Tube Cleaning Systems	VFD for Fans
Reducing condensing pressure	Auto Controls
Cycling of evaporators fans	
Cooling Load Management	
Piping Insulation	Doors/Curtains for Cold Rooms
Minimizing Heat Infiltration	Separation of Cold/Hot Areas
Insulation Paint	Maintenance of Heat Exchangers
Others	
Use of Energy Efficient Motors	Waste Heat Recovery from Compressors
Dedicated compressor for Packing Room Cooling	Chilling Centre Monitoring Systems
Use of Plate Heat Exchangers (PHE) in IBT Cooling	Installation of Falling Film Chiller before IBT
Use of Direct Cooling in IBT	Use of Vapor Absorption Systems
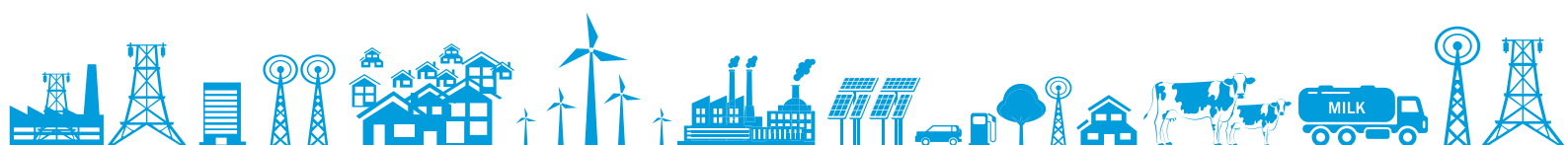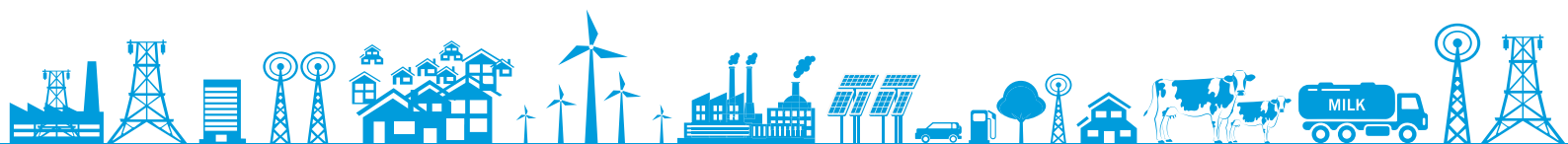
3.2.3 Energy Efficiency in Process

Dairy process for processing milk and value-added products has evolved significantly over time, going from manual production to automatic production. The energy efficiency improvement in process areas will result not only in reduction in demand of utilities (steam, chilling load, etc.) but will also improve productivity and quality. For example, installation of pasteurizers with high regeneration efficiency can result in reduction in energy demand. Some of the possible energy efficiency measures in process areas in dairy plant are highlighted in the table below:

Table 9: Energy Efficiency in Process Areas

Energy Efficiency in Process Area	
Pasteurization & Homogenization	
High Regeneration Efficiency Pasteurizers	Pasteurizers Hibernation (Tetra Pak, 2019)
Low Temperature Pasteurization	Use of Plate Heat Exchanger instead of Tubular Heat Exchanger
Use of Low Pressure Homogenization (Tetra Pak, 2019)	Partial Homogenization (Tetra Pak, 2019)
Process Optimization	-
Milk Powder Plant (NDDB, Energy Management in Milk Powder Plants, 2004)	
Application of Computational Fluid Dynamics (CFD)	Mechanical Vapor Recompression
Optimum Pressure Drop	Energy Efficient Fan
Heat Recovery from Exhaust Air	Higher Effect Evaporators
Higher Inlet Temperature of Drying Air	Auto Start up
Other Measures	
Auto CIP	Heat Pumps Application
Emerging Pasteurization Techniques	Insulation of Hot and Cold Pipes
Reuse first effect condensate	High speed electro mechanical machine

3.2.4 Energy Efficiency in Utilities

The utilities such as compressed air, electrical distribution systems, waste water treatment, lighting and other areas are also energy consuming sections in a dairy plant and here also many energy efficiency improvement opportunities are available for dairy units. The following table provides an overview of possible energy efficiency opportunities in utilities:

Table 10: Energy Efficiency in Utilities

Energy Efficiency in Utilities	
Compressed Air Systems	
Use of Screw Compressors	Use of Demand Side Controller
Energy Efficient Air Dryers	Auto Drain Valves
Use of VFD	Appropriate Ventilation in Compressor Room
Optimum Generation Pressure	Compressor Leakage (less than 5%)
Pneumatic Equipment to Electric Equipment	Proper distribution systems
Electrical Distribution Systems	
Automatic Power Factor Controller (pf. 1)	Harmonic Filters
Energy Efficient Transformers	Optimum Voltage and line balance
Optimum Loading of Transformers	Energy Monitoring Systems
Pumps	
Energy Efficient Pump Sets	Trimming of Impellers
Maintenance of Pump Sets	Coating for Casing
VFD for Pump Sets	Pumping System Layout
Motors	
Energy Efficient Motors	Star to Delta Conversion
kVAr Compensators	Preventive Maintenance
Optimum Loading	Belt Driven to Direct Coupled
Lighting & Fans	
Use of LED Lights	Use of Brushless Direct Current (BLDC) - Ceiling Fans
Occupancy Sensors	Use of Natural Light (Light Pipe)

Heating Ventilation and Air Conditioning (HVAC)	
Use of Star Rated Air Conditioners	Use of Energy Efficient Air Handling Unit (AHU)
Smart AC Controller	Variable Refrigerant Flow units
Energy Monitoring and Control	Optimum Cooling at 24°C
Renewable Energy	
Solar PV Installation	Solar Thermal (Evacuated Tube)
Biogas Utilization	Briquette fired boilers
Waste Water Treatment	
Use of Membrane Bio-Reactor (MBR) System	Bio-Gas Utilization (BIO CNG)
Energy Efficient Pump Sets	
Energy Efficient Blowers	
Automation and Control	
Other measures	
Use of Phase change materials	Cogeneration
Trigeneration	Application of Internet of Things (IOT)
Pinch Analysis	-
Water Conservation Measures	
Rainwater Harvesting	Water Efficient fixtures
Reuse of water in gardening	Application of IOT
Energy Management Systems	
Implementation of ISO 50001:2018 – Energy Management Systems	Energy Efficiency Targets and Improvements (Roadmaps)
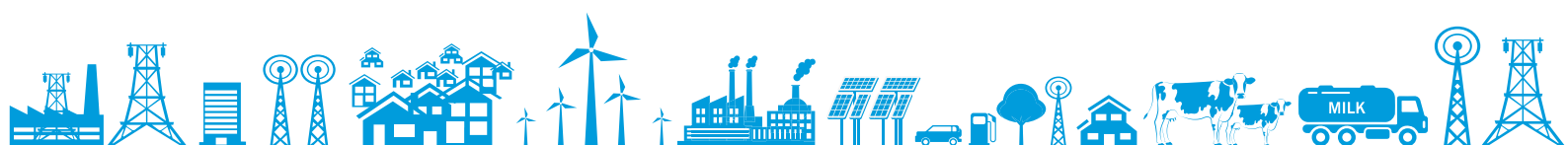
3.2.5 Best Practices and Key Indicators for Energy Efficiency

In addition to the above measures, the dairies can also follow industry best practices and monitor key performance indicators for ensuring energy efficient operations and processes.

Table 11: Best Practices for Energy Efficient Operations

Sr. No.	Measures	Productivity Impact	Estimated Savings
Steam Generation and Distribution			
1	Generate and transfer steam closer to rated boiler pressure	The thermal storage capacity of the boiler is increased, helping it to cope more efficiently with fluctuating loads, minimising the risk of producing wet and dirty steam.	3% - 4 % fuel savings
2	Utilize steam at lowest pressure in case of indirect heating	Better heat transfer, less cycle/ heating time, fuel saving and productivity.	For an indirect process requirement with temperature of 80°C, if steam at 3.5 kg/cm² is used instead of 2 kg/cm², the heat loss is in the range of 2% - 3%.
3	Maintain high boiler feed water temperature	Improved Steam to Fuel Ratio	Increasing feed water temperature by 6°C results in 1% fuel savings.
4	Maintain Flue Gas Stack exit temperature between as low as possible depending on fuel	Increased life of components in flue gas circuit like duct, fan and stack. Reduction in downtime and maintenance cost.	Every 22°C reduction in flue gas exit temperature results in 1% fuel savings.
5	Install Auto Blow Down System	Lower fuel cost due to reduction in makeup water and better boiler efficiency.	Annual savings of 18 Tons of briquette for a 2 TPH boiler operating with continuous manual blowdown.
6	Condensate Recovery from Process	Improved Steam to Fuel Ratio	10% - 15% fuel savings with 90% condensate recovery.
Refrigeration Systems			
7	Raise the evaporation temperature and lower condensing temperature to the extent possible	Optimum cycle time and energy consumption	Raising the evaporation temperature by 1°C reduces energy consumption by around 3%. Similarly, lowering the condensing temperature also reduces the energy consumption at the same rate
8	Avoid scale formation and fouling in heat exchangers	Optimum cycle time and energy consumption	2% - 3% savings in compressor power
9	Install Variable Frequency Drives (VFDs) for evaporator fans.	None	10% - 15% savings in evaporator fan power consumption
10	Waste Heat Recovery from chiller compressor	Lower load on condenser	7% - 8% fuel savings
11	Replacing shell and tube condenser with evaporative condenser	Water savings	50% savings in condenser auxiliary power and 8% - 10% savings in compressor power.

Sr. No.	Measures	Productivity Impact	Estimated Savings
12	Installation of VFD for chiller compressor	None	8% - 10% power savings (may vary as per site condition)
13	Installation of Prechiller before IBT	Lower temperature in peak load	20% - 30% savings in compressor power
Compressed Air			
14	Arrest air leakages in the compressed air system	Zero down time due to instrumentation fault / low compressed air pressure fault. Target less than 5%	Every 10% reduction in air leakage reduces the electrical energy consumption by 10%.
15	Generate compressed air at the optimum pressure	None	A reduction in the delivery pressure by 1 bar in a compressor would reduce the power consumption by 8%.
16	Replacement of old inefficient compressor with screw compressor	Zero down time due to less maintenance	10% - 15% compressor power savings
17	Installation of VFD in air compressor to avoid unloading	None	15% compressor power savings (may vary as per site condition)
Process Area			
18	Process control optimization	High productivity improvement	10% - 12% cost savings
19	Proper monitoring of pasteurization process parameters	Monitoring of key parameters allows proper functional evaluation of pasteurizer, which helps in upkeep of productivity.	Every 1°C increase of milk temperature after regenerative heating zone reduces steam consumption by 1.9 kg/ kl of milk. Every 1°C reduction of milk temperature after regenerative cooling zone reduces chilling load by 0.33 TR / kl of milk.
Others			
20	Replace low efficiency pumps with energy efficient pumps	Reducing the cycle time for process applications	15% - 25% savings in power
21	Use of VFDs for controlling the pump speed as per process requirement	None	20% - 30% savings in power
22	Improvement of overall power factor of the plant	None	10% - 20% cost savings
23	Installation of light pipe to avoid artificial lights during day time	None	100% savings in power
24	Replacement of Ceiling Fans with Energy Efficient BLDC fans	None	50% power savings
25	Replacing old-rewound motors with energy efficient motors	None	20% - 30% savings in power
26	Energy savers for split ACs	None	20% - 30% savings in power
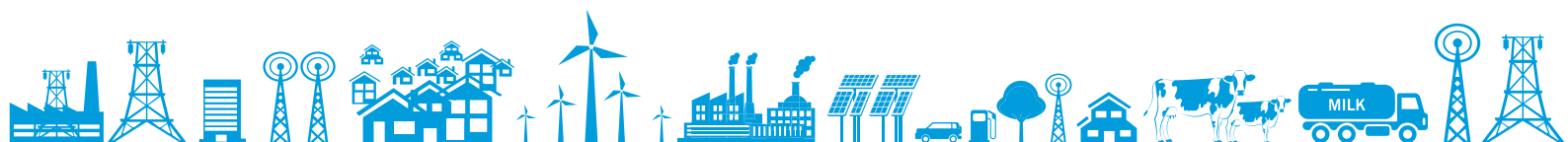
Sr. No.	Measures	Productivity Impact	Estimated Savings
27	Bio Gas Generation from ETP	None	2% - 3% energy reduction
28	Solar Thermal System	None	5 kl Solar thermal can result in INR 2.5 lakh saving

Monitoring of critical parameters of facilities and equipment is essential for ensuring optimal performance of key energy consumers in the dairy. Some of the useful energy indicators which plants can utilize for monitoring their performance are given below:

Table 12: Energy – Key Performance Indicators

Sr. No.	Parameter	Measurement Unit	Indicator
1	Boiler Steam Pressure	kg/cm²	Nearer to boiler rated pressure
2	Boiler Steam Temperature	^{o}C	Nearer to boiler rated rating
3	Boiler Water TDS	ppm	3,200 – 3,500 ppm
4	Oxygen in Boiler Flue Gas	%	FO/NG fired – 2.5% – 3% Briquette/Wood fired – 4%
5	Boiler Flue gas temperature	^{o}C	120 - 180 ^{o}C for package boilers
6	Steam to Fuel Ratio / Evaporation Ratio		2 - 3.5 for biomass fired boilers 4 - 7 for coal fired boilers 11 - 14 for oil /gas fired boilers
7	Specific Steam consumption at Pasteurization process	kg steam / kl milk	Indirect: 20 - 22 kg /kl Direct: 16 - 19 kg / kl
8	Feed Water temperature	^{o}C	Above 85°C
9	Range of Cooling Tower	^{o}C	9 - 12°C
10	Approach of Cooling Tower	^{o}C	3 - 4°C
11	Refrigeration Compressor Specific Energy Consumption	kW/TR	0.8 - 0.9 kW/TR for Screw Compressors 1.1 - 1.3 kW/TR for Reciprocating Compressors
12	Ice Bank Tank (IBT) & Cold Room Temperature	^{o}C	IBT: 0°C - 0.5^{o}C Cold Room temperature based on product stored
13	Compressed air Generation Pressure	kg/cm²	Closer to user requirement
14	Compressed air Loading %	%	80 - 90%
15	Compressed air Unloading %	%	10 - 20 %
16	Compressed air SEC	kW/cfm	0.18 kW/cfm for Screw Compressors 0.14 kW/cfm for Reciprocating Compressors
17	Pasteurization Raw milk inlet temperature	^{o}C	4 - 7°C
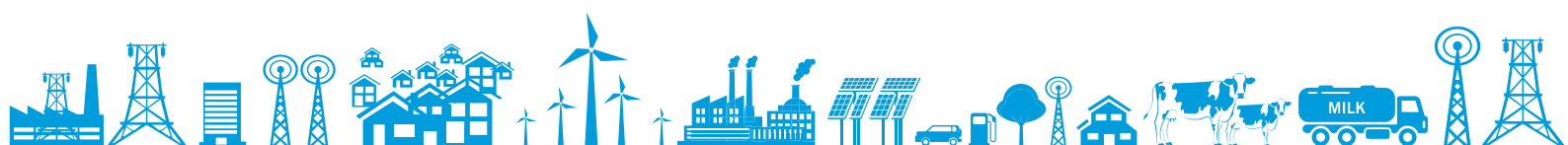
Sr. No.	Parameter	Measurement Unit	Indicator
18	Temperature after pre-heating by Regeneration	^{o}C	9 – 10°C lesser than pasteurization Temperature
19	Pasteurization Temperature	^{o}C	75 - 79°C, depending on holding time
20	Temperature after pre-cooling by Regeneration	^{o}C	15 - 20°C
21	Chilled Milk Temperature	^{o}C	3 – 4°C
22	Electrical Parameters for Motors	kW,V, I, A, PF	Voltage +/-5% of rated voltage Within +/-5% of rated current Motor Loading › 80% for better efficiency range
23	Electrical Parameters	kW,V, I, A, PF, Harmonics	Plant LT voltage should be 410 -415V PF closer to unity Transformer loading - 50% -60% VTHD ‹ 8% at 415 V side ITHD ‹ 15% at 415 V side
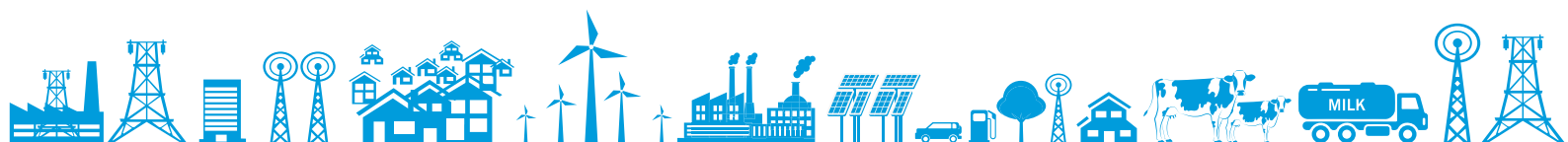
4. Energy Efficient Technologies
– Case Studies

4. Energy Efficient Technologies – Case Studies
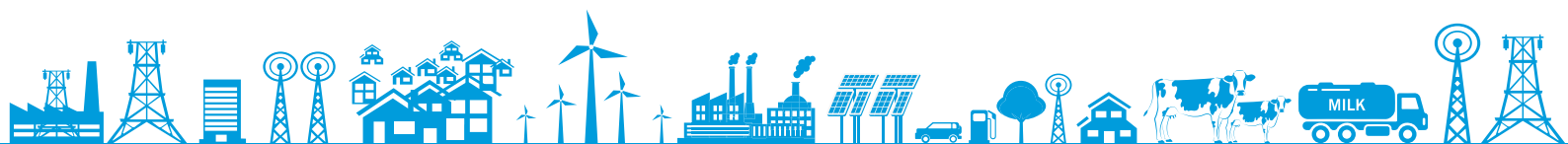
The energy efficiency measures mentioned in previous chapters are some of the measures implemented in dairy units. The following chapter focuses on some of the above-mentioned technologies which are promising and have been implemented in a few dairies and also have great potential for implementation (Case Study). These technologies are described in more detail and wherever possible, a case reference from a dairy that has implemented the technology has been included. In most of the examples, typical energy saving data, Greenhouse Gas (GHG) emission reduction, investments, payback period, etc., have been highlighted. As these case studies are included to provide confidence to dairies to implement technologies, the applicability of these measures may vary from unit to unit and further technical and financial analysis would be required for individual dairy units. Following case studies are mentioned in detail in the subsequent section:

Table 13: Case Studies for Dairy Sector

Sr. No.	Technologies
Steam Generation and Distribution	
1	Conversion of Furnace Oil Fired Boiler to Fully Automated Biomass Fired Boiler
2	Condensate Recovery System
3	Steam Operated Pumping Traps
4	Installation of Microturbine
Refrigeration Systems	
5	Installation of Screw Refrigeration Compressor
6	VFD in Chiller Compressor
7	Evaporative Condenser
8	Falling Film Chiller
9	Direct Cooling Method – IBT
Waste Heat Recovery	
10	De Superheater for Compressors
11	Heat Pump
12	Thermal Energy Storage for BMC

Sr. No.	Technologies
Utilities	
13	VFD for Air Compressor
14	Demand Side Controller for Compressed Air
15	Energy Efficient Pumps
16	Package Type Biogas Reactor
17	Methane Capture from dairy effluents
18	IoT based Water Management System
Renewable Energy	
19	Solar Rooftop system
20	Solar Thermal System
21	Solar-Wind Hybrid system

4.1 Case Studies in Steam Generation and Distribution

4.1.1 Conversion of Furnace Oil Fired Boiler to Fully Automated Biomass Fired Boiler

Baseline Scenario

The unit has installed two numbers of 3 TPH FO-fired three pass boilers for steam generation, which is used in process applications such as pasteurization, curd making, CIP, crate washing, etc. The daily furnace oil consumption of one boiler was identified to be at 650 litre/day, with 15 hours working per day. The average steam demand is 450 - 600 kg/hr at 7.5 - 10 kg/cm². Normally, temperature levels of process steam of the dairy plant are below 130ºC. Steam requirement is about 18-22 kg/kl of Dairy products. The following table shows the steam requirement in the plant:

Table 14: Seam requirement in plant

Sr. No.	Section	Steam Pressure	Steam Flow Rate	Hours of operation per day	Actual Steam Requirement per day (kg/day)
		kg/cm²	kg/hr	Hours	kg/day
1	Pasteurizer – 10 kl/hour	8	250	10	2,500
2	CIP 1 - 10 kl	3.5	900	0.33	300
3	CIP 2 - 10 kl	3.5	900	0.33	300
4	Curd Pasteurizer - 2 kl/hour	3.5	75	3	225
5	Product – Cup Curd - 400 litre	3.5	55	3	165
6	Ghee – 1,000 litre	3.5	180	9	1,620
7	Peda Vat 1 - 500 litre	3.5	70	9	630
8	Peda Vat 1 - 500 litre	3.5	70	9	630
9	Paneer Vat – 1,000 litre	8	100	1.5	150
10	Butter Vat – 1,000 litre	8	100	1.5	150
11	Autoclave – 1,200 bottles	8	150	3	450
	Total steam requirement				**7,120 kg/day**
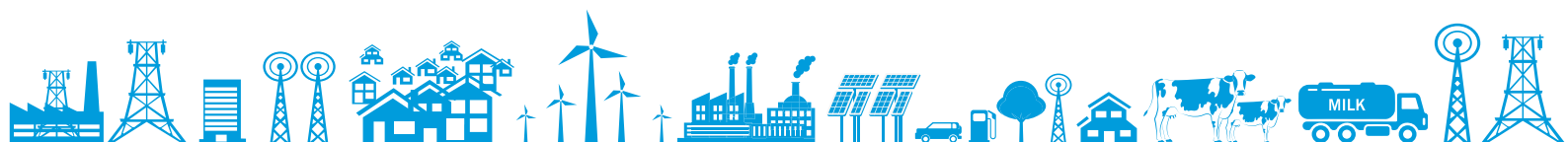
The average steam generation per day is 0.7 tons with an average consumption of 420 to 600 kg/hr. The peak steam requirement in plant is 1,200 kg/hr, when all processes are in operation. The boiler and fuel parameters are shown below:

Table 15: Boiler and Fuel Parameters

Parameter		
Boiler Type	Fire Tube, FO Fired, Shell Type	Fire Tube, FO Fired, Shell Type
Boiler Capacity	2 TPH	2 TPH
Boiler Design Pressure	10.5 kg/cm²	10.5 kg/cm²
Boiler Operating Pressure	7.5 – 9.5 kg/cm²	
Average Operating Hours	15 hours per day (2 shifts/ day)	
Fuel		
Fuel Type	Furnace Oil	
Fuel GCV	39,580 kJ/kg	
Fuel Firing Process	Auto	
Cost of Fuel	INR 33/- per kg	
Average Fuel Consumption	650 litres per day	
Number of working days	365 days per year	
Annual Fuel Bill	INR 78.3 lakh	

Past record shows that the average fuel consumption is 650 litres/day for 15 hr/day of operation. The boiler efficiency was also calculated using direct method, as shown below:

Table 16: Boiler Efficiency

Boiler Efficiency Direct Method		
Feed Water Temperature	35	°C
Calorific value of fuel	39,580	kJ/kg
Steam Flow	475	kg/hr
Fuel Firing Rate	41.98	kg/hr
Enthalpy of steam at 8 kg/cm²	2,769	kJ/kg
Feed Water Enthalpy at 35 °C	146	kJ/kg
Boiler Efficiency	75	%
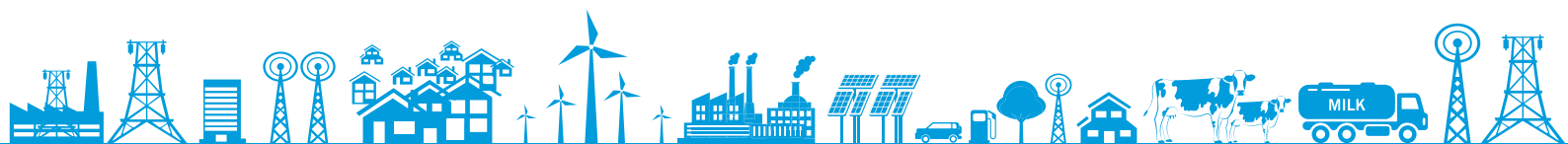
Proposed System

An efficient replacement for the current oil-fired boiler will assist in cutting down the increasing production cost. As far as the dairy plant is concerned, their objective is to go towards greener production and with minimal production cost. A sustainable fuel to generate heat for the process should be seen as a sustainable development opportunity. It is therefore highly recommended to install a new boiler in the plant with an alternative sustainable fuel like wood or briquette.

Furnace oil used in Boiler can be totally substituted by Wood or Briquette with an equivalent ratio of 2.7:1 kg/litre on the basis of calorific value. This usually results in saving of more than 60% in operating cost and will have attractive payback period.

Pre-requisite of the boiler substitution:

Availability of good quality new fuel (wood / briquette)

The availability of good quality and continuous supply of fuel is very important. To be feasible for this project, it is suggested that the boundary of the fuel supply distance should have less than a 30 km radius circle. In case of sudden unavailability of fuel, there should be another fuel option.

Availability of sufficient space for new boiler installation

Another factor is the availability of sufficient area. The required space for the boiler and the fuel storage has to be checked with the supplier and the plant has to make necessary arrangement for the same. It is highly recommended to install new generation biomass fired boiler with automation which works on the principle of continuous monitoring and controlling. Briquette has GCV up to 18828 kJ/kg; 3.2 kg of Briquette is equivalent to 1 litre of furnace oil. At INR 33/litre FO price and Briquette at INR 7.5/kg, the substitution will result in savings of INR 9/litre of FO fired. Similarly, about 5 kg of Wood (30% moisture) of GCV 12252 kJ/kg is equivalent to 1 litre of furnace oil. The savings in this case will be of INR 12.00/litre of FO fired with wood at INR 3.0/kg.

Merits

- ❖ Automation results in feeding optimum amount of fuel to boiler and thus reduces unburnt loses.
- ❖ Ensures max possible feed water inlet temperature, so that the generation will be maximum possible.
- ❖ Better water quality.
- ❖ Ensures periodic maintenance of boiler tubes, hence reduction in radiation loss.
- ❖ Zero emissions.
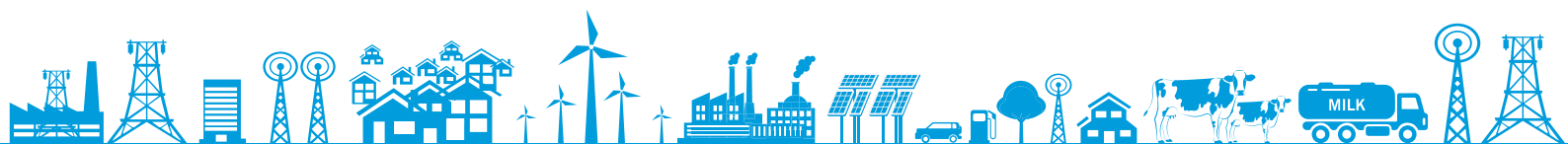
Limitations

❖ It is suggested that the boundary of the fuel supply distance should be less than a 30 km radius circle.

❖ Estimation of proper back pressure.

❖ Availability of sufficient space for new boiler installation.

❖ Storage area for fuel to keep it dry and away from moisture attack.

Cost Benefit Analysis

The expected fuel savings to be achieved by installation of fully automated biomass fired boiler is 2,18,363 litre of FO annually. The annual monetary saving for this project is **INR 36.79 lakh, with an investment of INR 130 lakh and a payback period of 3.5 years**.

Table 17: Cost Benefit Analysis – Energy Efficient Boiler

Sr. No.	Description	Unit	FO	Wood
	Average steam consumption	kg/hr	433	433
	Steam Enthalpy at 10 Kg/cm² pressure	kJ/kg	2,794	2,794
	Boiler Efficiency	%	75	75
	Fuel Calorific Value	kJ/kg	40,375	12,552
	Fuel Consumption	kg/hr	40	129
	Fuel Cost	INR/kg	33	3
A	Cost of fuel per hour	INR/hr	1,319	386
	Ash generated (Total)	kg	0	12
	Rate of Ash Disposal	INR/kg	0.2	0.2
B	Cost of Ash Disposal per hour	INR/hr	0	2.4
	Power Consumption for Utilities	kW	14	19
	Rate of Power	INR/kWh	6	6
C	Cost of Power Consumption per hour	INR/hr	84	114
	Labour for fuel feed per hour	Nos	0	2
	Manual-hour rate of labour	INR/hr	75	75
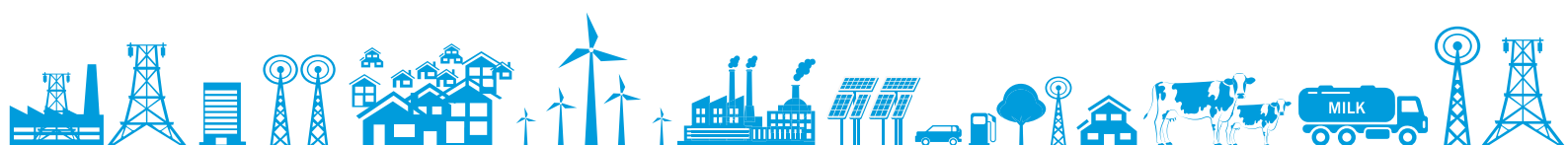
Sr. No.	Description	Unit	FO	Wood
D	Cost of Labour per hour	INR/hr	0	150
E	Total Running Cost per hour (A+B+C+D)	INR/hr	1,403	652
	Annual hours of operation	hrs	5,475	5,475
F	Total Running Cost per annum	INR lakh	83.8	39.4
	Average Annual Maintenance Cost	INR lakh	2	5
G	Total Operational Cost per annum	INR lakh	76.4	39.6
H	Total Saving per annum with Solid fuel	INR lakh		36.8
I	IRR	%	32.23	
J	Net Present Value (NPV) at 70 % Debt (12% rate)	INR lakh	78.81	

Energy & GHG Savings

Annual Fuel Savings

2,18,363 litre of FO

Annual Energy Savings

210 TOE

Annual GHG Savings

611 T CO_2
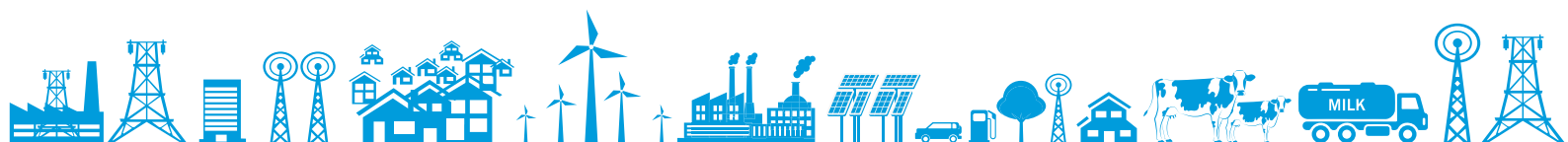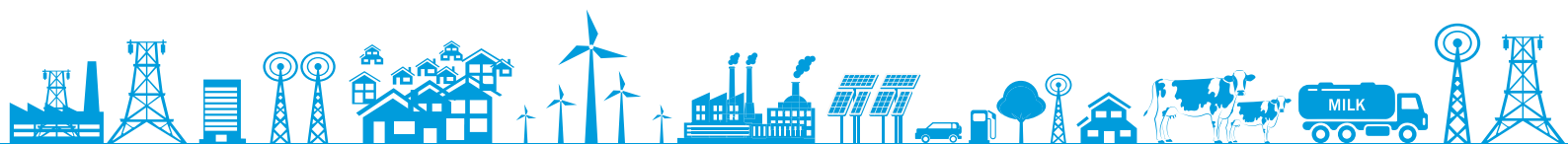
Table 18: Vendor details – Energy Efficient Boiler

Equipment Detail	Energy Efficient Boiler
Supplier 1	
Supplier Name	Forbes Marshall
Address	Forbes Marshall Pvt Ltd Pune – 411 034
Contact Person	Mr. Rupesh Bhawsar
Mail Id	rbhawsar@forbesmarshall.com
Phone No	+91 8980024819
Supplier 2	
Supplier Name	Thermax Pvt Ltd
Address	Thermax Pvt Ltd 410, Mahakant Complex Mavlankar Marg, Ahmedabad - 380006
Contact Person	Mr. Jainak Patel
Phone No	+91 9426464977

4.1.2 Condensate Recovery System

Baseline Scenario

The unit has installed one 3 TPH briquette-fired boiler and two FO-fired boilers for the process applications, such as pasteurization, curd making, CIP, crate washing, etc. Briquette-fired boiler is running and the others are on standby. The heating process in dairy is done by indirect heating. One of the major applications of steam is pasteurization process, where the milk is heated to 72°C for 16 seconds and quickly cooled to 4°C. This process slows spoilage caused by microbial growth in the food. Hot water at around 70°C to 80°C is used for indirect heating in the pasteurization process. The condensate after the process heating is currently drained or used in cleaning crates. As the condensate has some heat available, it can be utilized in the boiler or any other indirect heating for processes such as CIP, crate washing, etc. It was also observed that since most of the condensate drains are left open to atmosphere, it results in flashing of steam, which is a wastage of energy.

Proposed System

Condensate recovery is a process to reuse the water and sensible heat contained in the discharged condensate. Recovering condensate instead of draining it can lead to significant savings of energy, chemical treatment and make-up water. Install a flash vessel and condensate transfer/ pumping unit to recover all the condensate from various processes. Condensate pumping/ transfer system can pump a huge quantity of condensate, effectively utilizing steam, known as motive steam. Condensate is one of the purest forms of water having low electrical conductivity of only 5 µS/cm or TDS value of 3.5 ppm.
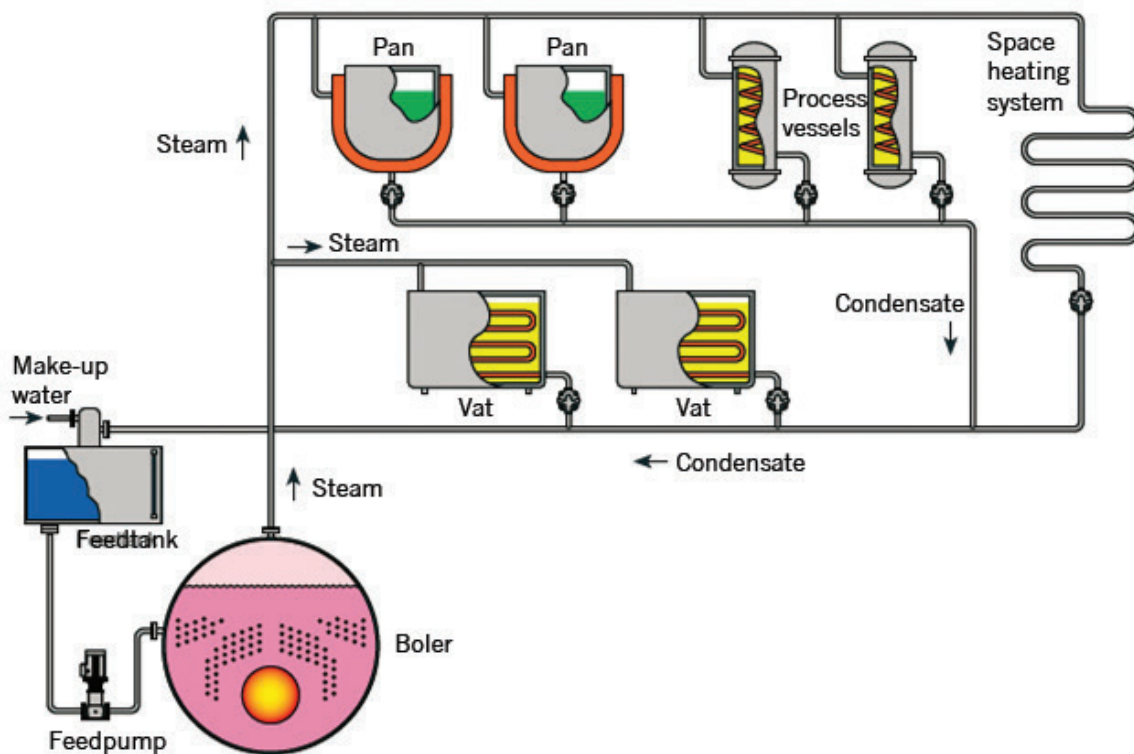
Figure 16: Typical condensate recovery system
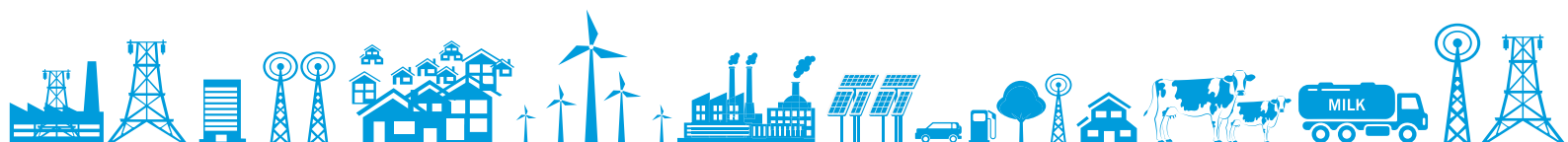
Condensate flows from receiver of the pump to the pump body and the level of water starts increasing and reaches the high level. This is sensed by the conductivity-based level sensor, which activates the motive steam inlet valve. Steam enters the pump at high pressure and the pressure in the pump body keeps on building till it overcomes the back pressure of the delivery side. Now, the outlet check valve opens and the condensate starts flowing out of the pump body, using high pressure of the steam. As soon as the level in the pump reaches the low-level position, the inlet valve for the motive steam is de-activated and the pump is de-pressurized. The pump again starts filling and the cycle repeats. The system requires no electric motor for operation. As the quantity of condensate discharged at each stroke is known, the total volume passed during a given period can be calculated by counting the number of strokes during the period. Such a counter is provided, enabling display of the total condensate pumped. The totalized volume of condensate pumped is displayed on an electronic unit.
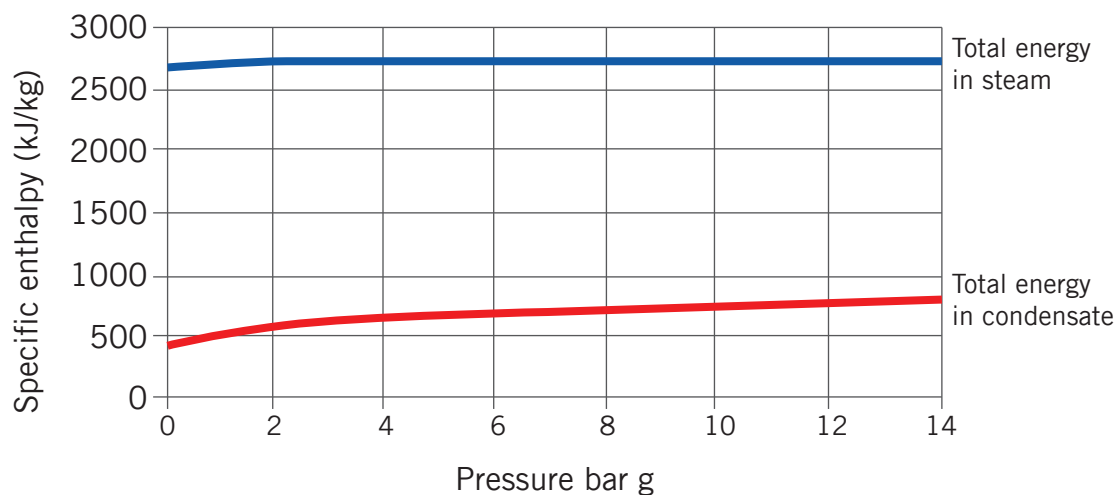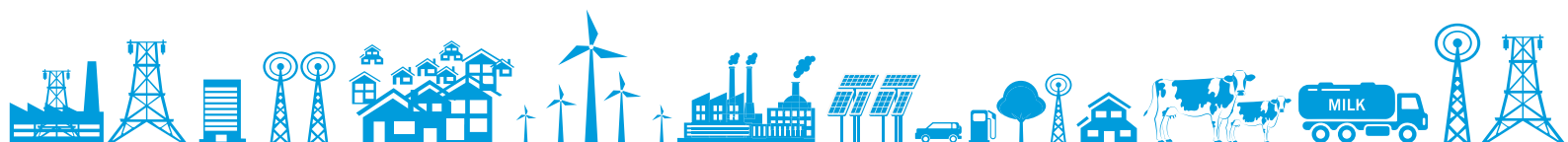
Figure 17: Heat content in condensate

A flash steam generator can be installed for recovery of flash steam just before the condensate recovery system. When high pressure condensate is discharged from steam traps to low pressure condensate return lines, excess energy is released in the form of flash steam. This flash steam can be used to heat boiler feed water or for low pressure steam application.

Merits

❖ High availability due to zero moving parts.
  ◈ High reliability and equipment availability.
  ◈ Low wear & tear.
  ◈ Low maintenance.
  ◈ Low downtime.

❖ High motive inlet pressure; no need of pressure reducing valve/ station till 10 kg/cm^2, where low pressure steam is not available, hence saving on installation cost.

❖ High discharge of condensate: 50 litre per stroke.

- ❖ High condensate temperature return: No cavitation issues over electrical pumps.
- ❖ Conductivity-based level controller (a stringent quality & design process followed in European market, to ensure safe operation).
- ❖ A large LED display with flow totalizer to display the total volume displaced.
- ❖ Suitable for outdoor installations.
- ❖ Energy efficient pump; steam trap drain and pump vent taken back to the receiver tank to minimize vent losses.
- ❖ Electrical motor required.

Limitations

- ❖ Requires regular maintenance.
- ❖ Estimation of proper back pressure.
- ❖ Inventory of electronic spare parts to be maintained.

Cost Benefit Analysis

The expected fuel savings to be achieved by installation of condensate recovery system is 1.1 tons of Briquette, annually. The annual monetary saving for this project is **INR 7.41 lakh, with an investment of INR 6.40 lakh and a payback period of 10 months**.

Table 19: Cost Benefit Analysis – Condensate Recovery Systems

Parameters	UOM	
Boiler Capacity	TPH	3
Operating Pressure	kg/cm²	9
GCV	kJ/kg	16,736
Fuel Cost	INR/kg	6.6
Fuel Consumption	kg/hr	209
Boiler Efficiency	%	75
Enthalpy of steam at 9 Bar	kJ/kg	2,773
Steam Flow	kg/hr	1,024.00
Condensate Available considering losses	kg/hr	900
Condensate Working Pressure	kg/cm²	1.5
Flash Steam	%	5.19
Mass of Flash Steam	kg/hr	46
Mass of Condensate Available	kg/hr	853.33

Parameters	UOM	
Latent Heat of flash steam	kJ/kg	2,107.5
Fuel saved from condensate recovery	kg/hr	11
Fuel saved from flash steam recovery	kg/hr	7
Total Fuel Saved	kg/hr	18
Operating Hours	hours	17
Operating Days	days/year	360.00
Annual Fuel Savings	kg	1,12,348.24
Monetary Savings	INR lakh	7.41
Investment	INR lakh	6.40
Payback Period	months	10
IRR	%	143.60
NPV at 70% debt (12% rate)	INR lakh	34.64

Energy & GHG Savings

Annual Fuel Savings

1.12 T of briquette

Annual Energy Savings

44.94 TOE

Annual GHG Savings

-
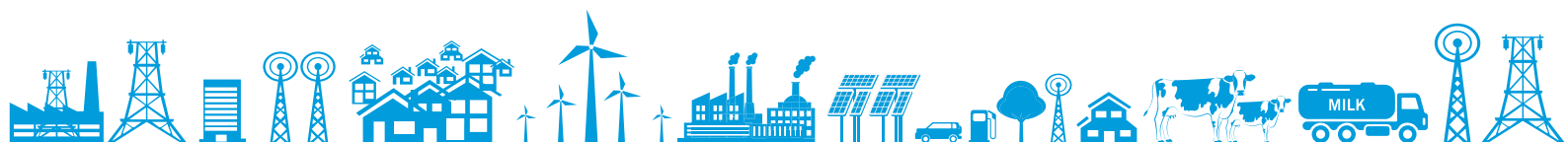
Reference Plant Implementation

Table 20: Reference Implementation – Condensate Recovery Systems
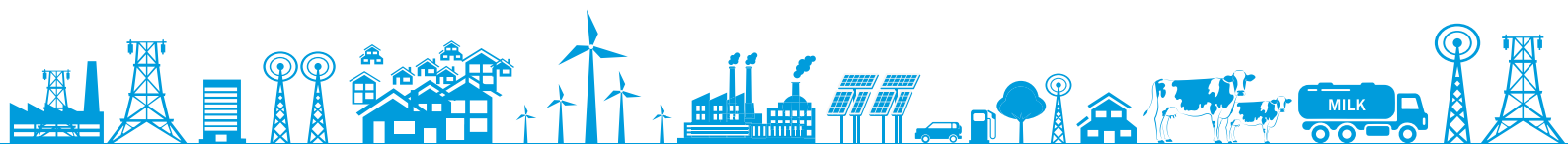
Project Name	Installation of Condensate Recovery System
Supplier 1	
Objective	Installation of condensate recovery system to recover the condensate and use it as feed water for boiler.
Unit profile	Amul Fed Dairy is the apex organization of the Dairy Cooperatives of Gujarat. It manufactures products like milk, butter milk, flavored milk, lassi, ghee and ice cream, etc.
Installation Photo	
Assumptions Made	❖ Operating hours – 16hrs/day ❖ Boiler efficiency – 81% ❖ GCV of fuel – 15,062 kJ/kg
Savings (INR lakh)	₹ 7.11
Investment (INR lakh)	₹ 3.20
Simple Payback Period	6 months
Replication potential	In all the dairy units irrespective of size and milk chilling centers.
Outcomes	❖ 148.15 T of biomass saved annually. ❖ Increase in feed water temperature.
Unit contact details	**Mr. Paresh Mehta** **Amul Fed Dairy** Plot No 35, Gandhinagar Ahmedabad Road, Bhat , Gujarat Phone: 93750 51780
Cluster Reference	Gujarat Dairy Cluster
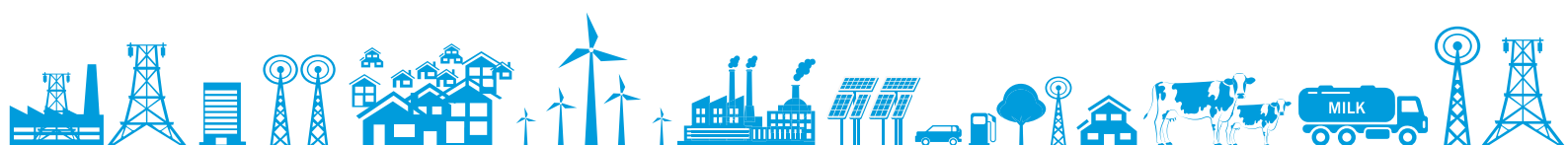
Vendor Details

Table 21: Vendor Details – Condensate Recovery Systems

Equipment Detail	Condensate Recovery Systems
Supplier 1	
Supplier Name	Forbes Marshall
Address	Forbes Marshall Pvt Ltd Pune – 411 034
Contact Person	Mr. Rupesh Bhawsar
Mail Id	rbhawsar@forbesmarshall.com
Phone No	+91 8980024819
Supplier 2	
Supplier Name	Thermax Pvt Ltd
Address	Thermax Pvt Ltd 410, Mahakant Complex Mavlankar Marg, Ahmedabad - 380006
Contact Person	Mr. Jainak Patel
Phone No	+91 9426464977

4.1.3 Steam Operated Pumping Traps

Baseline Scenario

The unit has installed two FO-fired boilers of 2 TPH capacity each for the hot water requirement inside the plant. Boiler details are given below:

Table 22: Boiler details

Boiler	Fuel Type	Design Capacity (TPH)	Operating pressure (kg/cm²)	Design pressure (kg/cm²)
Boiler 1	FO - Running	2 TPH	8	10
Boiler 2	FO - Standby	2 TPH	-	10

The FO is initially preheated using an electric heater in tank and then used for firing inside the boiler. The major steam consuming equipment are:

❖ 1 No. of 5 kl Heat Exchanger at CIP section

◇ Operating pressure   - 3.5 kg/cm^2

❖ 2 Nos. of Crate Washers

◇ Operating Pressure   - 3.5 kg/cm^2

❖ 4 Nos. of CIP Tanks

◇ Operating pressure   - 3.5 kg/cm^2

For the 5 kl heat exchanger in CIP section, the steam flow to the Heat Exchanger is regulated by a Proportional Integral Derivative (PID) based Temperature Control Valve (TCV), which is taking feedback from the temperature sensor at the outlet hot water line. Now, as the set temperature of hot water is attained, the TCV tends to close position. This in turn causes the steam flow rate and thus steam pressure be reduced, which in turn causes water logging at the steam trap due to the lack of required differential pressure across the trap.
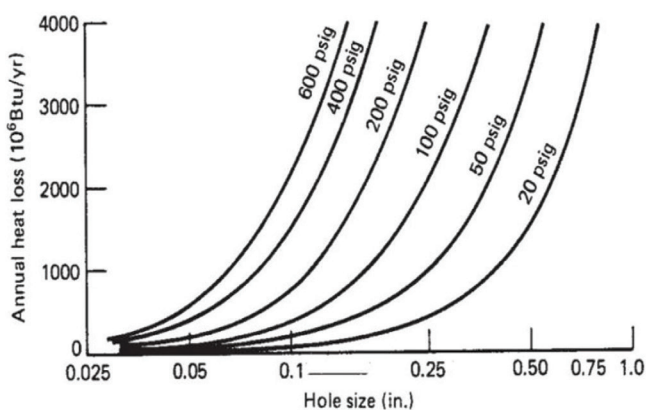
Figure 18: Steam Loss Chart

A steam trap will be operational only above the rated minimum differential pressure. Normally, operation of a steam trap requires a minimum differential pressure of 0.1 kg/cm^2, however, this may vary with manufacturers. If the condensate flow pressure is lesser than the minimum required differential pressure, water logging happens which is also called stalling. This leads to problems of hammering, reduction of thermal performance of heat exchanger, corrosion of heating surfaces, inevitably reducing the service life of the exchanger.
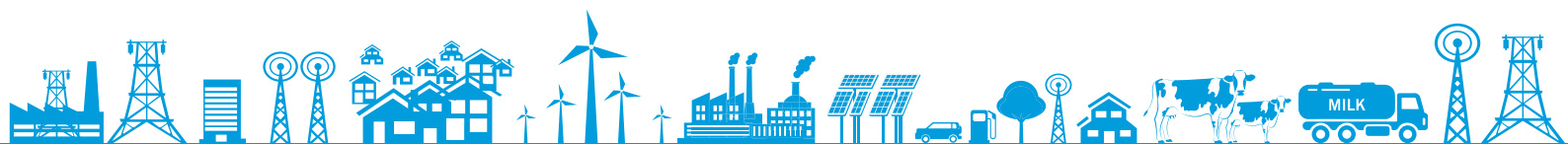
Now, to avoid this stall condition of steam traps, equipment operator normally operates the by-pass valve, either keeping bypass line partially open full-time or intermittently opening and closing it. In both the cases, live steam loss occurs, thereby increasing the energy consumption. The orifice size of 15 NB bypass valve open is 5 mm at 3.5 kg/cm² operating pressure. Through this orifice size, steam loss is 30 kg/hr from the steam loss chart.

Proposed System

It is recommended to replace the ball float steam trap with Steam Operated Pumping Trap (SOPT). With this system in place, whenever the condensate pressure is low, motive steam/ air shall provide the additional thrust to make the condensate flow and avoid any stalling.

Merits

❖ Improved condensate recovery.

❖ Reduced steam leakages through the system.

Limitations

❖ Proper maintenance is required.

Cost Benefit Analysis

The expected fuel savings by installation of SOPT is 4,162 kg of FO annually. The annual monetary saving for this project is **INR 1.54 lakh, with an investment of INR 1.51 lakh and the Payback Period for the project is 12 months**.

Table 23: Cost Benefit Analysis – Installation of Steam Operated Pumping Traps

Parameters	UOM	
Orifice Size	mm	5
Operating Pressure	kg/cm²	3.5
Steam loss through orifice	kg/hr	30
Considering 50% live steam leakage	kg/hr	15
Enthalpy of steam at 3.5 kg/cm²	kJ/kg	2,723
Total heat loss	kJ/hr	40,856
GCV of Fuel	kJ/kg	41,003
Boiler Efficiency	%	79
Fuel Loss	kg/hr	1.26
Operating hrs	hrs	3,300
Annual Fuel Savings	kg	4,162.297
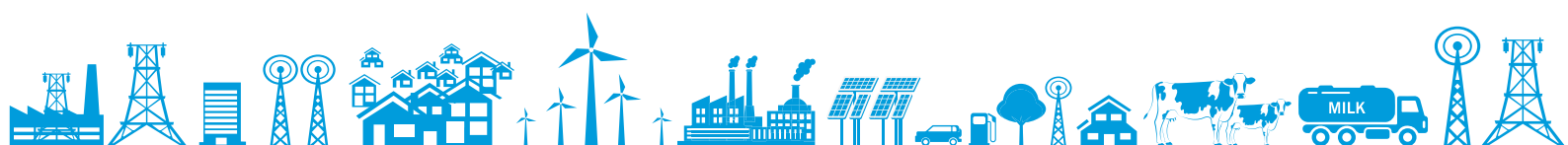
Parameters	UOM	
Fuel Cost	INR/kg	37
Monetary Savings	INR lakh	1.54
Investment	INR lakh	1.51
Payback period	months	12
IRR	%	128.76
NPV at 70% debt (12% rate)	INR lakh	7.11

Energy & GHG Savings

Annual Fuel Savings
4,162 kg of FO

Annual Energy Savings
4.08 TOE

Annual GHG Savings
12.79 T CO$_2$
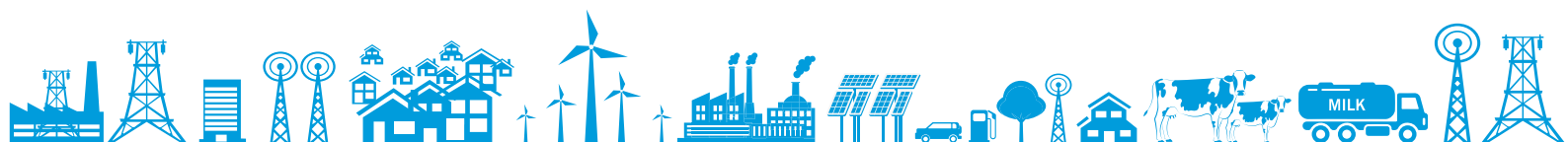
Vendor Details

Table 24: Vendor Details – Steam Operated Pumping Traps

Equipment Detail	Steam Operated Pumping Traps
Supplier 1	
Supplier Name	Forbes Marshall
Address	Forbes Marshall Pvt Ltd Pune – 411 034
Contact Person	Mr. Rupesh Bhawsar
Mail Id	rbhawsar@forbesmarshall.com
Phone No	+91 8980024819

4.1.4 Installation of Microturbine

Baseline Scenario

The unit has installed four boilers to generate steam of required quantity and pressure for process applications in the plant. Dairy plants need steam in various heating applications such as milk pasteurization process and powder plant. All heating process in dairy is through indirect method, i.e., there is no direct mixing of steam with any fluid. The boilers are connected to a common steam header and steam is redistributed to various processes at reduced pressure using PRV. The details of boiler installed in the plant is shown below:

Table 25: Boiler Details

Boiler	Fuel Type	Design Capacity (TPH)	Operating (TPH)	Design pressure (kg/cm²)
Boiler 1	NG/Biogas/FO	15 TPH	12 TPH	24
Boiler 2	NG/Biogas/FO	10 TPH	8 TPH	22
Boiler 3	NG/FO	10 TPH	8 TPH	17.5
Boiler 4	NG/FO	12 TPH	10 TPH	17.5

The two major applications of steam inside the plant are pasteurization and powdering plant process. During pasteurization process, milk is heated up to a temperature of greater than 73 °C to kill bacteria. For this purpose, hot water is used at a temperature of around 85 °C. The hot water is generated by using low pressure (LP) steam at 3 kg/cm² in hot water Plate Heat Exchanger (PHE). For powdering plant, 15 TPH boiler and steam is generated at a pressure of 24 bar which is then distributed at 8 bar using a PRV. The steam at 8 kg/cm² is used to heat milk in evaporator column. In evaporator columns, milk is heated with steam under vacuum to remove water content in milk to make powder. The minimum steam pressure required in dairy is 3 kg/cm² for pasteurization process and maximum steam pressure required is around 8 kg/cm² for powder plant. Even though steam pressure required is lesser at user end, boilers in dairy plants are generating steam at higher pressure (maximum steam pressure of up to 17.5 kg/cm²). Since steam is generated at higher pressure in boiler compared to user end pressure requirement, pressure is reduced through Pressure Reducing Valves (PRV) as per each user requirement. In PRV, pressure of the steam is reduced to a pre-set limit, so as the steam comes out at a lower pressure, it will get utilized in the user end process applications. During the process of steam pressure reduction, there is a loss of steam pressure energy in PRV without any use. The table below shows the steam parameters before and after the PRV which is going to powdering plant:

Table 26: Parameters – Before and After PRV

Inlet Conditions	UOM	
Inlet Steam Pressure (At the Turbine Main Inlet Control Valve)	kg/cm²	21
Inlet Steam Temperature (At the Turbine Main Inlet Control Valve)	°C	217
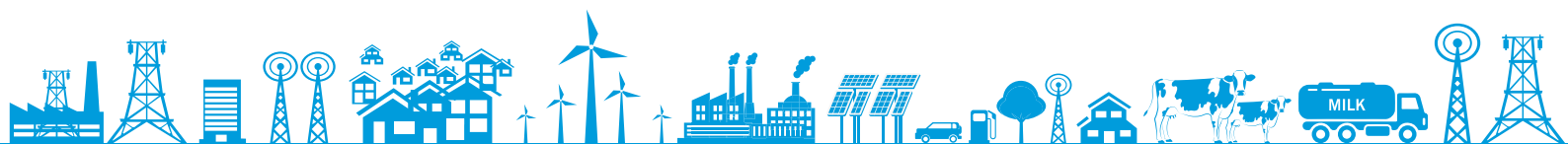
Inlet Conditions	UOM	
Inlet Steam Flow (At the Turbine Main Inlet Control Valve)	TPH	6
Exit Steam Pressure (At the Turbine Exhaust Flange)	kg/cm²	9
Exit Steam Temperature (At the Turbine Exhaust Flange)	°C	180
Exit Steam Flow (At the Turbine Exhaust Flange)	TPH	6

Proposed System

It is recommended to install a 90-kW generating potential microturbine in the HP line supplying steam to powdering plant. By replacing the existing PRV with a microturbine, nearly 90 kW of power can be generated, which can be used in non-critical loads like ETP, admin building, lighting loads, etc. The existing PRV line can be kept in standby and can be used in situations of sudden load fluctuations, or additional steam requirements. Micro turbine offers several potential advantages compared to other technologies for small-scale power generation. These advantages include a small number of moving parts, compact size, lightweight, greater efficiency, lower emissions, lower electricity costs and opportunities to avoid pressure loss in steam systems. They have the potential to be located on sites with space limitations to produce power.

Performance curves
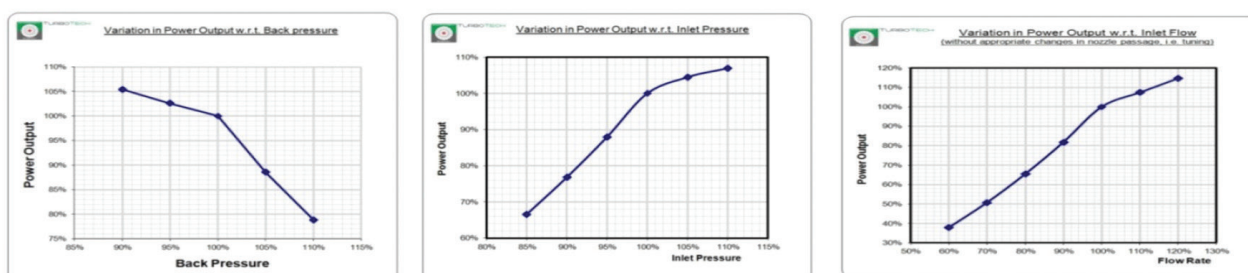
Figure 19: Variation in Power Output – Performance Curve

Auxiliary Power

AC Supply: Single and Three Phase @ 50 Hz

Table 27: Auxiliary Power Consumption – Micro Turbine

Sr. No.	Utility	Start up and Shut Down	Continuous Demand
1	Auxiliary Oil Pump	1.5 hp	Not Required
2	Auxiliary Power	0.5 hp	0.5 hp
	Total Power	2 hp	0.5 hp
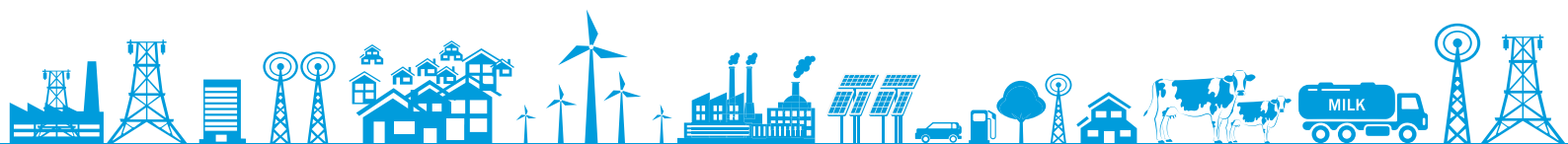
Merits

❖ Reduced pressure loss in system.

❖ Compact size and lightweight.

❖ Free availability of power.

Limitations

❖ Plant may need to do minor steam piping changes to accommodate turbine in system and to combine all low-pressure user pipelines at one place.

❖ Correct quantification of following parameters is necessary:

◇ Steam pressure requirement at the outlet of turbine.

◇ Quantity of steam input and variation in input steam flow rate to turbine (minimum steam flow and maximum steam flow) for successful design of turbine

Cost Benefit Analysis

The expected electricity savings by installation of micro turbine is 5,18,400 kWh annually. The annual monetary saving for this project is **INR 40.95 lakh, with an investment of INR 53.69 lakh and a payback period of 16 months**.

Table 28: Cost Benefit Analysis – Micro Turbine

Parameters	UOM	Value
Inlet Pressure	kg/cm²	21.00
Back Pressure	kg/cm²	9.00
Saturated Steam Temp. at Inlet	°C	217
Steam Flow Rate	x 1,000 kg/h	6.00
Steam Condition at Inlet	Dry-Saturated	100%
Enthalpy at Inlet	kJ / kg	2
Isentropic Enthalpy Drop	kJ / kg	207
Actual enthalpy Drop	kJ / kg	66
Generator Efficiency		95%
Temperature at Exit	°C	143
Enthalpy at Exit	kJ / kg	(64)
Electrical Power Output	kW	90
Boiler Operation Hours	hrs/day	16
Auxiliary Power	kW	0.37
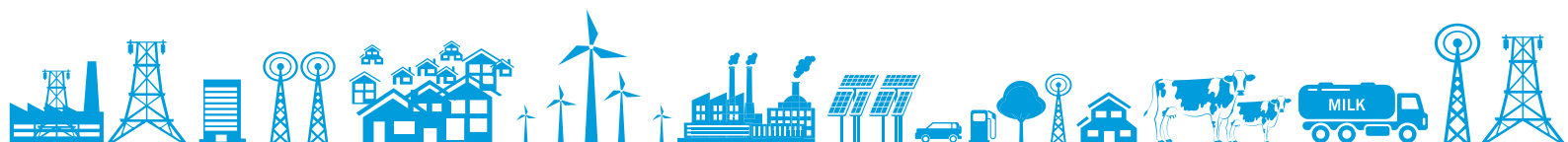
Parameters	UOM	Value
Electricity Cost	INR/kWh	7.90
Operating Days	days	360
Annual Electricity Savings	kWh	5,18,400
Annual Cost Savings	INR lakh	40.95
Investment	INR lakh	53.69
Payback	months	16
IRR	%	100.81
NPV at 70% Debt (12% rate)	INR lakh	182.94

Energy & GHG Savings

Annual Electricity Savings	Annual Energy Savings	Annual GHG Savings
5.18 lakh kWh	44.58 TOE	425.09 T CO$_2$
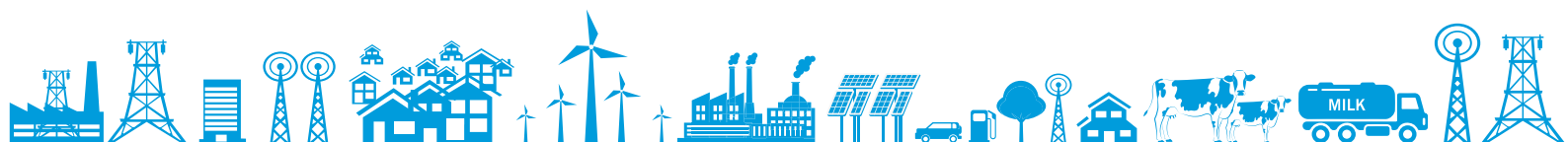
Vendor Details

Table 29: Vendor details - Microturbine

Equipment Detail	Micro turbine
Supplier Name	TurboTech Precision Engineering Private Limited
Address	TurboTech Precision Engineering Private Limited Survey No. 8/2, Honnasandra Village, Kasaba Hobli, Bengaluru
Contact Person	Mr. Saurabh Tripathi
Email Id	saurabh@turbotechindia.com
Phone No	+91 96060 85791

4.2 Case Studies in Refrigeration Systems

4.2.1 Installation of screw refrigeration compressor

Baseline Scenario

The unit has five reciprocating chiller compressors of 90 kW and 70 TR each, based on vapor compression ammonia cycle. These compressors cater to the chilled water requirements and FCU units in the cold storage area. Of the five compressors installed, two compressors are running during morning time and three compressors are running during night time for ice formation in the IBT. The performance of the chiller compressor is shown below:

Table 30: Operating Parameters of compressors

Parameters	UOM	
Rated Refrigeration Capacity (2 x 70 TR)	TR	140
Rated Power (2 x 90 kW)	kW	180
Design SEC	kW/TR	1.29
Condensing Temp	^{0}C	35 to 40
Suction Pressure	psi	35.55
Discharge Pressure	psi	177.79
Discharge Temperature	^{0}C	100 to110
Total Operating Power	kW	122
Total Operating TR	TR	92
Operating SEC	kW/TR	1.33

Currently the reciprocating compressor is running continuously at full load irrespective of the load variations in the plant and operating SEC is 1.33 kW/TR which is on higher side. As in any dairy processing unit, during the day time, when all the processes (mainly pasteurization and pre chilling of raw milk) are in operation, the compressor is 80% to 100% loaded and consumes more power. During the night, the cooling requirement drops and the compressor runs only for the purpose of maintaining the temperature on the Ice Bank Tank (IBT). During this time the total refrigeration load on the plant is less, but still the compressor takes the same power as it was consuming during the peak load.

Proposed System

It is recommended to replace the existing reciprocating compressors with 155 TR screw compressor equipped with VFD. The table below shows the comparison of screw and reciprocating compressor:
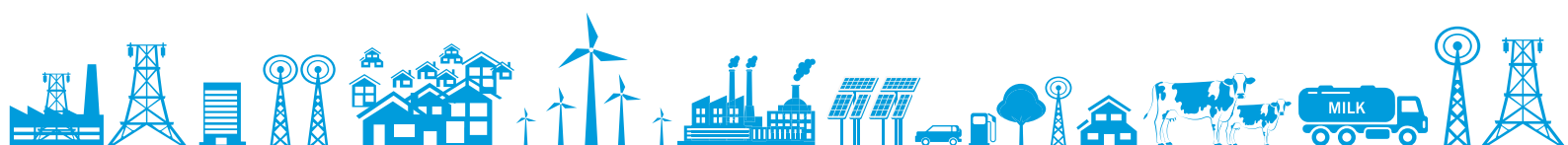
Comparison Between Screw Compressor and Reciprocating Compressor	
Screw Compressor	Reciprocating Compressor
Fully automatic and has variable capacity control system from 10 to 100%. This means at any % of capacity, screw would operate precisely at this point and power consumption will be linear correspondingly, which means compressor perform at peak efficiency under varying load condition.	Unloaded step-wise only, that means partial loads operate at lower suction than designed suction which load to lower volume efficiency and high-power consumption resting in higher kW/ TR.
Ideal for larger plant as they can reduce installation cost, installed power and space by eliminating 3 to 4 reciprocating compressors.	Ideal for small plant. Spares inventory for maintaining 3 to 4 reciprocating compressors more/ high.
BKW / TR is on lower side at any suction temperature	Always on higher compare to screw.
Connected motor rating also less	High compare to screw.
Direct coupled. No belt loss.	Belt direction minimum 3% for belt losses.
No tolerance required.	Tolerance required at 2.5%.
Fewer moving party and simple rotation motor which means less maintenance, vibration levels, less friction loss.	Many moving parts. That means high repair cost.
Having efficient oil separation system for better oil management and low oil carry loss.	Oil carry over more.
Having PLC based control panel which constantly monitor the system and maintain most efficient operation condition.	Through manual cutouts.

The screw compressor with VFD proposed for the plant will operate at lower kW/TR of 1.00 compared to 1.33 kW/TR when operating with reciprocating compressor. Also, the VFD installed along with compressor will result in smooth control of operation as the suction pressure is given as feedback to the compressor. Based on the refrigeration load, the refrigerant temperature required will vary, hence the suction pressure. During the light load condition when the pasteurization process stops, compressor runs only to maintain IBT temperature and to maintain the temperature in cold storage during this time, with suction pressure as the feedback. Once the evaporator achieves the desired temperature, with proper feedback, the speed of the compressor can be reduced and hence power savings can be achieved.

Merits

❖ Variable Volume Ratio control.

❖ Efficient Oil Separation & low oil carry over.

❖ PLC based system for efficient operation.

❖ Higher reliability of operation.

❖ Reduced maintenance.
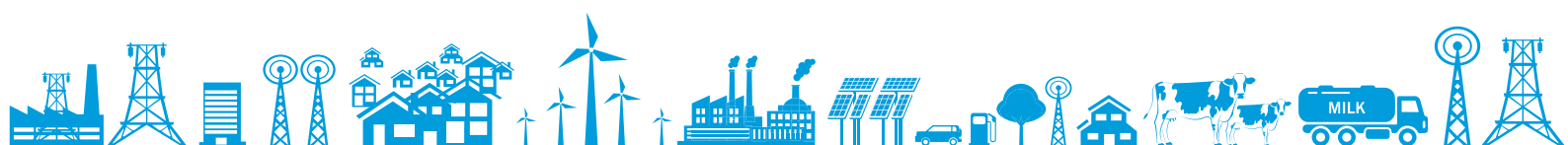
Limitations

- ❖ Higher installation costs.
- ❖ May require system stoppage during installation.

Cost Benefit Analysis

The expected savings by installation of Screw Compressor with VFD is 2,79,690 units of electricity annually. The annual monetary saving for this project is **INR 15.38 lakh with an investment of INR 52.00 lakh and the payback period for the project is 3.4 years.**

Table 32: Cost Benefit Analysis – Installation of Screw Compressor

Parameters	UOM	
Rated Refrigeration Capacity (2 x 70 TR)	TR	140
Rated Power (2 x 90 kW)	kW	180
Design SEC	kW/TR	1.29
Condensing Temp	°C	35 to 40
Suction Pressure	psi	35.55
Discharge Pressure	psi	177.79
Discharge Temperature	°C	100 to110
Total Operating Power	kW	122
Total Operating TR	TR	92
Operating SEC	kW/TR	1.33
Recommended Design TR	TR	155
Recommended Design Rate Power	kW	159
New SEC	kW/TR	1.02
New Power Consumption	kW	94.19
Power Savings	kW	28
Energy Cost	INR/kWh	5.5
Operating Hours	hrs	8,600
Savings on VFD	%	5.00
Savings on VFD	kW	4.71
Total Power Savings	kW	33
Annual Energy Savings	kWh	2,79,690.37
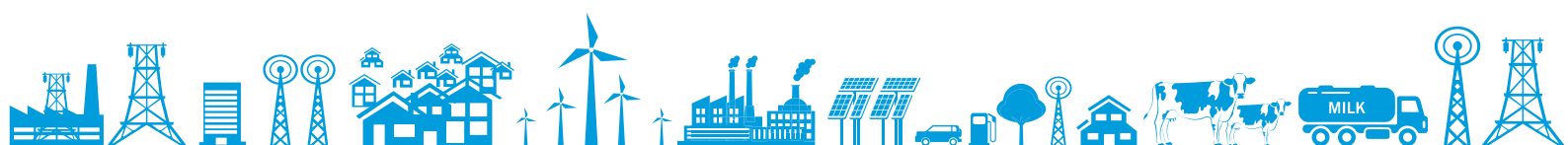
Parameters	UOM	
Annual Cost Savings	INR lakh	15.38
Investment	INR lakh	52.9
Payback Period	Years	3.44
IRR	%	44
NPV at 70 % Debt (12% rate)	INR lakh	53.75

Energy & GHG Savings

Annual Electricity Savings

2,79,690 kWh

Annual Energy Savings

24.05 TOE

Annual GHG Savings

232.72 T CO_2

Vendor Details

Table 33: Vendor details – Screw Compressor (Refrigeration)

Equipment Detail	Screw compressor with VFD
Supplier Name	Frick India Ltd
Address	New No. 243 (Old No. 185) Anna Salai, Chennai – 600 006
Contact Person	Mr. T.T.Krishnamoorthy
Email Id	ttk@frickmail.com
Phone No	9444818846

4.2.2 VFD in Chiller Compressor

Baseline Scenario

The dairy unit has installed five reciprocating chiller compressors of 33 TR each, based on vapor compression ammonia cycle. These compressors cater to the chilled water requirements and Fan Coil Unit (FCU) in the cold storage area. Of the five compressors installed, two compressors are running in morning time and three compressors run during night time for ice formation on the IBT. The performance of the chiller compressor is shown below:

Table 34: Operating Parameters of compressors

Parameters	UOM	
Rated size of compressor	kW	33
Rated Capacity	TR	45
No of Compressors in operation	Nos	2
Compressor 1 Power	kW	41.60
Compressor 5 Power	kW	38.90
Suction Pressure Compressor 1	psi	30
Suction Pressure Compressor 5	psi	39
Discharge Pressure Compressor 1	psi	196
Discharge Pressure Compressor 5	psi	190
Discharge Temperature	°C	92
Condensing Temperature	°C	38
Total Operating Power	kW	80.50
Operating TR	TR	51.93
SEC	kW/TR	1.55

Currently, the reciprocating compressor is running continuously at full load irrespective of the load variations in the plant. As in any dairy processing unit, during the day time, when all the processes (mainly pasteurization and pre-chilling of raw milk) are in operation, the compressor is 80% to 100% loaded and consumes more power. During night, the cooling requirement drops and the compressor runs only for the purpose of maintaining the temperature on the Ice Bank Tank (IBT). During this time the total refrigeration load on the plant is less but still the compressor takes the same power as it was consuming during the peak load, because there is no speed control mechanism.

IBT Temperature

The figure here shows the temperature profile of IBT for a duration of 24 hrs. It is seen that at night the temperature is subzero for IBT 2 and IBT 1. During this time, the compressor is running only to maintain ice on the IBT and for the cold store rooms. Plant is running two low speed compressors during night time without any speed control.
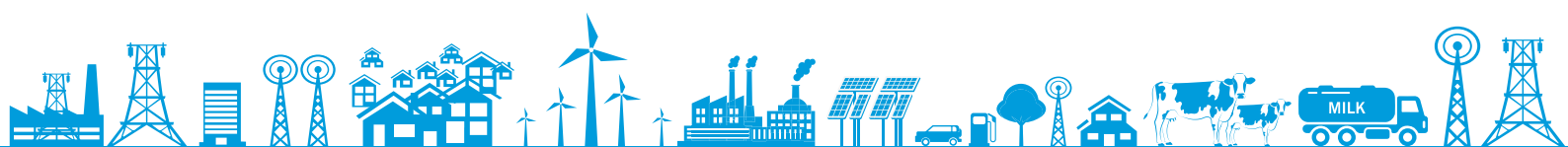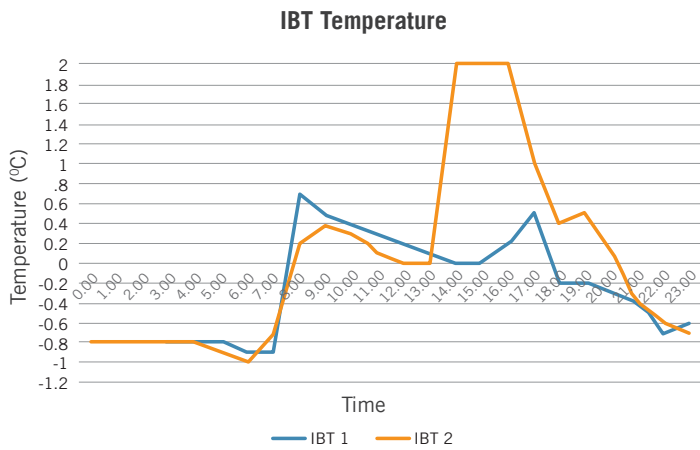
Figure 20: IBT temperature profile

Total compressor power for a system is a function of its suction pressure, discharge pressure, total system load, part load controls and unloading (specifically in the case of screw compressors which do not unload linearly). A lower refrigerant temperature results in lower suction pressure and increased compressor power requirements. A lower condensing pressure, which is a function of the condenser capacity and operations, results in a lower compressor discharge pressure and less compressor power. The above figure shows the variation of SP with time for the compressors installed in the plant. It is seen that Compressor 1 is operating with a higher suction during day time due to high demand and compressor 2 is operating with SP of 30 psi. During the 20:00 pm third compressor is also switched on and it is clearly seen that SP of compressor 1 drops to 28 PSI during this time and all the compressors are running at low suction which clearly indicates low demand of load. During night time there is a good potential for VFD as it can reduce the speed of one compressor based on suction and help in reducing power consumption.
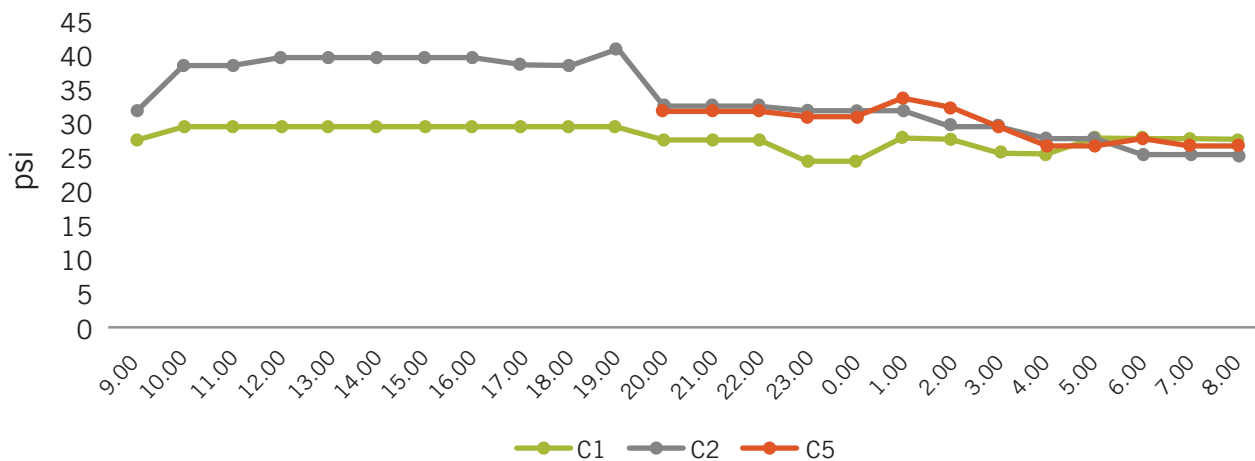
Figure 21: Compressor Suction Pressure

Once the evaporator gets wet with the help of refrigerant and temperature is attained, if there is no speed control the compressor will do the same work to attain lower refrigerant temperature which results in lower suction pressure thereby consuming same power as it is loaded. In such cases VFD can reduce the power consumption with the help of speed control by proper feedback mechanism.

Proposed System

It is recommended to install VFD for one high speed compressor with suction pressure as the feedback. The VFD helps in smooth control of operation of the compressor and the high-speed compressor can take care of the load, when suction pressure of the low speed compressor exceeds the set value. At this time, the compressor with VFD can take care of the additional demand due to increased suction.

Merits

❖ Better operating efficiencies.

❖ Reduced power consumption.

❖ Smooth control of compressor.

❖ VFD can act as a soft starter.

Limitations

❖ Speed reduction is possible up to only 25 Hz.

Cost Benefit Analysis

The expected electricity savings by installation of VFD for refrigeration compressor is 25,200 units annually. The annual monetary saving for this project is **INR 1.38 lakh with an investment of INR 2.66 lakh and payback period for the project is 23 months**.

Table 35: Cost Benefit Analysis – VFD for Refrigeration Compressor

Parameters	UOM	
Total Compressor Power	kW	80.50
Refrigeration Load	TR	51.93
SEC	kW/TR	1.55
VFD Power Savings	%	10
Power Savings on one compressor	kW	4.2
Operating hours	hrs	6,000
Energy Savings	kWh	25,200
Cost Savings	INR lakh	1.38
Investment	INR lakh	2.66
Payback Period	months	23
IRR	%	73.04
NPV at 70 % Debt (12% rate)	INR lakh	5.78

Energy & GHG Savings

Annual Electricity Savings

25,200 kWh

Annual Energy Savings

2.17 TOE

Annual GHG Savings

20.66 T CO$_2$
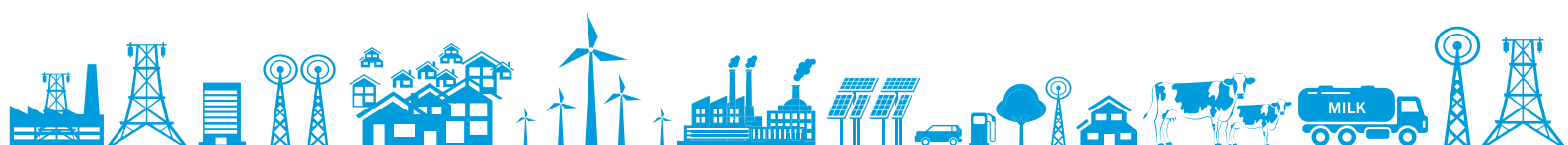
Vendor Details

Table 36: Vendor details – VFD for Refrigeration Compressor

Equipment Detail	VFD for chiller compressor
Supplier Name	Danfoss Industries Ltd
Address	703,7th Floor, Kaivanya Complex,Near Panchwati Cross Road Ambawadi, Ahmedabad
Contact Person	Mr. Srihari Vyas
Email Id	Shrihari@danfoss.com
Phone No	9825024991
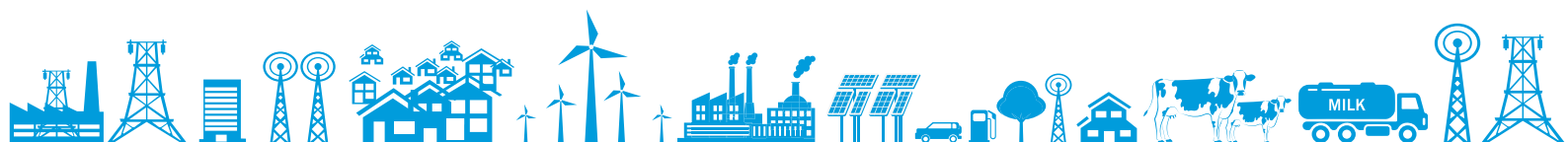
4.2.3 Evaporative Condenser

Baseline Scenario

The unit has installed two reciprocating chiller compressors of 180 HP and 150 HP with 100 TR capacity each, for chilled water requirement in the plant. In a refrigeration cycle, when the compressor runs, the refrigerant starts flowing through the system. The compressor continuously sucks low pressure, low temperature refrigerant vapors from the evaporator and pumps it to the condenser at high pressure and temperature. While flowing through the condenser, the high temperature vapors release their heat to atmosphere and condense to high pressure liquid state. After condenser, this high-pressure liquid enters the expansion valve where it is throttled to low pressure. On throttling, the pressure and temperature of refrigerant decreases and when this low pressure, low temperature throttled liquid flows through evaporator, it sucks heat and produces cooling. On absorbing heat in evaporator, all the low-pressure liquid evaporates to low-pressure, low-temperature vapors, which are again sucked by the compressor. In this way, all these processes go on continuously and as long as the compressor runs, the system produces cooling around the evaporator. The dairy has installed a PHE condenser for 180Hp Chiller and a shell & tube condenser for 150 Hp Chiller and both the systems have open cooling tower arrangement for the refrigeration system. The schematic of existing condenser system is given below:

Fan Power - 5.4 kW

Condenser Load - Q_o - 158.5 TR

Condenser

Pump Power - 17.71 kW
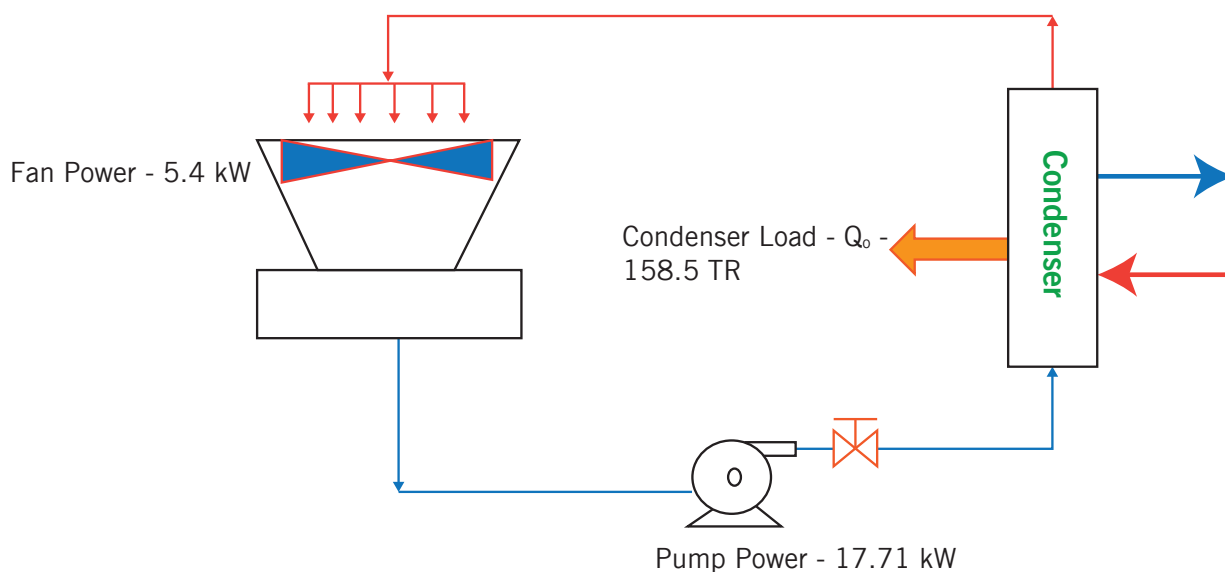
Figure 22: Existing Condenser System

The plant is having a normal PHE condenser with cooling tower arrangement for the 180 HP bchiller. The compressor is running at 40°C condensing temperature and -2°C evaporation temperature. As the current system has separate PHE condenser and CT, the auxiliary loads are on the higher side and the water quality can affect the condenser performance due to scaling and fouling. This can result in increased power consumption of chiller compressor. During the study it was also found that condensing temperature was on the higher side. The lower the condensing temperature is, the better the performance of chiller compressor. The following table shows the power consumption of existing system:
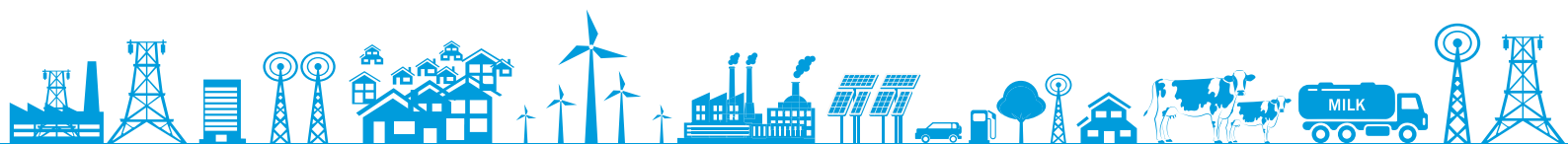
Sr. No.	Parameter	UOM	
1	Chiller Compressor	kW	103
2	Condenser Pump	kW	17.71
3	Cooling Tower Fan Power	kW	5.4

Proposed System

It is recommended to replace the existing PHE condenser with evaporative condenser.
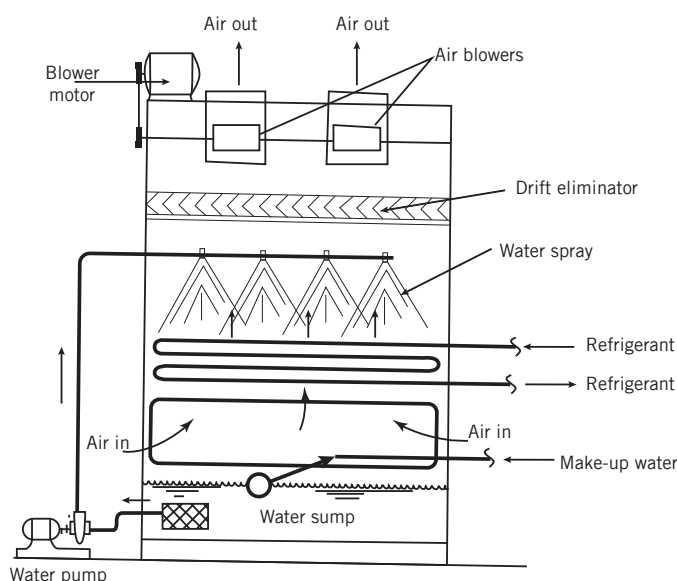
Figure 23: Evaporative Condenser

Evaporative condensers combine the features of a cooling tower and water-cooled condenser in a single unit. In these condensers, the water is sprayed from the top part on a bank of tubes carrying the refrigerant and air is induced upwards. There is a thin water film around the condenser tubes from which evaporative cooling takes place. In evaporative condenser, the vapor to be condensed is circulated through a condensing coil, which is continually wetted on the outside by a recirculating water system.

Air is pulled over the coil, causing a small portion of the recirculating water to evaporate. The evaporation removes heat from the vapor in the coil, causing it to condense. The heat transfer coefficient for evaporative cooling is very large. Hence, the refrigeration system can be operated at low condensing temperatures (about 11 to 13°C above the wet bulb temperature of air). The water spray countercurrent to the airflow acts as cooling tower. The role of air is primarily to increase the rate of evaporation of water. The required air flow rates are in the range of 350 to 500 m³/h per TR of refrigeration capacity.

With the installation of evaporative condenser, condensing temperature of 36°C can be achieved for the same cooling capacity. As a result, the compressor power will come down drastically at 4°C lower condensing temperature compared to existing condensing temperature of 40°C.

Merits

❖ Reduces fouling tendency.
❖ The air and water flow in a parallel path.

- ❖ Increased water flow over the coil.
- ❖ Evaporative cooling in the fill.
- ❖ Colder spray water.

Demerits

- ❖ High upfront cost.
- ❖ Requires system modification.

Cost Benefit Analysis

The expected electricity savings to be achieved by installation of evaporative condenser is INR 1.98 lakh units annually. The annual monetary saving for this project is **INR 13.07 lakh, with an investment of INR 29.52 lakh and a payback period of 27 months.**

Table 38: Cost Benefit Analysis – Evaporative Condenser

Parameters	UOM	
Existing System - Measured		
Chiller Compressor Rating	kW	132.3
Power Consumption	kW	103
Evaporator Temperature	$^{\circ}C$	-2
Condensing Temperature	$^{\circ}C$	40
Condenser Heat Load Q_o	TR	158.5
Condenser Pump Power	kW	17.71
Cooling Tower Fan Power	kW	5.4
Proposed System		
Design of new condenser with 25 % safety margin	TR	198.12
Evaporative Condenser Model available	TR	200
Evaporative Condenser Fan Power	kW	5.5
Evaporative Condenser Pump Power	kW	4
Energy Savings		
Total Auxiliary Power of Existing Condenser	kW	23.11
Total Auxiliary Power of Evaporative Condenser	kW	9.5
Savings in Auxiliary Power	kW	13.61
Current Compressor Power @ 40°C condenser temperature	kW	103

Parameters	UOM	
Compressor Power @ 36°C condenser temperature (with installation of Evaporative Condenser)	kW	94
Savings in Compressor Power due to reduction in condenser temperature	kW	9
Total Savings	kW	22.61
Power Cost	INR/kWh	6.6
Operating Hours	hrs/day	24
No of Days	days/year	365
Annual Energy Savings	kWh	198,129
Annual Cost Savings	INR lakh	13.07
Investment for 200 TR evaporative condenser	INR lakh	29.52
Payback Period	months	27
IRR	%	63.79
NPV at 70 % Debt (12% rate)	INR lakh	52.75

Energy & GHG Savings

Annual Electricity Savings
1.98 lakh kWh

Annual Energy Savings
17.04 TOE

Annual GHG Savings
162.47 T CO$_2$
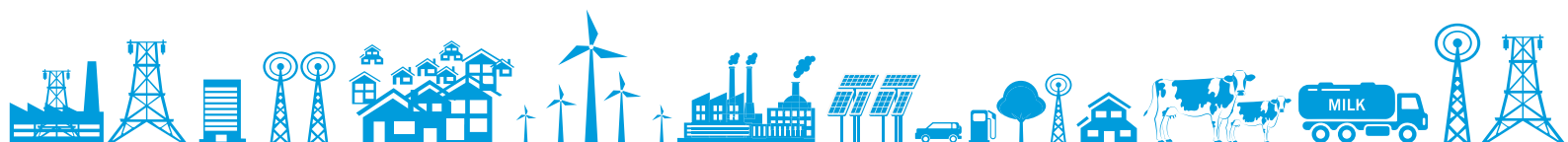
Vendor Details

Table 39: Vendor Details – Evaporative Condenser

Equipment Detail	Evaporative Condenser
Supplier 1	
Supplier Name	VINI Enterprise
Address	13, Nutan Patidar Society, Vallabhwadi, Maninagar, Ahmedabad-380008.
Contact Person	Mr. Saurin Dave
Mail Id	saurin@vinienterprise.com
Phone No	+91 97270 12111
Supplier 2	
Supplier Name	Frick India Ltd
Address	3rd Floor, Tiecicon House, Dr. E Moses Road, Jacob Circle, Dr E Moses Rd, Lower Parel, Mumbai
Contact Person	Mr Mohan Garad
Mail Id	mumbai@frickmail.com
Phone No	+91 9833994591

4.2.4 Falling Film Chiller (FFC)

Baseline Scenario

The unit is receiving milk from village level collection center and has bulk milk coolers for processing at different temperatures. To meet the chilling requirement, the unit has installed refrigeration compressors of 450 TR capacity. During normal running conditions the base load of the plant is 300 TR and additional compressors run based on load requirement. For chilled water generation, three IBTs are used. The following table shows the performance of chiller compressors:

Table 40: Chiller compressor performance

Parameters	UOM	
Compressor design Power	kW	360
Compressor design load	TR	450
Suction Pressure	kg/cm²	3.51
Discharge Pressure	kg/cm²	13.44
Discharge Temperature	°C	95
Evaporator Temperature	°C	-2
Condensing Temperature	°C	39
Operating Power	kW	332
Operating TR	TR	350
SEC	kW/TR	0.95

The incoming milk is received at different temperatures and as a result, the load on the refrigeration system also fluctuates. The process return water to IBT from prechiller and other processes is also at high temperature, which in turn increases the temperature of IBT. This results in higher chilled water temperature which leads to inefficient chilling of milk. The process return water from pasteurization process is at 7°C – 10°C and from pre-chiller installed at raw milk reception is 12°C – 14°C, due to high incoming temperature of milk. There is an unevenness in the return water temperature and this is directly going to IBT tank. In the present condition, the average temperature maintained at IBT is 7°C to 10 °C and as a result, the unit is facing difficulty to maintain 4°C for milk dispatch. Thus, the unit is able to dispatch milk at only 5°C to 6°C. At the current situation, the temperature the plant is getting is around 5°C – 6 °C for milk dispatch and it is uneven. Because of this, load on the refrigeration plant is also increasing, which results in higher SEC for chiller compressor.
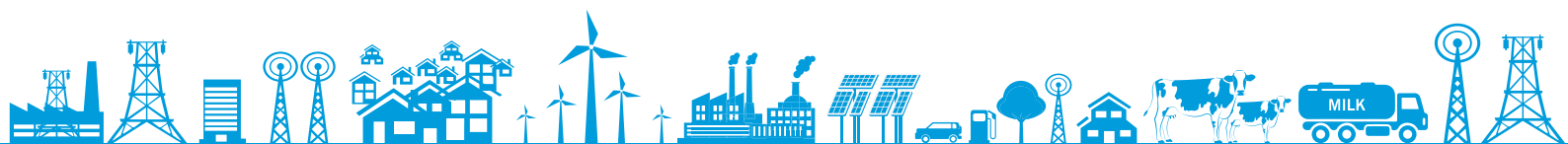
Proposed System
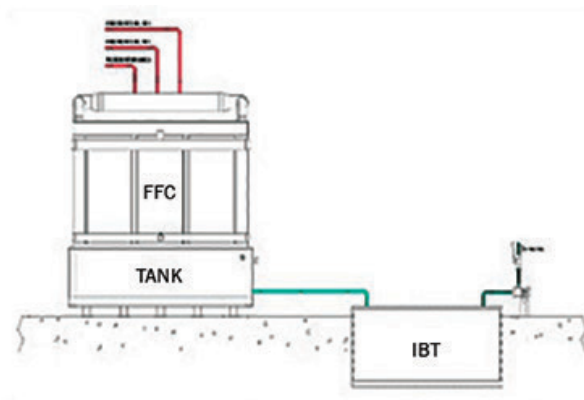
Figure 24: Falling film chiller
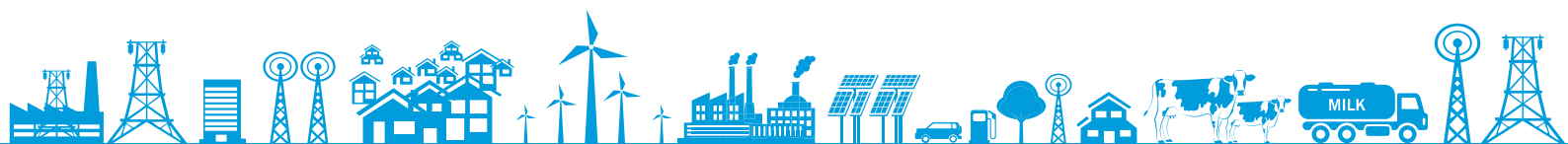
It is recommended to install falling film chiller before IBT to pre-chill the incoming process return water at higher temperature. FFC can instantly bring down the process return water temperature to 0.5°C - 1°C, thus maintaining the IBT temperature less than 0.5°C all the time and thereby reducing the chiller compressor load.

The new system will improve the quality of chilled milk and milk products as IBT can continuously generate chilled water at lower temperature and hence meet the requirement of cooling the milk to 4°C.

Falling Film Chillers are suitable for continuous chilling of liquids close to their freezing point (i.e. water to 0, 5°C). Also, viscous liquids, detergents, etc., and polluted liquids not easily handled in large quantity by conventional heat exchangers, can all be chilled with the Falling Film Chiller. The water to be cooled is pumped into a distribution tank and as previously described the water is evenly distributed so that it falls as a continuous film over the cooling surface and into a base tank or directly over the product. The refrigerant runs through the pillow plate. It can be either a primary refrigerant such as ammonia, R134a, R22 etc., evaporating directly in the plate, which can be circuited for dry expansion, flooded or pumped systems, or as a secondary refrigerant such as glycol, brine or a similar heat transfer fluid.

When Using NH_3 as the refrigerant, oil drains must be provided in the lowest point of the evaporator (liquid) supply. For flooded systems, the separator liquid level must be a minimum of 0.5 m above the suction when using NH_3 and 1.0 m using R22. Using a falling film chiller with a DX system, a suction gas heat exchanger is required if the temperature difference between refrigerant and water inlet is less than 10°C. This suction heat exchanger provides the gas superheat. The minimum evaporation temperature is -3°C with water of 1°C and -2.5°C with water of 0.5°C. This is to prevent ice-build-up on the plates.

Conventional IBT often runs at low evaporation temperatures, which results in lowering of refrigeration capacity and higher power consumption as compared to FFC, which runs at much higher evaporation temperature. The FFC being an open system also results in low or zero maintenance and therefore is free from such botherations due to which the plant always maintains a high efficiency.

Merits over conventional PHE

Table 41: Falling Film Chiller vs Plate Heat Exchanger

Sr. No	Falling Film Chiller	Plate Heat Exchanger
1	Water Chilling down to temperature as low as 0.5 ^{o}C	Not suitable for low water temperature applications
2	FFC allows the operation with polluted liquid as well	Not suitable for polluted liquid applications
3	In case of ice building on plates there is no damage to the plates	Plates get damaged during ice building
4	U value or efficiency of FFC remains same	Due to scale deposition the efficiency of PHE or U value decreases drastically. Needs frequent cleaning
5	Low or no maintenance and operating cost	Periodic maintenance which adds to operating costs
6	Design and operating parameters may vary based on load requirements	Design and operating parameters need to be same for low temp application because any change in operating parameters may result in heavy losses or damage of PHE
7	Low affinity of soiling, easy to clean	
8	No Gaskets	Require time to time change of gaskets
9	Flexibility of usage	Limitations of Usage

Demerits

- ❖ High upfront cost.
- ❖ Requires system modification.

Cost Benefit Analysis

The expected electricity savings to be achieved by installation of FFC is 5.04 lakh kWh annually. The annual monetary saving for this project is **INR 37.80 lakh, with an investment of INR 39.78 lakh and a payback period of 13 months**.

Table 42: Cost Benefit Analysis – Falling Film Chiller

Parameters	UOM	Option 1 - CHW supply from existing IBT system	Option - 2 CHW supply from dedicated FF chiller
Actual CHW Temperature requirement ^{o}C	^{o}C	1	1
CHW supply temperature ^{o}C	^{o}C	Varying due to incoming fluctuations in process water return temp of 10 - 14°C	1
Refrigeration load	TR	350	350
Power Consumption	kW	332	262
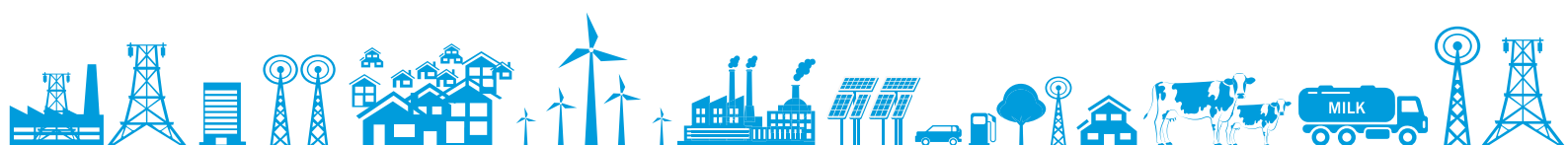
Parameters	UOM	Option 1 - CHW supply from existing IBT system	Option - 2 CHW supply from dedicated FF chiller
Specific power	kW/TR	0.95	0.75
Operating days/annum	days	300	300
Operating hrs/day	hrs	24	24
Annual energy consumption	kWh	23,94,000	18,90,000
Annual electricity saving	kWh	5,04,000	
Power cost INR7.5/kWh	INR lakh	179.55	141.75
Annual cost saving	INR lakh	37.80	
Investment	INR lakh	39.78	
Payback Period	months	13	
IRR	%	121.28	
NPV at 70 % Debt (12% rate)	INR lakh	173.32	

Energy & GHG Savings

Annual Electricity Savings

5.04 lakh kWh

Annual Energy Savings

43.34 TOE

Annual GHG Savings

413.25 T CO$_2$

Vendor Details

Table 43: Vendor Details – Falling Film Chiller

Equipment Detail	Falling Film Chiller
Supplier Name	Omega Ice Hill Pvt Ltd
Address	Omega Ice Hill Pvt Ltd 39, First Floor, Raghushree Market Near Ajmeri Gate, Delhi
Contact Person	Mr Abhishek Jindal
Mail Id	abhishek.jindal@omega-icehill.in
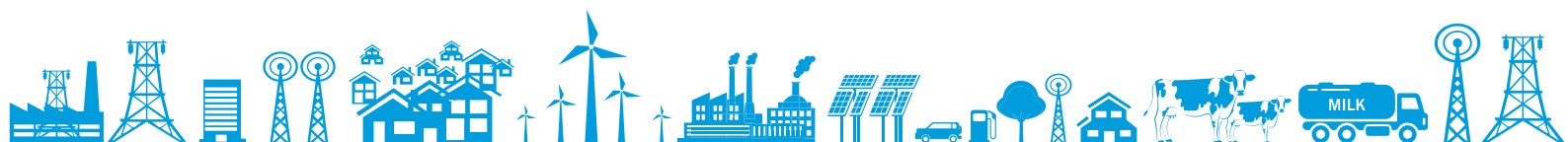
4.2.5 Direct Cooling Method – IBT

Baseline Scenario

A dairy unit in Pune has a milk processing facility. VATS cooling is maintained by conventional IBT tank provided with all civil constructed wall (except bottom side) thermal insulation. The top face of the tank is open and covered by wooden planks supported on MS angle fabricated support structure. IBT is basically a thermal storage system which is bulky in nature and utilizes old technology of ice bank with agitator.

IBT tank cooling source from Ammonia-based refrigeration plant 70 TR – (KC3 & MX 300), Ammonia evaporation on -10 to -15°C. Mechanical stirrers (agitator) are provided (one in each section of IBT tank) for creating forced circulation inside IBT tank for uniform cooling of water inside IBT Tank. IBT tank is used in refrigeration system for making ice during off peak hours and using this thermal stored energy during peak hours. The charging of the IBT tank is done almost 20 hrs to 24 hrs/day, depending on product quantity received and ambient conditions.

Operating efficiency analysis (Existing loss study)

The energy consumption is much higher than the estimated required energy. The specific energy consumption in summer is about 50-60% more than that of winter. Condensing pressures are higher in summer and hence, condensing temperatures are about 5°C higher in summer. Energy consumption is 10% higher for 5°C. Higher condensing ice bank systems have poor charging and discharging characteristics, which increases energy consumption. Stirrer adds to the energy consumed. The compressors operate much longer, especially in the summer. This also adds to cooling tower load and hence inefficient chiller operation.

In summer, recorded cooled product temperature was much higher as system was not able to meet the cooling demand. It is estimated that it fell short by 20%. Ice Bank system is not getting charged to optimum level and not able to discharge when required. Theoretical energy consumption estimates are much lower than the actual consumption, hence there is a scope of incorporating Direct Cooling, using PHE Chiller System, to improve the performance of the system and to achieve better cooling throughout the year.
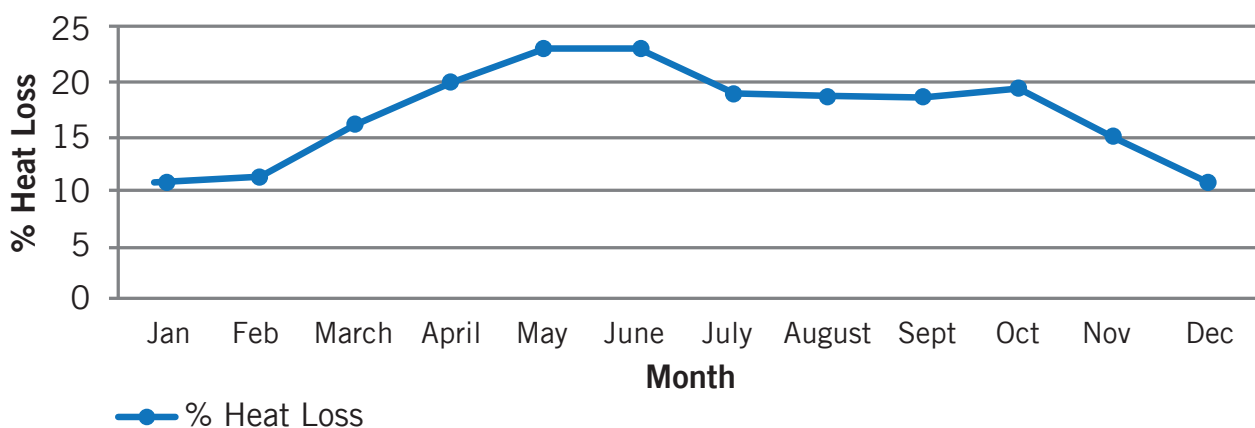
Figure 25: Typical operating efficiency analysis for different seasons
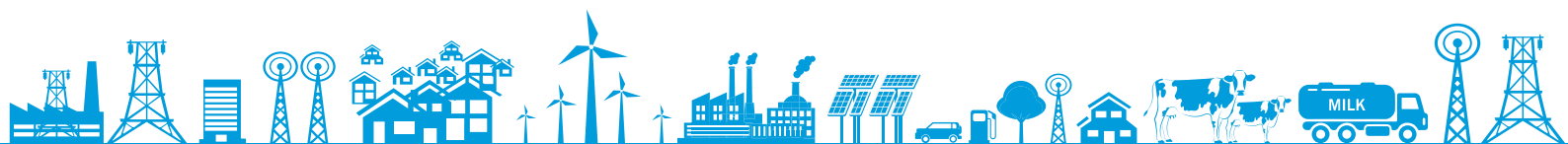
Proposed System

The proposed system is designed for direct cooling of constant requirement of chilled water at process 1.0-1.5°C. Direct cooling PHE evaporator will have a primary and secondary circuit to avoid the freezing of process water. The new design direct cooling method Ammonia compressor with suction pressure of 2-2.5 kg/cm² to evaporative condenser can maintain condensing temperature at 35°C. HPR will supply ammonia at 8-10 kg/cm² to PHE evaporator. PHE evaporator will have ammonia thermal expansion valve modulation based on chilled water supply temperature. Primary circuit of PHE evaporator will transfer the cooling load at -0.3°C on secondary side of PHE chiller. Process chilled water (4-5°C) will be in continued circulation with the help of low temperature pumps. To cater to the load requirement of process 1.0-1.5°C, the process return water will be fed through the secondary side of PHE evaporator, which will have temperature controller along with 3-way valve to maintain the output temp of 1.0 – 1.5°C.

Merits

❖ Low energy consumption at ammonia compressor due to higher suction pressure.

❖ Closed looped system, no cooling loss or addition of external heat from ambient.

❖ Capacity augmentation - existing installed refrigeration plant will be able to cater to higher production.
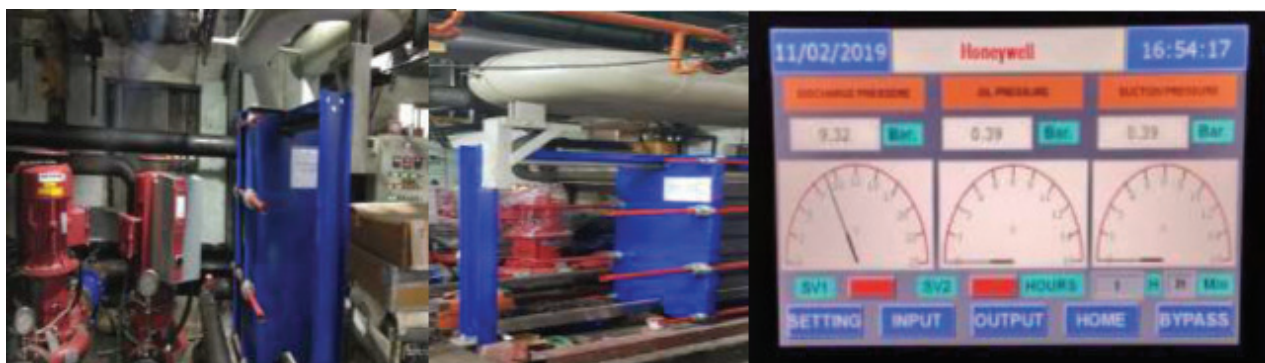
Figure 26: Post Implementation – Direct Cooling Method

Limitations

❖ Automation required on existing system.

❖ Estimation of proper cooling load.

❖ Minimum cooling load required to maintain stable suction pressure.

Cost Benefit Analysis

The estimated electrical savings to be achieved by installation of direct cooling method of 3.20 lakh units per annum. The annual monetary saving for this project is **INR 27 lakh, with an investment of INR 70 lakh and a payback period of 30 months.**
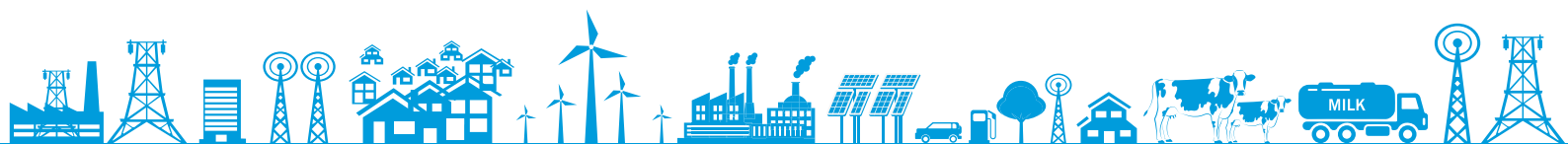
Table 44: Cost Benefit Analysis – Direct Cooling in IBT

Parameters	UOM	Value
Existing refrigeration plant capacity	TR	70
Suction pressure	kg/cm²	1 – 0.8
Ammonia evaporation temp	⁰C	-15
IBT Supply temp	⁰C	1.0 -1.5
Sp. Energy consumption	kW/TR	1.11
Existing Electrical energy consumption	kWh/month	89,385
Addition of new refrigeration capacity	TR	100
Total TR	TR	170
New suction pressure	kg/cm²	2.5
Ammonia Evaporation temp	⁰C	-5
Sp. Energy consumption	kW/TR	0.8
IBT supply temp	⁰C	1
New electrical consumption with additional capacity	kWh/month	62,517
Total units saved	kWh/month	26,868
Annual electrical savings	kWh	3,22,000
Monetary savings	INR lakh	27.0
Investment	INR lakh	70.0
Payback Period	months	31
IRR	%	56.63
NPV at 70% Debt (12% rate)	INR lakh	104.77

Energy & GHG Savings

Annual Electricity Savings	Annual Energy Savings	Annual GHG Savings
3,22,000 kWh	27.69 TOE	274 T CO_2
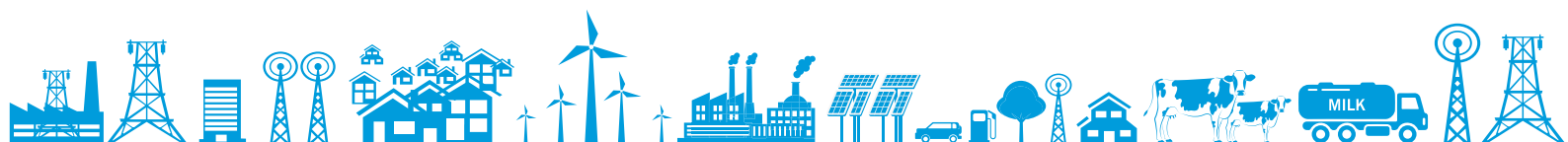
Vendor Details

Equipment Detail	Direct Cooling Method
Supplier Name	Honeywell Automation – Energy services
Address	56 & 57, Hadapsar Industrial Estate, Pune
Contact Person	Hari Mohan Singh
Mail Id	hari.singh@honeywell.com
Phone No	9011186665
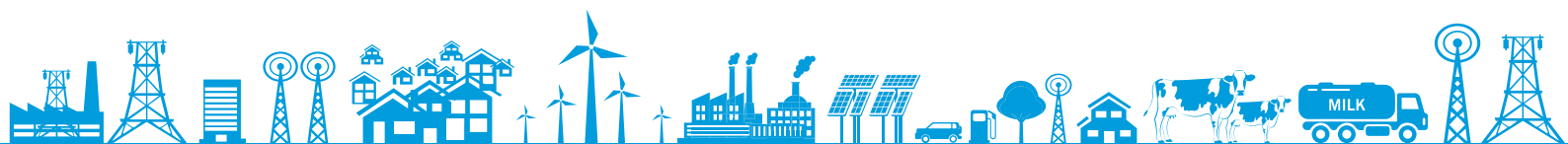
4.3 Case Studies – Waste Heat Recovery

4.3.1 Desuperheater for Compressors

Baseline Scenario

The unit has installed two reciprocating chillers of 33 TR capacity for the chilling requirement in the plant. One compressor runs continuously and second compressor runs based on load requirement. For the refrigeration purpose, vapor compression-based ammonia cycle is used. In a refrigeration cycle, when the compressor runs, the refrigerant starts flowing through the system.
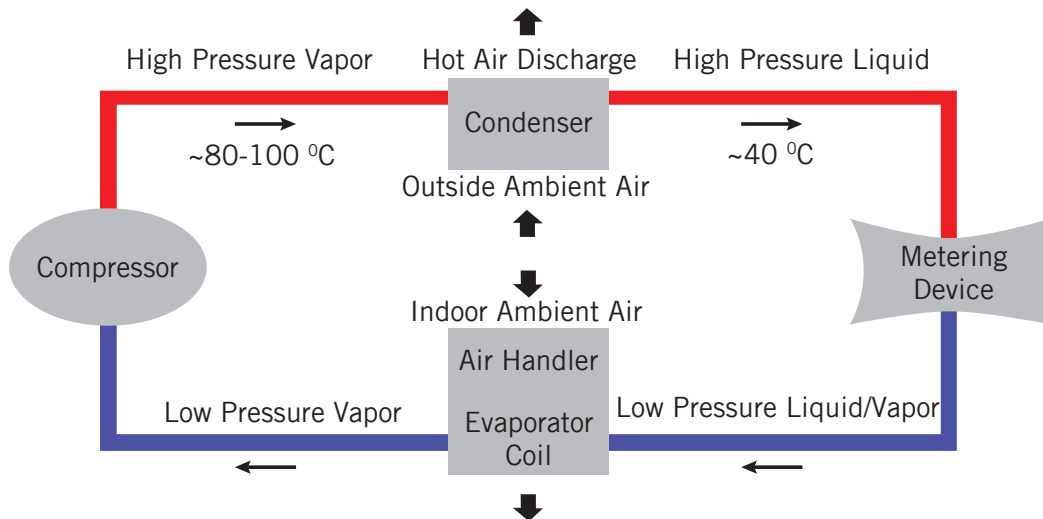
Figure 27: Vapor Compression Cycle

The compressor continuously sucks low pressure, low temperature refrigerant vapors from the evaporator and pumps it to the condenser at a high pressure and temperature. While flowing through the condenser, the high temperature vapors release their heat to the atmosphere and condense to a high pressure liquid state. After condenser, this high-pressure liquid enters the expansion valve where it is throttled to a low pressure. On throttling, the pressure and temperature of the refrigerant decrease and when this low pressure, low temperature throttled liquid flows through the evaporator, it sucks heat and produces cooling. On absorbing heat in the evaporator, all the low-pressure liquid evaporates to low-pressure, low-temperature vapors, which are again sucked by the compressor. In this way, all these processes go on continuously and as long as the compressor runs, the system produces cooling around the evaporator.

Refrigeration plants with air-cooled and water-cooled condensers produce a lot of waste energy by dumping the condensation energy to the ambient air. By installing a de-superheater, a large proportion of this waste energy can be turned into hot water, which can be used for many applications such as:

❖ CIP.

❖ Boiler feedwater heating.
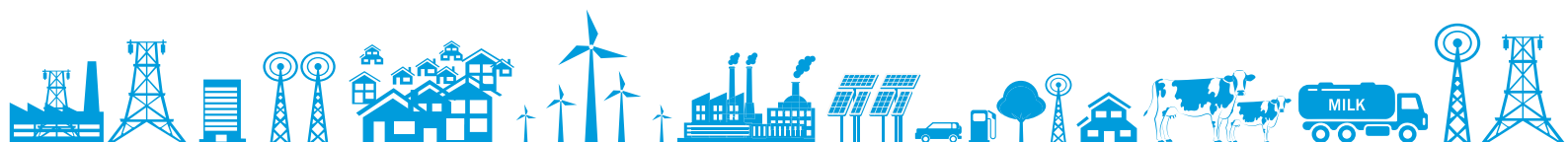
- ❖ Process heating for processes like curd and Ghee preparation.
- ❖ Crate washing and can washing in chilling centers.

Proposed System

It is recommended to install de-super heater on discharge side of chiller compressors to recover the waste heat of ammonia gas. The temperature of NH$_3$ gas will be around 100°C, which can be cooled to 60°C and the recovered heat can be used for heating water from ambient to 70°C. The design should ensure that adequate heat is recovered with the required temperature lift. Apart from the direct energy saving after getting hot water, the heat load on condenser is expected to come down and if the design is done appropriately, the condensing pressures can also marginally reduce, leading to reduction in power consumption of compressors. De-superheater units are located between the compressor and condenser to utilize the high-temperature energy of the superheated refrigerant gas. By using a separate heat exchanger to utilize the high temperature of the discharge gas, it is possible to heat water to a higher temperature than would be possible in a condenser. Key technical parameters for the heat recovery system are given below:

High Pressure Vapor   Hot Air Discharge   High Pressure Liquid

~60 °C
~30 °C

Desuperheater

~60 °C

Condenser

Outside Ambient Air

~40 °C

A desuperheater recovers heat from refrigerant before it reaches the condenser

Compressor

Metering Device

Indoor Ambient Air

Air Handler

Low Pressure Vapor   Evaporator Coil   Low Pressure Liquid/Vapor
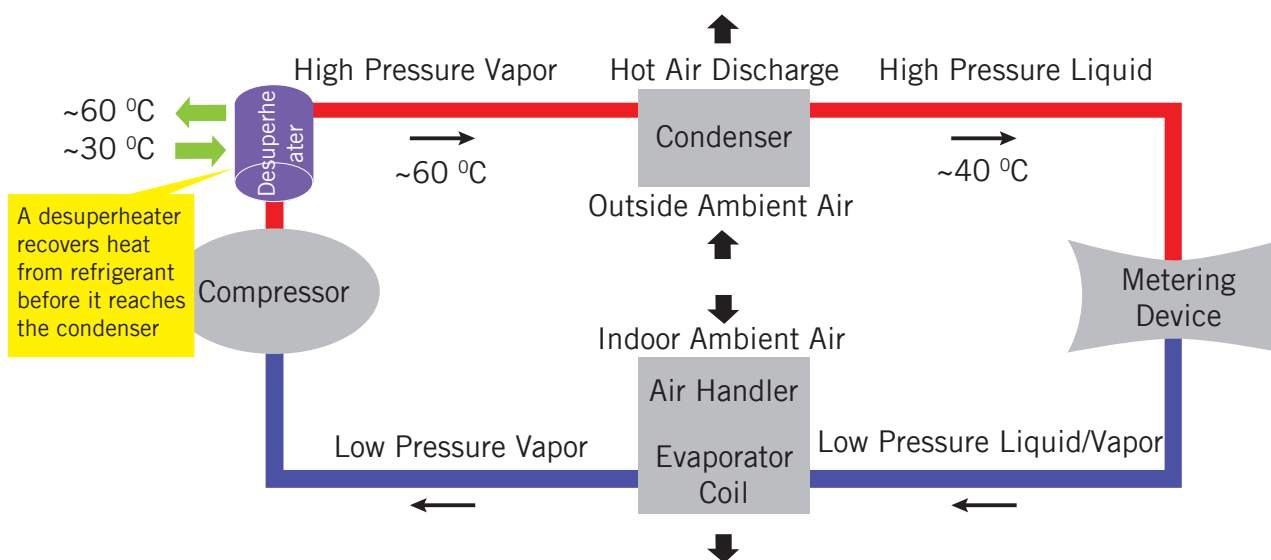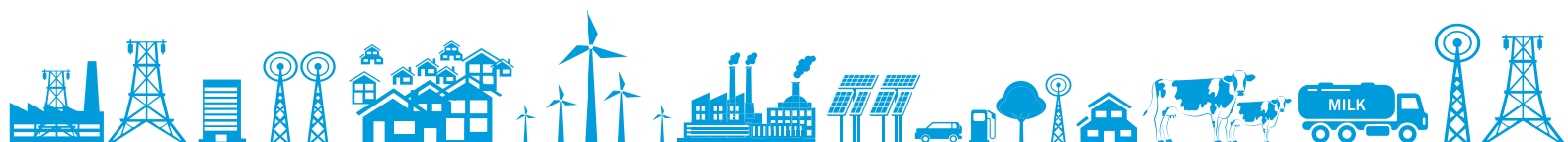
Figure 28: WHR from chiller compressor

Table 46: Key technical parameters of de super heater

Item	Value
Temperature of ammonia gas in/out	100°C/60°C
Temperature of water in/out	30°C/70°C
Amount of water that can be heated	294 litre/hr
Heat load recovered	16.4 kW

Cost Benefit Analysis

The expected fuel savings to be achieved by installation of de-superheater is 0.25 lakh kg of briquette annually. The annual monetary saving for this project is **INR 1.73 lakh, with an investment of INR 4.84 lakh and a payback period of 34 months**.

*Table 47: Cost Benefit Analysis – Installation of Desuperheater*

Parameters	UOM	
Size of compressor	kW	41
Heat Recovery possible	kW	16.4
Heat Recovery possible	kJ/hr	59,011
Amount of hot water available for process (from 30 to 70°C)	litre per hour of water at 70°C	294
Hours of operation	hours per day	15
Days of operation	days per year	365
Cost of Briquette	INR/kg	6.7
Calorific value	kJ/kg	77,023
Boiler efficiency	%	68%
Fuel Savings	kg/year	25,809
Annual Cost Savings	INR lakh	1.73
Investment	INR lakh	4.84
Payback	months	34
IRR	%	52.98
NPV at 70% Debt (12% rate)	INR lakh	6.55

[1]*For 15kW of refrigeration load 6 kW heat recovery possible*

Energy & GHG Savings

Annual Fuel Savings	Annual Energy Savings	Annual GHG Savings
25,809 kg of briquette	**11.36 TOE**	**-**
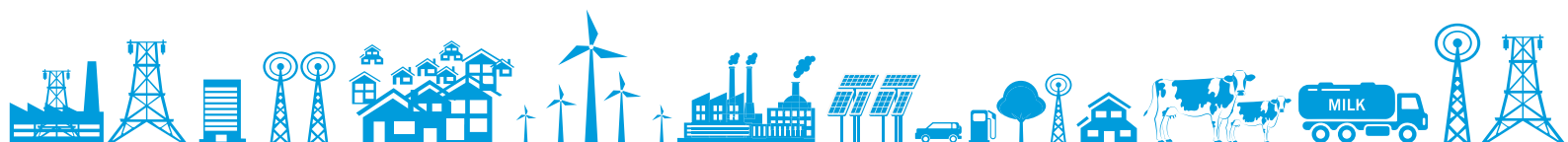
Reference Plant Implementation

Table 48: Reference Plant Implementation - Desuperheater

Project Name	Installation of Desuperheater
Objective	Installation of desuperheater to preheat boiler feed water from the superheated refrigerant gas.
Dairy profile	Ernakulam Dairy, a unit under Ernakulam Regional Co-operative Milk Producers' Unions (ERCMPU) of MILMA, has its plant at Thrippunithura, Ernakulam, Kerala and offers pasteurized Vitamin A-enriched milk and various milk-based products, such as butter, curd, ghee and Sambharam throughout the State.
Installation Photo	
Assumptions	• Fuel Cost – INR 7/kg • GCV – 18,409 kJ/kg • Annual operating hrs - 5475 • Feed water temperature – 30°C • Boiler efficiency – 0.70
Savings (INR lakh)	₹ 5.08 lakh
Investment (INR lakh)	₹ 16 lakh
Simple Payback Period	36 months
Replication potential	In all the dairy units, BMC and MCCs irrespective of size
Outcomes	• 13.27 kg/hr of briquette saved • Temperature of hot water achieved – 60°C • 30.50 TOE of annual energy savings • Increase in feed water temperature
Unit contact details	Mr. Babu Varghese Milma Ernakulam Dairy Thrippunithura P.O. Ernakulam – 682101, Kerala Phone: 0484-2780103 Email: ernakulamdairy@yahoo.co.in
Cluster Reference	Kerala Dairy Cluster

Vendor Details

Table 49: Vendor details – Desuperheater for Compressors

Equipment Detail	Desuperheater
Supplier Name	Promethean Energy Pvt Ltd
Address	Akshar Blue Chip IT Park, Turbhe MIDC, Turbhe, Navi Mumbai : 400706
Contact Person	Mr. Ashwin KP
Mail Id	ashwinkp@prometheanenergy.com
Phone No	+91 9167516848
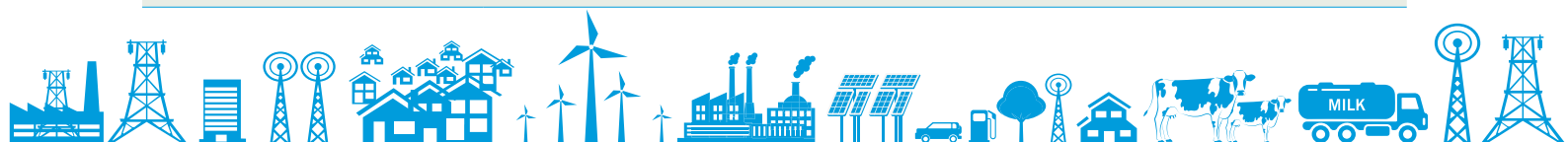
4.3.2 Heat Pump

Baseline Scenario

The unit has installed two HSD-fired boilers for the process applications, such as pasteurization, curd making, CIP, crate washing, etc. One 0.7 TPH HSD-fired boiler is running and the others are on standby. The heating process in dairy is done by indirect heating. The feed water temperature is 22°C and quantity required is 472 litres per hour. There is no preheating of feed water done in the plant and as a result, feed water is supplied at ambient condition to the boiler, which results in combustion of more fuel. The lower the temperature of feed water, the greater are the chances of formation of dissolved oxygen, which can lead to corrosion.

Proposed System

It is recommended to install a 28 kW electrical heat pump for preheating the boiler feed water from 22°C to 80°C. An electric heat pump (EHP) system works on the principle of the 'heat pump'. This is the cyclic process in which heat is taken up from an area of cold temperature and discarded into an area of high temperature. A heat pump cannot operate by itself; it requires an external energy source. In an EHP system, electrical energy is used to drive the heat pump. The heat pump is like a chiller unit where the utilization point is from condenser part for heating application. It has four basic components: compressor, condenser, expansion valve and an evaporator. When electrical energy is given to the unit, the compressor compresses the R134a refrigerant to a high temperature high pressure vapor. From compressor, the vapor goes to the condenser, which is basically a heat exchanger where on the one side, boiler feed water is circulated and on the other side, refrigerant flows. The heat from the refrigerant is dissipated to the boiler feed water, which is incoming at 22°C. This heat is used to preheat the boiler feed water to 80°C and fed to the boiler. The refrigerant is then expanded using an expansion valve to low temperature low pressure vapor and given to the evaporator. In the evaporator, using small fans installed on the top of the heat pump, the ambient air is used to evaporate the refrigerant due to its low boiling point. The low temperature low pressure vapor is sucked in by the compressor and the cycle is repeated. The COP of heat pump is 3, i.e., 1 kW of energy can generate 3.0 kW of heat energy.
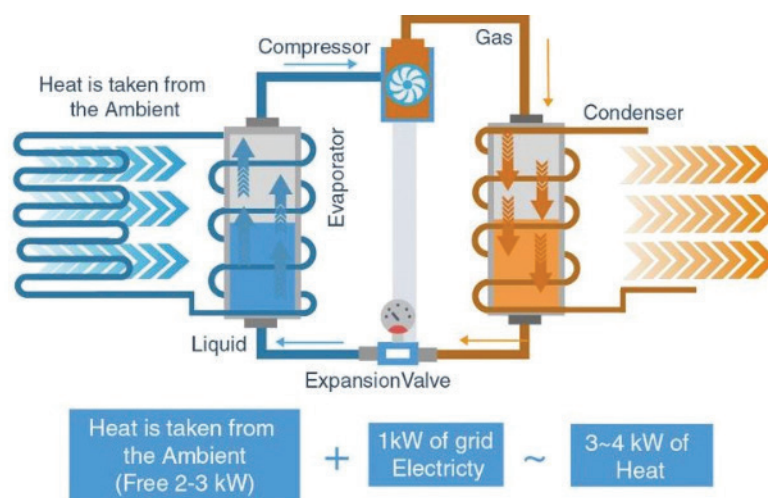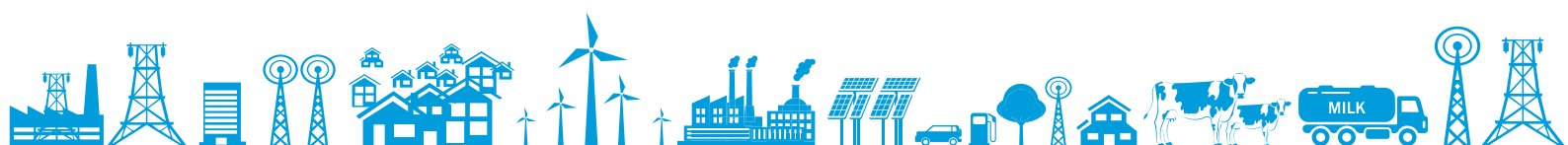
Figure 29: Heat Pump

Merits

- ❖ Highly compactible.
- ❖ Improves the efficiency of boiler.
- ❖ Simultaneous delivery of heating and cooling.
- ❖ Easy installation and occupies less space near the utilization point.
- ❖ Process temperature up to 85°C can be achieved.

Demerits

- ❖ High upfront cost.
- ❖ Requires system modification.

Cost Benefit Analysis

The expected fuel savings to be achieved by installation of heat pump is 8,247 litres of HSD annually. The annual monetary saving for this project is **INR 4.43 lakh, with an investment of INR 3.54 lakh and a payback period of 10 months**.

Table 50: Cost Benefit Analysis – Heat Pump

Parameters	UOM	
Feed Water Temperature	°C	22
GCV of fuel	kJ/kg	45,187
Boiler Efficiency	%	79
Feed Water Requirement	kg/hr	472
Feed Water Requirement for 6 hour boiler operation	kg/day	2,832
Max temperature delivered by heat pump	°C	80
Pipe line losses	%	10
Heat Energy required to raise temp to 80°C after losses	kWh/day	212.22
Operating hrs of heat pump	hrs/day	8
Electrical heat energy of pump	kW	26.53
COP of Heat Pump		2.5
Fuel required for equivalent energy	litre/day	22.91
Auxiliary Power Consumption of Heat Pump	kW	10
Energy Consumption of heat pump	kWh/day	76.4
Operating days	days	360
Fuel Cost	INR/litre	67
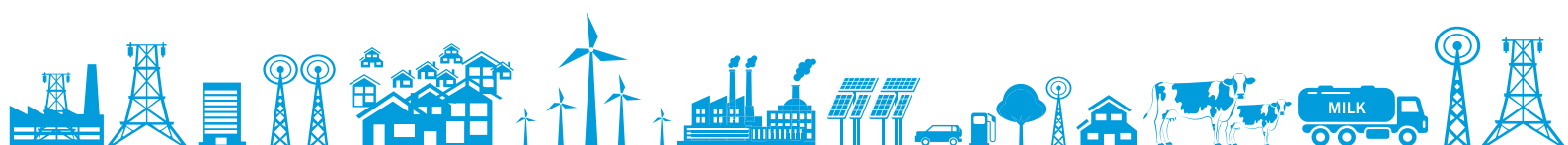
Parameters	UOM	
Electricity Cost	INR/kWh	4
Annual Fuel Savings	INR lakh	5.53
Electricity cost for running heat pump	INR lakh	1.10
Net Annual Savings	INR lakh	4.43
Size of Heat Pump available for producing 17.44 kW Electrical Heat Energy	kW	28
Investment for 28 kW Heat Pump	INR lakh	3.54
Payback Period	months	10
IRR	%	153.17
NPV at 70% Debt (12% rate)	INR lakh	20.80

Energy & GHG Savings

Annual Fuel Savings

8,247 litres of HSD

Annual Energy Savings

7.48 TOE

Annual GHG Savings

22.10 T CO_2

Vendor Details

Table 51: Vendor Details – Heat Pump

Equipment Detail	Electrical Heat Pump
Supplier Name	Aspiration Energy
Address	Aspiration Energy Pvt ltd Mandaveli, Chennai -600028
Contact Person	Mr. Logesh N
Mail Id	logesh@aspirationenergy.com
Phone No	+91 9840409624
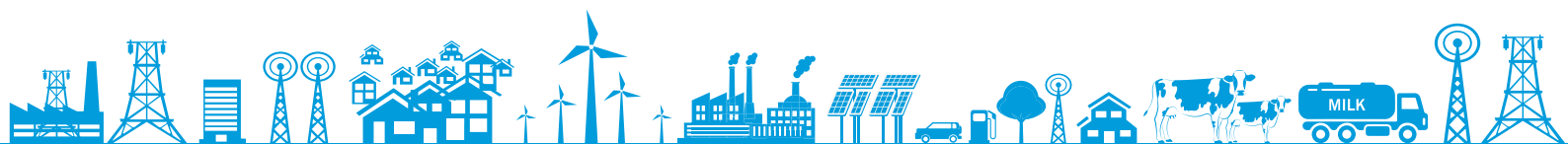
4.3.3 Thermal Energy Storage for BMC

Baseline Scenario

Milk is one of the most nourishing foods in the world. Milk contains numerous nutrients and makes a significant contribution to meeting the human body's needs for calcium, riboflavin, magnesium, selenium, vitamin B12 and pantothenic acid (vitamin B5). It is also one of the few consistent income sources for farmers. However, as soon as milk leaves the udder of the mammal, the bacteria in it start multiplying exponentially, which deteriorates the quality of milk by converting the lactose or sugar in the milk into lactic acid. It curdles the proteins and causes souring.

The hygienic quality of fresh milk is determined by milk handling practices at the milk producer level and the cooling practices at the milk collection centers. Poor quality of milk at the collection level cannot be corrected further up the dairy value chain. Therefore, it is very important that cooling should be done within one or one-and-a-half hour of milking, after which the naturally occurring preservatives in the milk (including carbon dioxide) stop working.
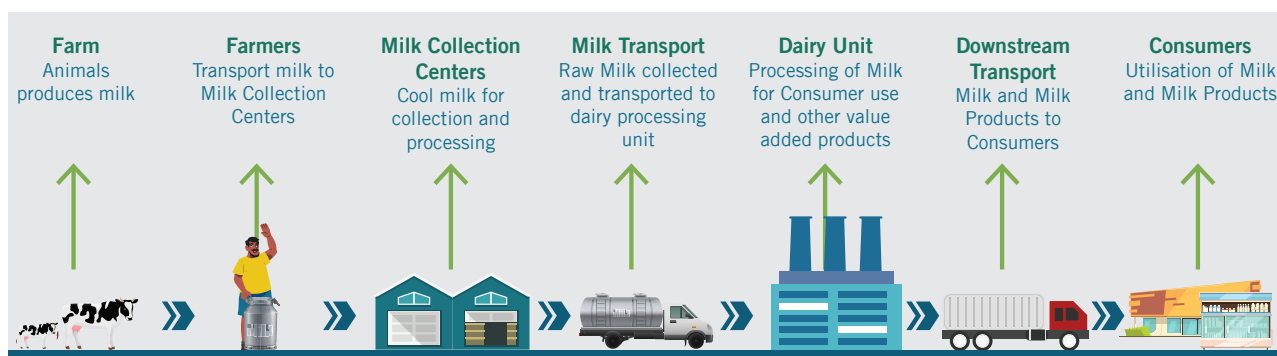
Figure 30: Dairy Value Chain

Dairies currently use bulk cooling tanks to cool their milk to about 4°C at their procurement centers. These tanks, of 1,000-5,000 litres capacity, keep the milk chilled till the tanker from the dairy arrives. These systems are designed as per ISO standards of cooling half of the rated bulk milk capacity to 4°C within 3 hours. Such standards work well for developed nations where milk production and cooling are co-located at the same vicinity. For India specific milk collection process, such coolers have following major drawbacks:

Table 52: Bacterial growth factor with milk temperature

Raw milk storage temperature (°C) for a period of 18 hours	Bacterial growth factor*
0	1.00
5	1.05
10	1.80
15	10.00
20	200.00
25	1,20,000.00
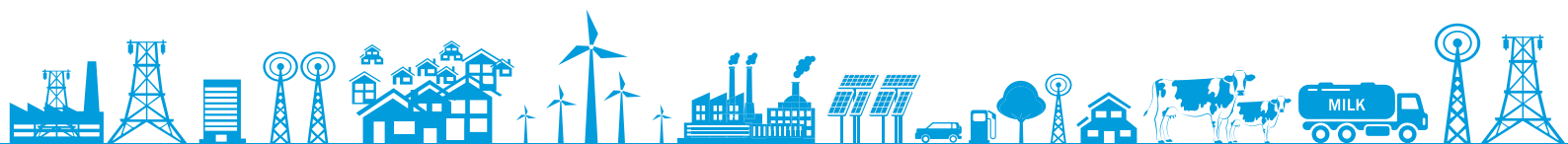
- ❖ An average Indian farmer delivers less than 10 L of milk per day. Insufficient milk collection in a village to cater to a single bulk cooler forces milk cooperatives to collect milk from nearby villages through milk societies. Uncooled milk collected from multiple societies is transported to a centralized bulk cooler before milk cooling process can be initiated. This entire process results in delayed and bulk arrival of milk at bulk cooler sites. Thus, milk is exposed to higher temperatures for a longer duration.

- ❖ Bulk coolers mostly operate at suboptimal capacity as there exist large variation in milk quantity production between lean and flush seasons. If these are undersized, cooling takes longer time. If these are oversized, the minimum milk requirement (typically ~15% of the tank volume) to start cooling process increases. Milk quality deteriorates in both the cases.

- ❖ Bulk coolers require the electric back-up via diesel generator sets, as electric grid supply is not reliable. It results in increased operational expenses and environmental pollution. In addition, diesel generators associated with these coolers are oversized by up to five times the rated power of compressor, just to handle the startup surge requirements. It results in additional diesel consumption due to part load operation.

Proposed System

Instant milk cooler is based on its thermal energy storage technology. It uses vapor compression cycle to convert electric energy into ice. This ice is later used to provide cooling without the need of grid availability during cooling process. Similar concepts of providing instantaneous cooling have been used at larger chilling centers, with capacity of 10,000 L/day or beyond. Efforts to miniaturize those systems have not been successful, simply because operating conditions and economics are totally different at small scale. It is an add-on to bulk cooler sites with following primary objectives:

- ❖ Delink the availability of grid supply and milk cooling requirement to minimize and even eliminate diesel generator.

- ❖ Eliminate the need of minimum milk quantity requirement of 15% of bulk cooler rated capacity to start the milk cooling process.

- ❖ Increase the cooling rates by three times to eliminate the impact of milk production variability on bulk cooler cooling capacities.

- ❖ Instant cooling of milk to reduce the overall time milk is subjected to elevated temperatures.
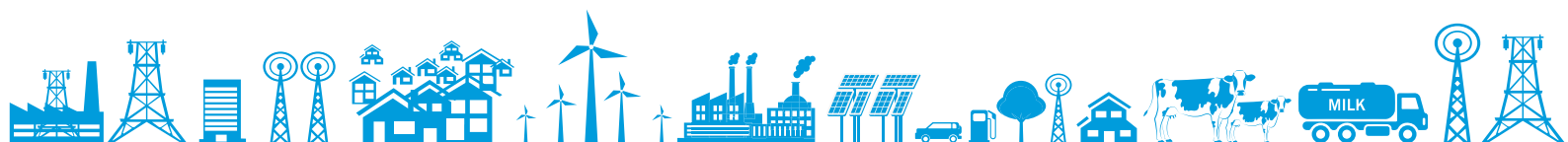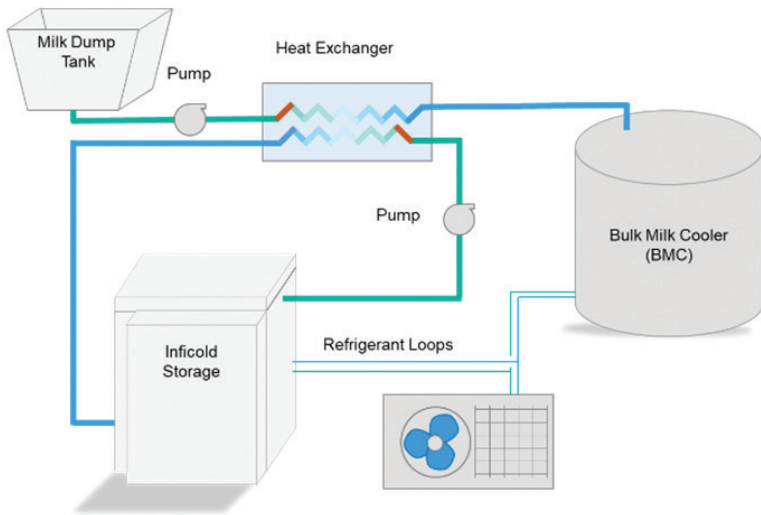
Figure 31: Schematic layout for Instant Milk Cooler

Instant milk cooler consists of an efficient ice bank tank, milk pump, plate heat exchanger and balance tank. Instant milk cooler automatically recharges its ice storage levels whenever grid power is available irrespective of the milk cooling requirements. It takes around 6-7 hours to fully charge the system with a single-phase grid supply. Milk is poured in the balance tank from where it is pumped in the plate heat exchanger to instant cool it to 4-7°C.

The milk flow rates are user adjustable in the range of 250-1,500 litre/hr. The outlet milk temperature is flow and quality dependent. The outlet temperature is 3-4°C milk outlet with milk flowrate of 250 L/hr; 5-7°C milk outlet with milk flowrate of 500 L/hr; and 8-10°C with milk flowrate of 1,000 L/hr, respectively. The energy storage in the ice bank tank is about 200 MJ.

The graph in the figure below compares the cooling provided by a standalone 2,000 L bulk milk cooler with a combination of instant milk cooler and 2,000 L bulk milk cooler. Milk flow rates used for the comparison were 1,000 litres per hour and the total 2,000 litres of milk was collected. At the end of the test, average temperature of milk collected in the tank was 4°C in both cases. Average time for
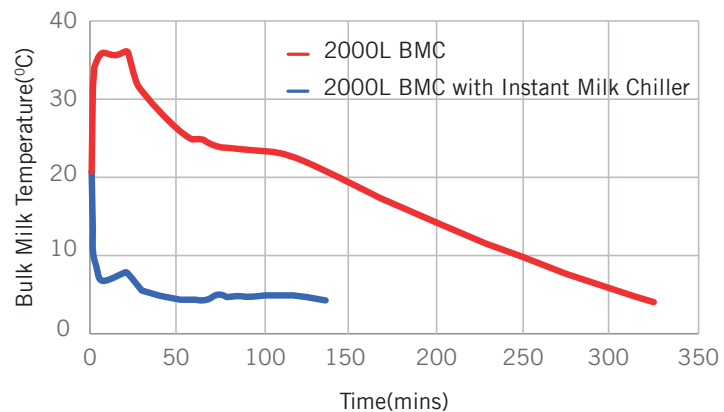
Figure 32: Cooling time with and without instant milk chiller

which milk was exposed to temperatures above 10°C is significantly higher with standalone 2,000 L bulk milk cooler. Since milk coming out of instant milk cooler is never above 10°C, the freshness and aroma of milk is maintained and a great value addition is achieved.

Merits

❖ Improves milk quality from typical 50 mins to 120 mins of Methylene Blue Dye Reduction Test (MBDRT).

❖ Eliminates usage of diesel generator for up to 1,500 litres of milk collection in a shift when the system is fully charged with ice.

❖ Can be used to enhance the capacity of an existing bulk milk cooler by handling cooling
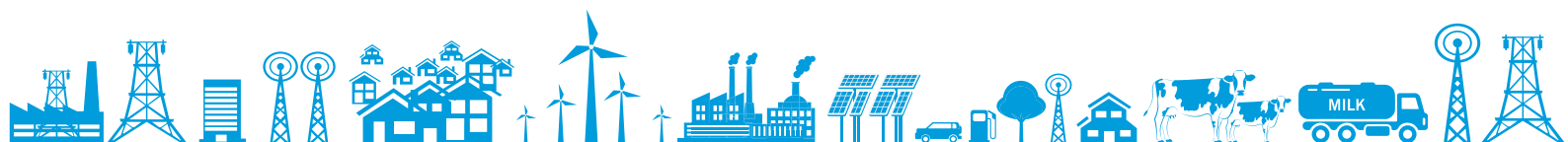
load of up to 1,500 litres of milk in a shift without availability of any source of power.

❖ Instant milk improves the milk quality and makes milk eligible for ultra-high temperature processing, which increases the sale value of the milk.

❖ Farmers at the installed pilot site have already started receiving INR 1/L. The extra income generation for the farmers is not considered in the payback analysis as it also depends on other milk handling practices. Assuming higher quality milk generates extra profit of INR 1 per litre, payback period is less than 6 months.

Limitations

❖ IMC is highly beneficial only when the dependence of BMC on Diesel Generator (DG) sets for power is high.

Cost Benefit Analysis

The expected fuel savings to be achieved by installing instant milk cooler in conjunction with a 2,000 L bulk milk cooler is 3.28 kl/year of diesel, which translates into annual monetary savings of INR 1.73 lakh. The value generation due to improved quality of milk is INR 1/litre, which translates to **INR 7.30 lakh/annum, with a total investment of INR 4 lakh and a payback period of 6 months**.
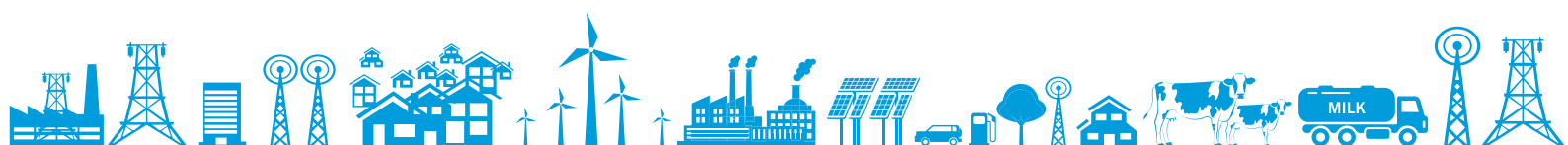
Table 53: Cost Benefit Analysis – Instant Milk Cooler

Parameters	UOM	
Milk processed	kl/shift	1
	kl/day	2
	kl/annum	730
Average Power consumption by compressor of 2000L Bulk milk cooler	kW	5.6
Average Cooling duration of 2000L milk in bulk milk cooler	hrs/day	6
	hrs/annum	2190
Power Cut	%	50
Fuel Cost (HSD)	INR/ litres	64
Electricity cost (Grid power)	INR/ kWh	6
Total DG runtime	hrs/ day	3
	hrs/ annum	1,095.0
GCV of HSD	kcal/ kg	11,840
Density of HSD	kg/ m^3	826.3
HSD consumption for DG	litres/ hr	3
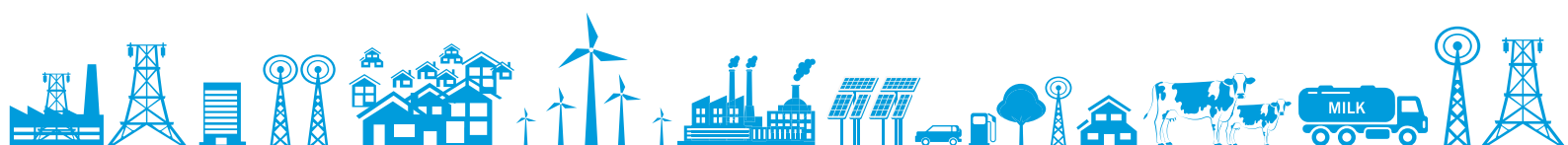
Parameters	UOM	
	kg/ annum	2,714.4
Thermal energy consumption from HSD	Mkcal/ annum	32.1
	TOE/ annum	3.2
	GJ/ annum	134.5
HSD savings	litres/ annum	3,285.0
Annual Cost Savings on Diesel	INR lakh/ annum	1.73
Value generation due to improved quality of milk	INR/litre	1.00
	INR lakh/ annum	7.30
Investment	INR lakh	4.00
Payback Period	months	6
IRR	%	246.13
NPV at 70 % Debt (12% rate)	INR lakh	41.74

Energy & GHG Savings

Annual Fuel Savings

3,285 litres of HSD

Annual Energy Savings

2.98 TOE

Annual GHG Savings

8.80 T CO$_2$

Reference Plant Implementation

Table 54: Reference Plant Implementation – Installation of Instant Milk Coolers

Project Name	Installation of Instant Milk Coolers
Objective	Improvement of milk quality and reduction of operational energy expenditure by instant milk cooling.
Dairy profile	The milk collection had an installation of 2 units of 1,000 L bulk milk cooler along with 2 units of 10kVA diesel generator. 1 unit of instant milk cooler was installed at the site.
Installation Photo	
Assumptions Made	❖ Average % Power outage – 18% ❖ Average daily milk collection – 2,000 L
Savings (INR lakh)	₹ 60,000 per annum on diesel + ₹ 7,30,000 per annum on improved milk quality.
Investment (INR lakh)	₹ 4,00,000
Simple Payback Period	6 months
Replication potential	In all the BMCs
Outcomes	❖ Annual Fuel savings – 1,242 litres of diesel. ❖ Annual GHG reduction – 1,837 kg. ❖ Milk quality has improved and is now eligible for UHT production. ❖ Usage of diesel generator has been eliminated.

Vendor Details

Table 55: Vendor Details – Instant Milk Cooler

Equipment Detail	Instant Milk Cooler
Supplier Name	Inficold India Private Limited
Address	G-21, Sector 11, Noida – 201301, Uttar Pradesh, India.
Contact Person	Dr. Nitin Goel
Email Id	ng@inficold.com
Phone No	+91-9873518652
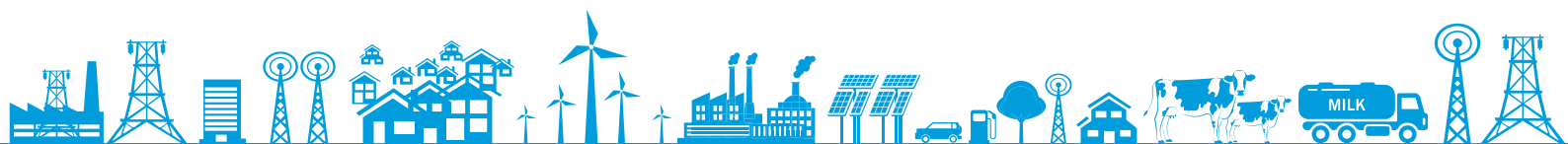
4.4 Case Studies – Utilities

4.4.1 VFD for air Compressor

Baseline Scenario

The dairy unit under consideration has installed a 15 kW screw compressor to cater to the requirements in the process and instrumentation section. The maximum working pressure of the compressed air in the system is in the range of 6-7 kg/cm². The operating characteristics of the compressor are shown below:

Table 56: Plant compressor loading pattern

Tag No.	Load %	Unload %	Load power, kW	Unload power, kW
Plant air compressor	36	64	17.5	6.6

It can be seen that the loading percentage of the compressor is only 36%, indicating a potential to install for VFD installation in the compressor. During the time the compressor goes into unload mode, there is no useful work done. Also, since the compressor is of screw type, the losses during unloading are higher in comparison with that of a reciprocating system.

Concept of VFD

Any compressor is design to go into load & unload conditions. The load and unload pressures for any compressed air system are set such that the average pressure delivered will be the required system pressure. The higher set point of the compressor therefore is a loss.

Also, in the present scenario, the installed compressor is of much higher capacity than compared to the system requirement, which is clear from the 64% unload that the compressor is operating with.

In these two conditions, the most suitable option is to go for a variable frequency drive (VFD). The difference between the normal & VFD condition in a compressor is as shown in the figure here.
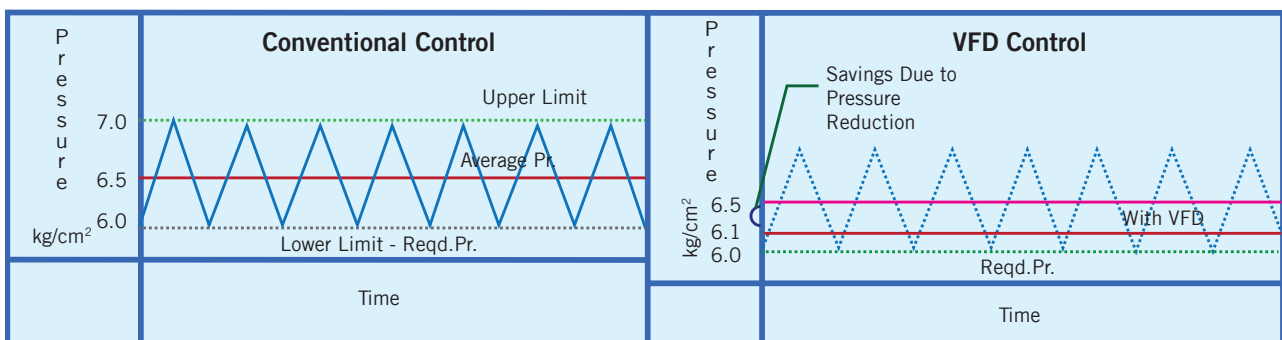
Figure 33: Capacity control of compressor

As can be seen from the figure, the VFD can be given a set point equal to that which is required in the system. The additional power that the compressor consumes over the required pressure will be the savings achieved.
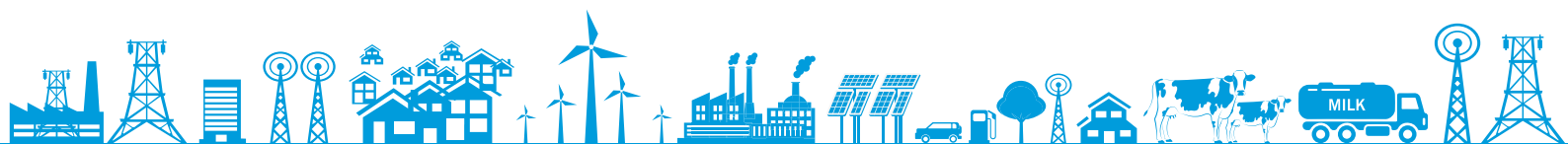
Proposed System

It is recommended to install VFD and operate that with closed loop for all the above listed compressors to avoid the unloading of the compressors. The feedback for VFD can be given as required receiver pressure. By installing VFD, the compressor can be operated in a pressure bandwidth of ±0.1 bar. Saving potential of 4.2 kW is available by means of installation of VFD in the Main plant air compressor.

Merits

- ❖ Reduced fluctuations in pressure.
- ❖ Ease of operation.
- ❖ Reliability.

Limitations

- ❖ Viable only up to 40% unload situations.
- ❖ Maintenance issues.
- ❖ Space constraints.

Cost Benefit Analysis

The expected savings by installation of VFD in the compressor is 1,8247 units annually. The annual monetary saving for this project is **INR 1.03 lakh, with an investment of INR 0.90 lakh and a payback period of 11 months.**

Table 57: Cost Benefit Analysis - VFD for Air Compressor

Parameters	UOM	Value
Unloading power of compressor	kW	6.6
Percentage unloading	%	64
Power savings	kW	4.2
Annual operating hours	hrs	4,320
Annual energy savings	kWh	18,247
Power cost	INR/kWh	5.65
Annual savings	INR lakh	1.03
Investment	INR lakh	0.9
Payback Period	months	11
TOE savings	TOE	1.57
TCO$_2$ savings	T CO$_2$	14.96
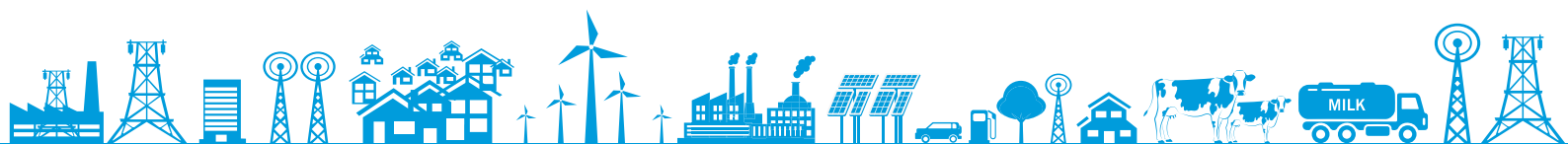
Parameters	UOM	Value
IRR	%	142.02
NPV at 70 % Debt (12% rate)	INR lakh	4.81

Energy & GHG Savings

Annual Electricity Savings

18,247 units

Annual Energy Savings

1.57 TOE

Annual GHG Savings

14.96 T CO$_2$

Vendor Details

Table 58: Vendor Details – VFD for Air Compressor

Equipment Detail	VFD for compressors
Supplier Name	Danfoss Industries Ltd
Address	703,7th Floor, Kaivanya Complex,Near Panchwati Cross Road
Ambawadi, Ahmedabad	
Contact Person	Mr. Srihari Vyas
Email Id	Shrihari@danfoss.com
Phone No	9825024991

4.4.2 Demand Side Controller for Compressed Air

Baseline Scenario

The unit has installed seven air compressors for their process and instrumentation applications. Out of the seven compressors installed, five compressors are in running condition and two are on standby. All the compressors are connected to a common header. The plant has installed a separate receiver of 2 m³ capacity at user points to avoid fluctuations in compressed air generation at user side. The schematic layout and the details of the compressor installed in the plant are given below:

Table 59: Compressor Details

Sr. No.	Details	Type	Motor Rating (kW)	Capacity (cfm)	Working Status	Set Points (kg/cm²)	Operating Band (kg/cm²)
1	Compressor 1	Screw	160	915	Running	7.3/7.0	0.3
2	Compressor 2	Screw	145	835	Running	7.3/6.7	0.6
3	Compressor 3	Screw	145	835	Running	7.3/6.6	0.7
4	Compressor 4	Screw	160	915	Running	6.9/6.2	0.7
5	Compressor 7	Screw	145	835	Running	7.3/6.6	0.7

All the compressors are connected to a common header and compressors are loading and unloading at different pressures based on the user application. This leads to a situation wherein one or more compressors tend to load more in comparison to the actual requirement. Due to this, there is additional compressed air generation creating an artificial demand. Artificial demand is due to the actual required pressure fluctuations at the demand side. Hence, most of the time, air (CFM) will be supplied more than required at the instant. Due to the supply of more air than the actual requirement, power consumption will also be higher than the required amount.

Proposed System

It is recommended to install a 6,000 cfm demand side controller/ intelligent flow controller in the common header line to minimize the artificial demand in the plant. Intelligent Flow Controller (IFC) controls the air flow and pressure being delivered, thereby reducing artificial demand in the Plant. The IFC is designed to operate at the intermediate point of the compressed air system, i.e., on the downstream side of the filter/ dryer/ receiver tank and the upstream side of the main piping distribution system. IFC creates useful storage through controlled differential pressure across upstream receiver and itself. This storage isolates the compressors from demand side fluctuations. Peaks are dealt with reserve energy from storage instead of additional power, allowing the compressors to run on reduced load. Thus, the mass of air consumed by artificial demand, pneumatic equipment, tools and air-leakages is reduced, which in turn results in the reduction in energy consumed by air compressors. The specification of the IFC proposed for the current plant running condition and pressure set points is given below:
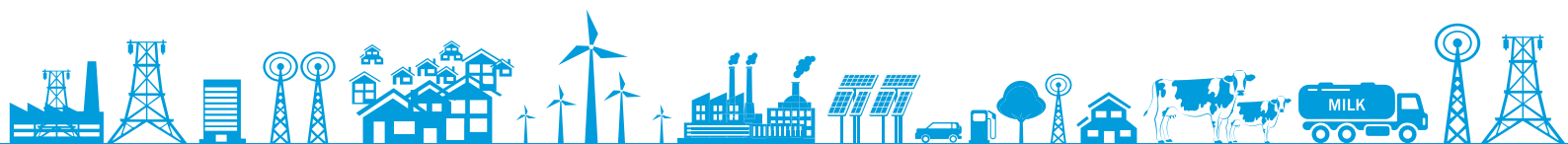
Application	Capacity (cfm)	Upstream Pressure (kg/cm²)	Downstream Pressure (kg/cm²)
Compressed Air Network	6,000	6.6	5.9

The intelligent flow controller works on the principle similar to a dam. Water flows inside the lake must go out in order to maintain the constant water level. In the case of a dam with gates, a reservoir will be created. The gates will be controlled based on the requirement at the downstream demand side and sudden requirement will be supplied for by the reservoir. Similarly, the intelligent flow controller will create the reservoir at the upstream side and will be controlled by the flow controller. The entire demand side line will be maintained with preset pressure value. Any changes in the demand side pressure requirements (artificial demand) will be taken care of by the flow controller and hence the artificial demand will be neglected. Thus, the intelligent flow controller reduces the loading percentage and increases the unloading percentage by means of reduction or elimination of artificial demand.

The IFC consists of multi-parallel flow control module/s along with controlled automatic bypass, both manifolded into welded steel headers with flanged inlet and outlet top side connections. The multi-parallel flow control module/s and the automatic bypass are 'fail to open' type. Both, the flow control module/s and the automatic bypass, parallel open in the event of failure of either pneumatic and/or electric power, making it a fail-safe equipment. Electro-pneumatic transmitters continuously monitor the downstream demand along with availability of enough mass of air on upstream for the microprocessor controller to send the correct signal to the IFC for processing. The IFC increases or decreases the flow to the plant according to the sensed downstream demand. The quick response of the IFC paces the flow dynamics of the system ensuring that adequate supply of air is instantly available for production. The position (of the amount of opening or closing of each flow control module/s) is indicated by arrow moving over 0° to 90° span as well as on touch screen display.

Merits

❖ Improves pneumatic equipment performance with constant air pressure within +/- 1 psig (0.07 bar).

❖ Reduces leakage losses in the plant.

❖ Isolates compressors from demand side peaks & troughs.

❖ Reduces load period of compressors & improves performance of VFD in air compressors.

❖ HMI Display with touch screen for easy access.

❖ Online as well as historical pressure trend, Inlet & Outlet pressure and system status are displayed on HMI screen.

Limitations

❖ Savings will be low if the compressor is already installed with VFD.

❖ If the overall leakage in the compresses air network is low, savings will be low.

Cost Benefit Analysis

The expected electricity savings to be achieved by installation of intelligent flow controller is 2.62 lakh units annually. The annual monetary saving for this project is **INR 20.74 lakh, with an investment of INR 14.20 lakh and a payback period of 08 months.**

Table 61: Cost Benefit Analysis – Demand Side Controller

Parameters	UOM	Value
Current Energy Consumption	kWh/day	15,000
Current cfm requirement	cfm	4,335
SEC of compressed air system	kW/cfm	0.145
Energy Savings	%	5
Proposed Energy Consumption	kWh/day	14,250
Annual Energy Savings (350 days operating)	kWh	2,62,500
Electricity Cost	INR/kWh	7.9
Annual Monetary Savings	INR lakh	20.74
Investment	INR lakh	14.19
Payback Period	months	8
IRR	%	175.26
NPV at 70 % Debt (12% rate)	INR lakh	98.58

Energy & GHG Savings

Annual Electricity Savings

2,62,500 kWh

Annual Energy Savings

22.58 TOE

Annual GHG Savings

215.25 T CO$_2$
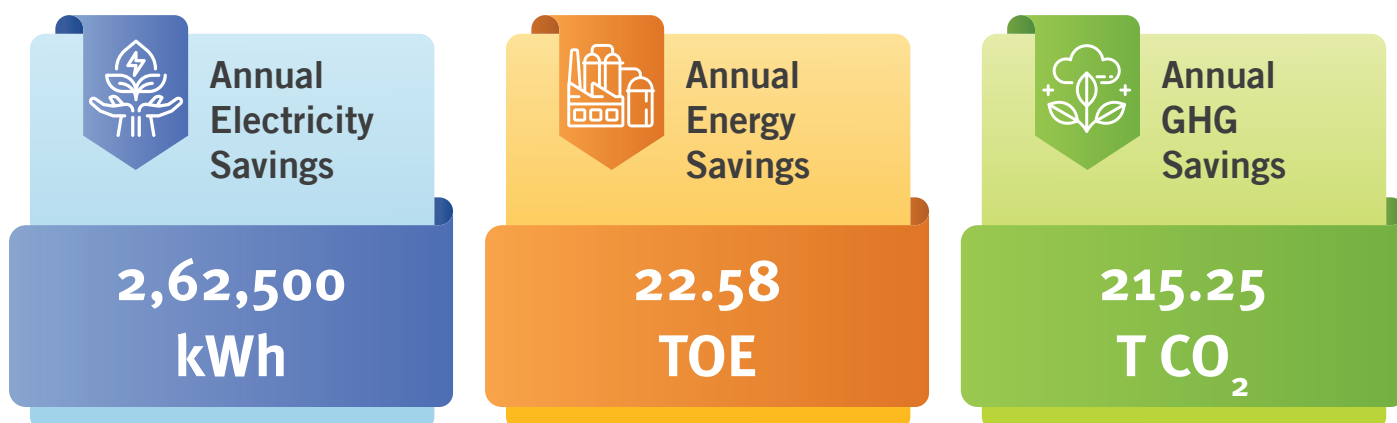
Vendor Details

Table 62: Vendor Details -Demand Side Controller

Equipment Detail	Demand Side Controller
Supplier Name	Godrej & Boyce Mfg. Co Ltd
Address	Godrej & Boyce Mfg. Co Ltd Pirojshanagar, Vikhroli, Mumbai
Contact Person	Mr. Arun Kumar Singh
Email Id	arunsing@godrej.com
Phone No	+91 9328029682

4.4.3 Energy Efficient Pumps

Baseline Scenario

The unit has installed two chilled water pumps for pumping chilled water from IBT to process, of which one is running and the other one is on standby. The chilled water is used in pasteurization process and pre-chiller, where the milk is cooled to 4°C. Chilled water required for the various processes is pumped using two pumps of 5.5 kW capacity each. After the process, the return water is coming at 6°C-8°C. The figure below shows the schematic of chilled water system in the plant:
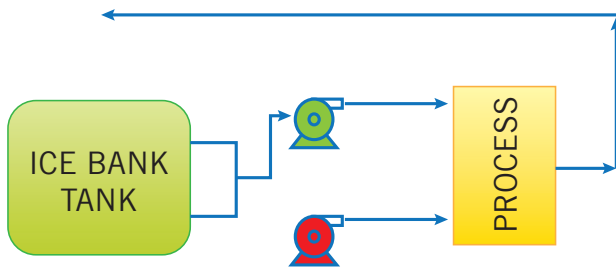
The design efficiency of the pump is 39%, which is very low and the measured efficiency is 31%, which is lower than the design efficiency. The reasons for low efficiency of pump are:

❖ Poor operational practices.

❖ Pump is very old and undergone frequent maintenance.

❖ Poor selection of pump.

Figure 34: Chilled Water Pumping Systems

Proposed System

It is recommended to replace the old chilled water pump with energy efficient pump. The highly efficient pump will consume less power than low efficiency pumps, which will lead to energy saving. Energy efficient pumps offer higher efficiency than conventional pumps and consume less power, thereby leading to significant energy savings. The new pumps installed have an overall efficiency of 53%. The pump – system curve is illustrated graphically as shown. The point where the system and the pump curve meet is known as

Figure 35: Pump Characteristic Curve

the Best Efficiency Point (BEP). The operating efficiency is highest and the radial bearing loads are lowest for a pump at this point. At or near its BEP, a pump operates most cost effectively in terms of both energy efficiency and maintenance. In practical applications, operating a pump

continuously at its BEP is not likely, because pumping systems usually have changing flow rate and system head requirements and demands. Selecting a pump with a BEP that is close to the system's normal operating range can result in significant operating cost savings.

Merits

- ❖ Higher operating efficiencies.
- ❖ Reduced power consumption.
- ❖ Optimum flow & head.

Limitations

- ❖ High installation cost.
- ❖ May require system stoppage during installation.

Cost Benefit Analysis

The expected energy savings to be achieved by installation of new energy efficient pumps is 17,520 units annually. The annual monetary saving for this project is **INR 0.70 lakh, with an investment of INR 0.98 lakh and a payback period of 17 months.**

Table 63: Cost Benefit Analysis – Energy Efficient Pump

Parameters	UOM	Present	Proposed
Power Consumption	kW	6	4.5
Flow	m³/hr	15.5	16
Head	m	40	45
Efficiency	%	35	51
Power Savings	kW	1.5	
Electricity Cost	INR/kWh	4	
Operating hrs	hrs/day	8.00	
Energy Savings	kWh	17,520	
Cost Savings	INR lakh	0.70	
Investment	INR lakh	0.98	
Payback Period	months	17	
IRR	%	66.74	
NPV at 70 % Debt (12% rate)	INR lakh	2.34	

Energy & GHG Savings

Annual Electricity Savings

17,520 kWh

Annual Energy Savings

1.51 TOE

Annual GHG Savings

14.37 T CO$_2$
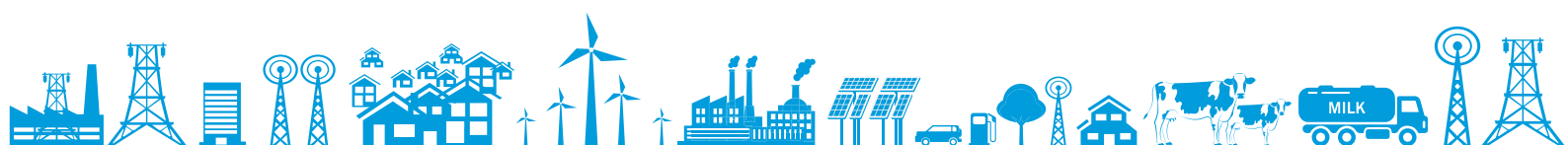
Reference Plant Implementation

Table 64: Reference Plant Installation: Energy Efficient Pump Sets

Project Name	Installation of energy efficient pups
Objective	Replacement of old chilled water pumps with energy efficient pumps
Unit profile	Trivandrum dairy - a unit under Thiruvananthapuram Regional Co-operative Milk Producers' Unions (TRCMPU) of MILMA, having its plant at Ambalathara, Trivandrum, Kerala, offers pasteurized Vitamin A enriched milk and various milk-based products such as Butter, Ghee, Paneer, Curd, buttermilk and ice cream throughout the state.
Installation Photo	
Assumptions Made	❖ Electricity Cost : 6 INR/kWh ❖ Operating hrs : 14 hrs/day ❖ Old Pump Efficiency : 42
Savings (INR lakh)	₹ 1.39
Investment (INR lakh)	₹ 2.20
Simple Payback Period	19 months
Replication potential	All dairies irrespective of size
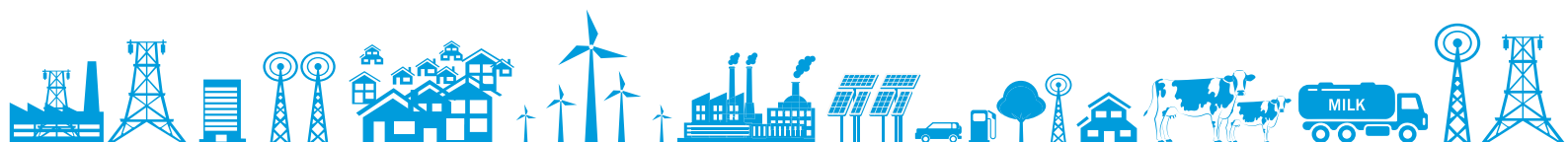
Project Name	Installation of energy efficient pups
Outcomes	❖ Efficiency of pump: 53 % ❖ Power Savings: 4.52 kW ❖ 1.99 TOE of annual energy savings. ❖ Carbon footprint reduction of 18.48 TCO_2 per year.
Unit contact details	Mr. Balasubramony G Trivandrum Dairy Ambalathara, Poonthura.P.O, Thiruvananthapuram – Kerala Phone: 9633802195 Email: milmatdengg@gmail.com
Cluster Reference	Kerala

4.4.4 Package Type Biogas Reactor

Baseline Scenario

The unit has a canteen catering food to around 600 employees. Currently, for all cooking purposes, biogas from ETP and Liquid Petroleum Gas (LPG) is used as fuel. The average amount of food waste generated per day from the canteen is 500 kg. It is disposed of outside.

However, the canteen waste being organic in nature and high in organic content, can be converted into biogas and manure, using an anaerobic digestion process. The anaerobic digestion process would address two aspects: generation of non-fossil fuel-based energy and the avoidance of waste going to landfill. The biogas generated can be further purified and can substitute the use of LPG in the canteen. The manure generated from the process can be used for gardening. Recently, there have been many developments in biogas digestion technologies and the economics have also improved substantially. With rising fossil fuel prices, especially that of LPG, the installation of bio-digesters to generate biogas can be a good substitute for conventional energy and would result in both environmental and cost benefits for the company.

Proposed System

The most commonly used models are fixed dome reactors, floating drum reactors and, of late, there has been development of a few mild steel-based digesters. There has not been much innovation in design during the last several years. With old designs, the usage of mild steel and concrete also adds up to the cost of the digester. One of the main challenges has been developing digesters with simplicity in operation and maintenance. Mild steel digesters have major challenges, such as rusting due to H_2S content in the biogas and exposure to wet weather conditions, among other problems.

It is recommended to install biogas plant, which is a fabric-based biogas technology, for processing the 500 kg of food waste produced daily. This technology would process all the canteen waste generated inside the plant, which is a better alternative to disposing of it outside.

Figure 36: Fabric used for biogas
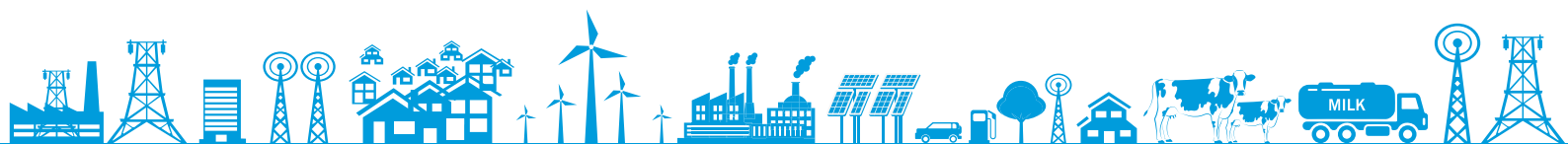
The schematic layout of the proposed system is given below:
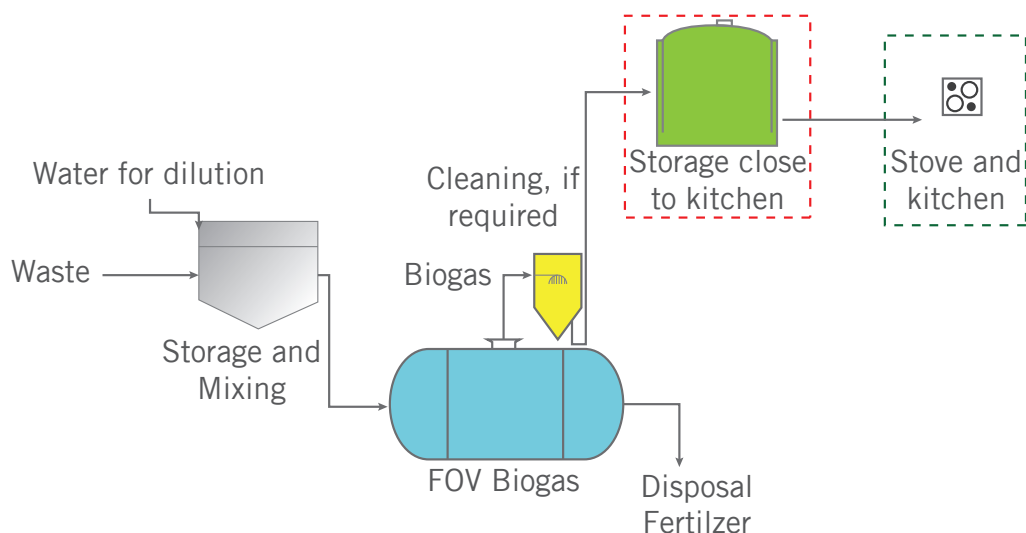
Figure 37: Layout of FOV Biogas Technology

The biogas plant will be initially loaded with active inoculum to start the process. After the initial loading is complete, the 500 kg of food waste is mixed with 500 litres of water to reach a slurry form by feeding in a crusher. The slurry will be fed into a feeding tank. The organic waste from the feeding tank will be fed into a 50 m^3 biogas reactor. The reactor will have 30 m^3 liquid space and rest 20 m^3 as gas storage space. The additional gas generated can be stored in a gas holder. About 1 m^3 of diluted organic waste in a slurry form will be fed into the reactor every day. The excess liquid slurry coming out of the digester can be re-circulated as replacement for fresh water.

On an average, the reactor will have a 30-day retention time. Under optimized running conditions, the biogas plant will generate about 50 m^3 of biogas per day. The feeding and digestate collection is a continuous process. The biogas generated will be piped to the kitchen and used for cooking by using biogas burners. The total area required for the biogas plant is about 80 m^2 of space. The design of the biogas plant can be adjusted according to space availability.

Benefits of new system

- ❖ Plug and flow digester (no settlement of sludge, natural mixing of organic waste).
- ❖ Low operations and maintenance costs.
- ❖ No rusting, unlike other designs, which are made of mild steel for digester tanks and for gas collection.
- ❖ No moving parts used for feeding, mixing and sludge outflow, since all the operations are based on natural gravity-based process. Very low captive power consumption for operating the digester.
- ❖ In-built gas space at the top of digester, which can hold up to 50% of total gas generated.
- ❖ Highest material quality.

Limitations

- ❖ High investment cost.
- ❖ Continuous availability of feed to reactor.

Cost Benefit Analysis

The expected energy savings to be achieved by installation of biogas technology is 9,000 kg of LPG annually, with energy reduction of 10.65 TOE/year. The annual monetary saving for this project is INR 4.79 lakh, with an investment of **INR 11.12 lakh and a simple payback period of 27 months.**

Table 65: Cost Benefit Analysis – Biogas Reactor Systems

Parameters	UOM	Existing System	Proposed System
Canteen waste generated per day	kg	500	500
LPG used per day	kg	25	NIL
Gas Potential from 500 kg waste	m³/day	50	50
Operating days/annum		360	360
Annual Energy Savings	kg LPG	-	9,000
LPG Cost	INR/kg	53.23	53.23
Annual Cost Savings	INR/lakh	4.79	
Investment	INR/lakh	11.12	
Payback Period	months	27	
IRR	%	62.31	
NPV at 70 % Debt (12% rate)	INR lakh	19.19	

Energy & GHG Savings

Annual Fuel Savings
9000 kg LPG

Annual Energy Savings
10.65 TOE

Annual GHG Savings
26.82 T CO$_2$

Reference Plant Implementation

Table 66: Reference Plant Implementation – Biogas Reactor

Project Name	Installation of Biogas Reactor
Objective	Installation of 500 kg/day biogas plant to process food waste from canteen, pizza wastes and solid waste and generate energy for cooking in canteen.
Unit profile	Amul Fed Dairy is a large-scale dairy unit located at Gandhinagar, Gujarat. The various products manufactured in AFDG dairy are liquid milk, butter milk, flavored milk, lassi, ghee and ice cream, with an average milk processing capacity of 32 lakh LPD.
Installation Photo	
Assumptions Made	❖ Canteen waste generated per day is 500 kg. ❖ Operating days – 360 ❖ Gas potential is 50 m^3/day ❖ LPG cost – INR 53.23/kg
Savings (INR lakh)	INR 4.79
Investment (INR lakh)	INR 11.12
Simple Payback Period	28 months
Replication Potential	In all large dairy units (> 10 lakh LPD) and cattle farms
Outcomes	❖ 25 kg per day LPG savings of monthly energy saving ❖ 10.66 TOE of annual energy savings ❖ 26.82 t CO_2 reduction per year
Unit contact details	Mr. Prashant Seth Amul Fed Dairy Plot No 35, Gandhinagar Ahmedabad Road ,Bhat , Gujarat Phone: 07574802084 Email: prashant.sheth@amul.coop
Cluster Reference	Gujarat Dairy Cluster

4.4.5 Methane Capture from dairy effluents

Baseline Scenario

The unit has installed a 300 klPD ETP plant to treat the effluents from various processes, the effluents generated from various sections of the production facilities are first received in a collection tank. Before mixing in an equalization tank, the effluents are passed through a fat trap unit. The low-density semi-solids, which float in the tank and contain fats, proteins, packing materials, etc., are known as 'dairy effluent scum' and are removed manually. After removing the dairy effluent scum (top layer), the effluents are further treated in aerobic or anaerobic conditions. The characteristics of dairy effluent scum vary with the products being produced in the plant and their relative proportion, as well as the methods of the operation used. The process involved is as below:

❖ Equalization tank for collection of raw effluent generated from plant for homogenization of the quantity and quality.

❖ Anaerobic biological treatment for removal of most of the suspended and dissolved organic impurities – it includes an Upflow Anaerobic Sludge Blanket (UASB) reactor followed by a settling tank.

❖ Aerobic biological treatment unit for polishing of aerobically treated effluent to achieve statutory disposal norms – It includes an aeration tank followed by a settling tank.

❖ Polishing treatment units: For further purification of treated effluent - It includes a duel media pressure filter, an Activated Carbon Filter, a Micron Filtration System, an Ultra-filtration system and a Reverse Osmosis system.

Effluent Characteristics:

Table 67: Effluent Characteristics

Sr. No.	Parameter	Raw Effluent	After Anaerobic	Treated Effluent
1	Effluent flow rate	300 m³/day	300 m³/day	300 m³/day
2	pH	4.0 – 9.0	7.0 – 8.5	7.0 – 8.5
3	Temperature	‹ 40° C	‹ 35° C	‹ 35° C
4	Chemical Oxygen demand (COD)	4,000 mg/l	‹ 600 mg/l	‹ 100 mg/l
5	Biochemical Oxygen demand (BOD)	2,500 mg/l	‹ 200 mg/l	‹ 30 mg/l
6	Oil & Grease	50 mg/l	‹ 20 mg/l	‹ 10 mg/l
7	Total Suspended Solids	500 mg/l	‹ 150 mg/l	‹ 50 mg/l

The wastewater generated from the unit will have various pollutants which exert high BOD and COD load. From the above table it is observed that incoming dairy effluent has a BOD of 2,500 mg/l and COD of 4,000 mg/l, which after treatment is reduced to less than 30 mg/l and 100 mg/l respectively.
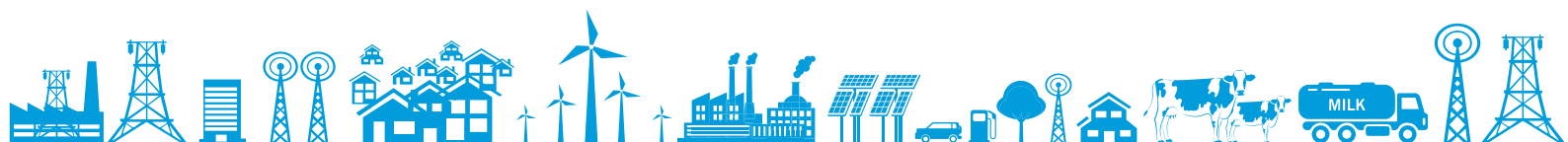
Current Treatment Process:

The raw effluent 300 m³/day from different trade activities flows to ETP by gravity. It first gets collected in equalization tank for homogenization of the quantity and quality. Acid/ Alkali solution is added to neutralize the effluent, if required. Homogenized and neutralized effluent from equalization tank is pumped @15 m³/h to UASB reactor bottom and distributed uniformly through the inlet distribution system. It passes upwards through the dense anaerobic sludge bed. Organic matter is rapidly utilized by biomass and converted to methane rich biogas. Upward circulation of water and biogas purging from the bottom of the reactor keeps the biomass in suspension and breaks any scum formation. The three-phase separator at the top of the UASB reactor allows effective degasification to occur. The dense, granular sludge particles, devoid of attached gas bubbles, sink back to the bottom establishing a return downwards circulation. The treated effluent flows into collection channels at the top of the settlers for discharge and transferred to the clarifier – 1. Washed out anaerobic biomass is recovered and recycled to the reactor. Excess biomass from Anaerobic Process is wasted to sludge dewatering system, if required. Biogas is collected in gas collection portion of three phase separator at the top of the reactor and transferred to a waste gas burner. Aerobically treated effluent is transferred to aeration tank. A culture of aerobic bacteria decomposes organic impurities in to CO_2. A coarse bubble aeration grid is provided to supply O_2 to aerobic bacterial culture. Air is supplied by the same twin lobe air compressor system. Treated effluent flows through the clarifier - 2 to retain bacterial culture. The heavy biomass flocs get settled in the bottom and clear treated effluent flows into outlet channel. Aerobically treated effluent is collected in a treated effluent collection sump, it is pumped to Duel media pressure filter for polishing. Reclaimed water will be suitable for irrigation or feeding to softener for reuse in boiler and cooling tower.
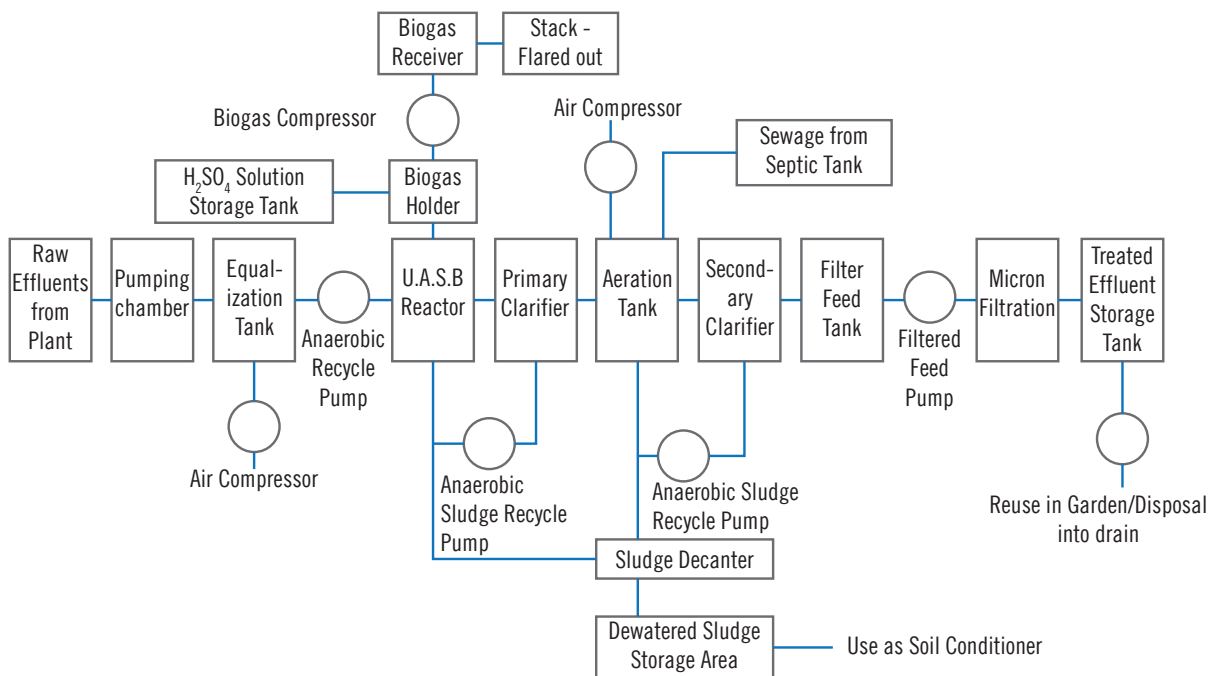
Figure 38: ETP Treatment Process
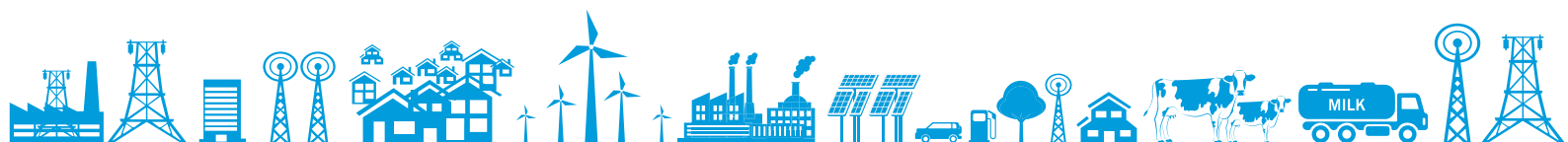
Currently the bio gas generated from the ETP is flared out through stack. Total biogas generated is 400-425 m³/d at design loading of 300 m³/d effluent flow and 4,000 mg/l COD, which has a calorific value equivalent to 23,430 kJ/ m³.

Proposed System

It is recommended to install biogas engine with generator to produce electricity from biogas rather than flaring it out. Biogas production will be continuous and for 24 hours a day. The organic fraction of the solid waste has been recognized as a valuable resource that can be converted into useful products using microbes. Anaerobic digestion is a well-established technology for treatment of organic wastes. Biodegradation of the organic wastes in the absence of oxygen produces biogas, which is a mixture of methane and carbon dioxide as major components and traces of hydrogen, ammonia, hydrogen sulphide, etc. Biogas can be used for thermal applications, such as water heating, drying, boiler fuel, etc., or for electricity generation. The digested material available after the anaerobic treatment may be used as a soil conditioner after composting/ vermicomposting. Dual benefits reaped using anaerobic digestion processes for organic solid waste are simultaneous removal of organic pollutants and waste stabilization as well as production of renewable energy in the form of biogas.

The biogas holder will have about 1 m³ storage volume. This biogas will be transferred to biogas holder for intermediate storage. Then the gas will be pumped through a compressor and stored in a biogas capsule. It will be then used in the biogas engine. The estimated potential of generation is 90-950 kWh/day, which is around 40 kW generation considering a generator efficiency of 37% and gas availability of 85%.

Figure 39: Biogas Generation and Utilization Process

Benefits of new system

❖ Proper disposal of dairy effluents leads to arresting release of methane to atmosphere.
❖ Capturing methane from effluents provides an alternative source of energy.

Limitations

❖ High investment cost.
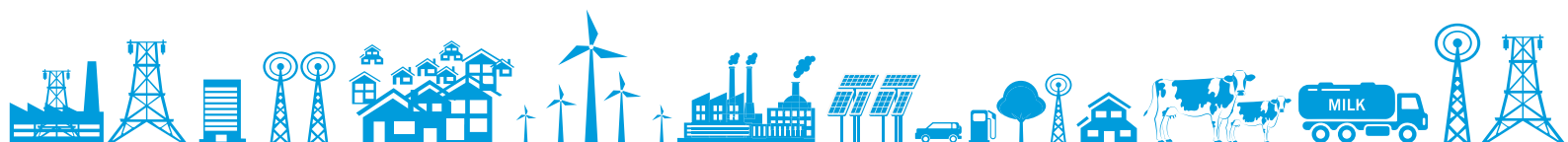
Cost Benefit Analysis

The expected electricity savings by 40 kW Biogas power generator is 2,51,989 kWh annually. The annual monetary saving for this project is **INR 16.12 lakh, with an investment of INR 31.86 lakh and a simple payback period of 24 months**.

Table 68: Cost Benefit Analysis – Biogas Power Generator

Parameters	UOM	
COD Inlet	mg/l	4,000
COD after anaerobic Digestion and before polishing	mg/l	600
Flow	m³/day	300
COD Reduction	mg/lit	3,400
CH4 Generation Potential	m³/kg COD	0.4
CH4 Generation per day	m³/day	408
GCV	kJ/m³	23,430
Energy Generation per day	kJ/day	95,59,603
Generator Efficiency	%	35
Power Generation	kW	38.74
Bio Gas Availability	%	85.00
No of operating hours	hrs/day	24
No of days	days/year	365
Annual Electricity Generation	kWh	2,88,489
Annual Auxiliary Power Consumption @ 100 units per day	kWh	36,500
Total Electricity Generation	kWh/year	2,51,989
Electricity Cost	INR/kWh	6.4
Annual Savings	INR lakh	16.12
Investment	INR lakh	31.86
Payback Period	months	24
IRR	%	71.44
NPV at 70 % Debt (12% rate)	INR lakh	67.14

Energy & GHG Savings

Annual Electricity Savings	Annual Energy Savings	Annual GHG Savings
2,51,989 kWh	**21.67 TOE**	**206.63 T CO$_2$**
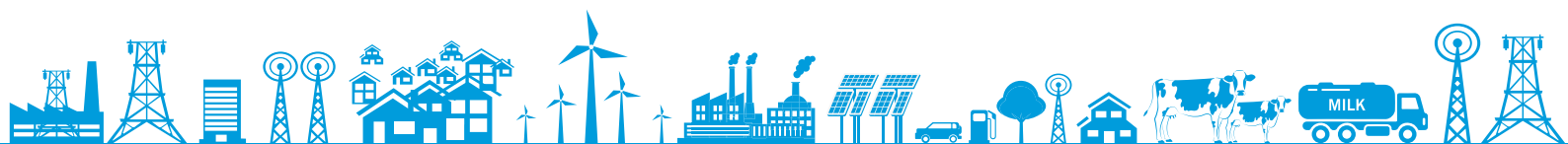
Reference Plant Implementation

Table 69: Reference Plant Implementation – Biogas Utilization

Project Name	Methane capture from dairy effluents
Objective	To capture methane from dairy effluents and used as a fuel
Unit profile	Amul Fed Dairy is a large-scale dairy unit located at Gandhinagar, Gujarat. The various products manufactured in AFDG dairy are liquid milk, butter milk, flavored milk, lassi, ghee and ice cream with an average milk processing capacity of 32 lakh LPD.
Installation Photo	-
Assumptions Made	❖ COD load per day – 13,600 kg/day ❖ Operating days – 360 ❖ GCV of biogas – 25,104 kJ/m^3 ❖ Gas potential is 50 m^3/day ❖ NG cost – INR 28/m^3
Savings (INR lakh)	INR 288 lakh
Investment (INR lakh)	INR 250 lakh
Simple Payback Period	11 months
Replication Potential	In all large dairy units (> 10 lakh LPD) and cattle farms
Outcomes	❖ 2,874 m^3/day natural gas equivalent biogas generation. ❖ 864 TOE of annual energy savings. ❖ 459 T CO$_2$ reduction per year.
Unit contact details	Mr. Prashant Seth Amul Fed Dairy Plot No 35, Gandhinagar, Ahmedabad Road, Bhat, Gujarat Phone: 07574802084, Email: prashant.sheth@amul.coop
Cluster Reference	Gujarat Dairy Cluster
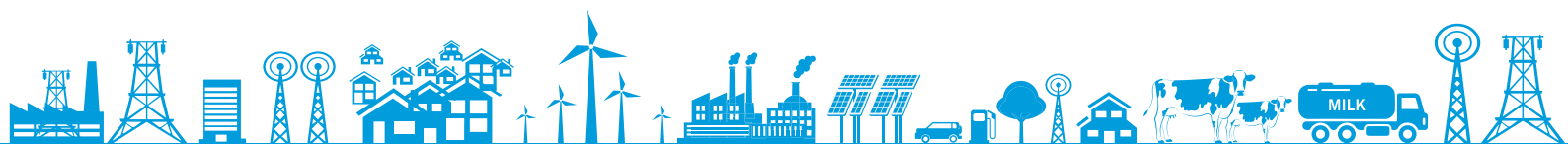
Vendor Details

Table 70: Vendor Details – Biogas Utilization – Power and CNG

Equipment Detail	Bio Gas Power Generator
Supplier 1	
Supplier Name	Environponics Solutions Pvt Ltd
Address	9, New Natraj Park Society, Bopal Ghuma Road, Bopal, Near India Colony, Bopal, Ahmedabad, Gujarat 380058
Contact Person	Mr. Deep Modi
Mail Id	environponics@yahoo.com
Phone No	+91 9825021159
Supplier 2	
Supplier Name	Sun Envrio Technologies Pvt Ltd
Address	Ashok Colony, Plot No. 22, Near Union Bank, Pratap Nagar, Nagpur - 440 025
Contact Person	Ms. Prachi Doye
Mail Id	sunenviro@sunenv.com
Phone No	+91-712-2282608
Supplier 3 (Biogas to Bio CNG)	
Supplier Name	Atmos Power
Address	39/3B & 39/8B, Nana Chiloda Rd, Phase 3, GIDC Naroda, Ahmedabad, Gujarat 382330
Contact Person	Mr Navneet
Mail Id	mkt@atmospower.net
Phone No	+91 9099903701
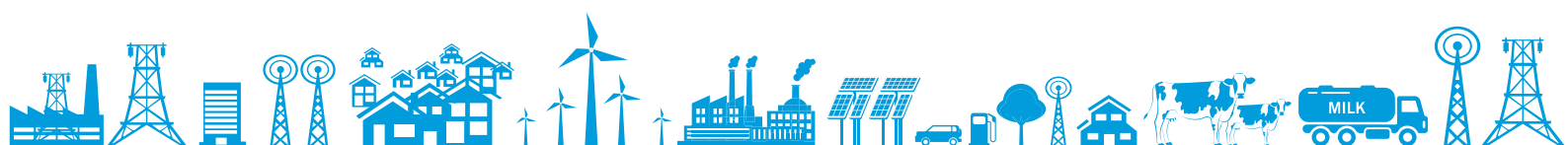
4.4.6 IoT based Water Management System

Baseline Scenario

Water is an important utility for dairy plants as it governs the hygiene of plants. In the past, abundant and inexpensive sources of water were taken for granted in the dairy processing industry and not much thought was given to economize its use. But, in recent times we have witnessed acute water scarcity and drought conditions in various parts of Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Gujarat and Rajasthan. With the available water sources becoming scarce, many dairy plants, located in such areas, find it difficult to operate or otherwise expand their operations.
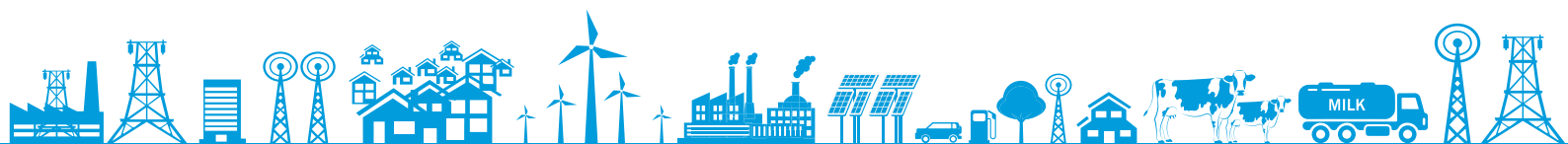
On an average, currently, the dairy unit processes roughly about 250,000 litres of milk per day. The milk brought into the plant first is chilled, stored, filtered, clarified and then sent into the central processing unit. Here at the central processing unit the milk that is brought into the plant starts its processing journey. It is pasteurized, homogenized and the cream is separated. After this, the processed milk is sent into other units of the plant to pack or make by-products out of. Water is consumed at various points in the facility either as RO water, soft water or raw water. The source of water is either from the nearby borewells or external vendor purchases. The water being used at the central processing unit is water from the RO plant through the pump house. The line which carries water from the RO output splits into two lines; one feeding the central processing unit and the other feeding the ultra-heat treatment plant. Roughly, about 400,000 litres of water is used daily. Certain lacuna observed at the site include the following:

- ❖ Facility's mechanical engineering team had personnel to note down the values - manual errors made while noting down the reading was plausible.
- ❖ Location of meters at far off places – Hard to reach, as well as occupational hazards.
- ❖ No real-time data of water being consumed since values were noted down only once a day.
- ❖ Plausible inaccurate and inefficient meter reading led to inaccurate costing of the products.
- ❖ Inaccurate production efficiency calculations.

Dairy processors, therefore, are aggressively challenged to conserve water, necessitating the need for not only reducing water consumption but also employing water management solutions to ensure tracking of the usage.

Proposed System

Water management is an activity of planning, developing, distributing and optimum use of water resources under defined water policies and regulations. Indiscriminate use of water results in excessive wastewater generation, which becomes a burden for the dairy in terms of treatment and disposal costs. The IoT system measures the water consumption at various points within the infrastructure and calculates the total water usage and the health of the infrastructure. This consumption pattern is compared with other days, weeks and months'

data to ensure a healthy water infrastructure is maintained. The architecture is based on IIoT (Industrial Internet of Things), which is a recent technology. The function monitors the level of the water in OHTs and sumps, ensuring the availability of enough water. Moreover, the user, such as the ground staff or plant manager, can interact with the dashboard using the mobile application or remote desktop application.

Merits

- ❖ Real-time productivity and water consumption monitoring.
- ❖ Helping the executive of the firm keep track of productivity trends and monitor assets.
- ❖ Identifies potential inefficiencies in water consumption.
- ❖ CIP process monitoring in real-time.
- ❖ Monitors section-wise consumption of the plant, identifies production and cleaning.
- ❖ Tracks and monitors borewell, water pump operations.
- ❖ Monitors every shift-wise consumption to track plant operation effectively.
- ❖ Provide vigilance over the water infrastructure (RO plant, softener, ETP).
- ❖ Excess consumption detection and notifications.
- ❖ Alerts to help make ground staff aware about leakage, wastage and overconsumption.
- ❖ Suitable for outdoor installations.
- ❖ Helps identify the health of RO and softener plants.
- ❖ Quarterly consultant visits by our technical team with water experts along with monthly reports, which helps in water auditing.

Limitations

- ❖ Replacement of mechanical flowmeters in infrastructure with digital meters.

Cost Benefit Analysis

The annual monetary saving for this project is **INR 1.70 lakh, with an investment of INR 1.12 lakh and a payback period of 08 months.**

Table 71: Cost Benefit Analysis – IOT Based Water Management System

Parameters	UOM	
Measurement point Cost	INR	1,10,000
Total water Consumption daily	INR	12,000
Per kl	kl	69
Average monthly increment tariff per kl	INR/kl	0.5
Number of consumption points	Nos	17

Parameters	UOM	
Number of level measurement points	Nos	4
Minimum Consumption error Expected at one point	%	1
Energy and Maintenance Savings	INR	10,000
Monetary Savings	INR lakh	1.12
Investment	INR lakh	1.70
Payback Period	months	8
IRR	%	181.12
NPV at 70% Debt (12% rate)	INR lakh	8.10

Reference Plant Implementation

Table 72: Reference Plant Implementation – IOT based water management system

Project Name	IoT based water management system
Objective	To conserve the water, use in dairy industry - IoT based water management tool
Unit profile	Winner Dairy was established on 25 January 1993 at Pondicherry. It is involved in Manufacture of dairy product and production of raw milk. Winner Dairy's daily production unit outlet processes nearly 2,50,000 litres of milk every day and produces milk-based by-products as well.
Installation Photo	
Assumptions Made	• Total water consumption at the facility • Cost incurred in water infrastructure • Expenditure in electricity due to water infrastructure • Operating hours of the plant
Savings (INR lakh)	₹ 1.70
Investment (INR lakh)	₹ 1.10
Simple Payback Period	8 months
Replication potential	All dairies and milk chilling centers irrespective of size
Outcomes	• Excess consumption detection, alerts and notifications leading to a reduction in water usage translating to monetary savings • Real time productivity and water consumption monitoring • Help the executive of the firm to keep track of productivity trends and monitor assists.

Project Name	IoT based water management system
Unit contact details	Mr. Ayyanar Winner Dairy Email : er.sp.senthil@gmail.com Phone: +91 8883054141
Cluster Reference	Tamil Nadu, Pondicherry

Vendor Details

Table 73: Vendor Details – IOT Based Water Management System

Equipment Detail	IoT based water management system
Supplier Name	FluxGen Engineering Technologies
Address	1064, 1st floor, BTM layout 2nd Stage, Bangalore
Contact Person	Mr. Ganesh Shankar
Mail Id	ganesh@fluxgentech.com
Phone No	+91 9731925888
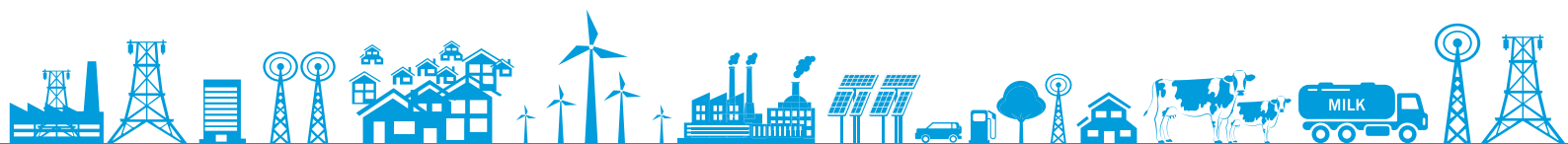
4.5 Case Studies - Renewable Energy

4.5.1 Solar rooftop system

Baseline Scenario

The unit is purchasing electricity from grid for the power requirement in its plant. The contract demand of the plant is 260 kVA, with electricity priced at INR 7.0/kWh, with an average load of 150 kW to 200 kW. The unit has enough rooftop area which can be utilized to install solar PV for self-generation of electricity rather than purchasing from grid. The site specifications for rooftop PV are given below:

Table 74: Site Specification – For Solar PV

Parameters	
Effective Rooftop available	200 sq. m. true south
Location	Latitude : 23.05 Longitude : 72.55
Altitude above sea level, m	58
Direct Normal Irradiance	5.82 kWh/m²/day
Wind	2.1 m/sec
Humidity	32%

The following graphs highlights solar irradiance:

Latitude : 23.05   Longitude : 72.55

Annual Average : 5.82 kWh/m^2/day

Monthly Average	
JAN	6.47
FEB	7.27
MAR	7.14
APR	6.78
MAY	7.28
JUN	5.50
JUL	2.64
AUG	2.51
SEP	5.14
OCT	6.92
NOV	6.35
DEC	6.03

Figure 40: Solar Irradiance

Proposed System

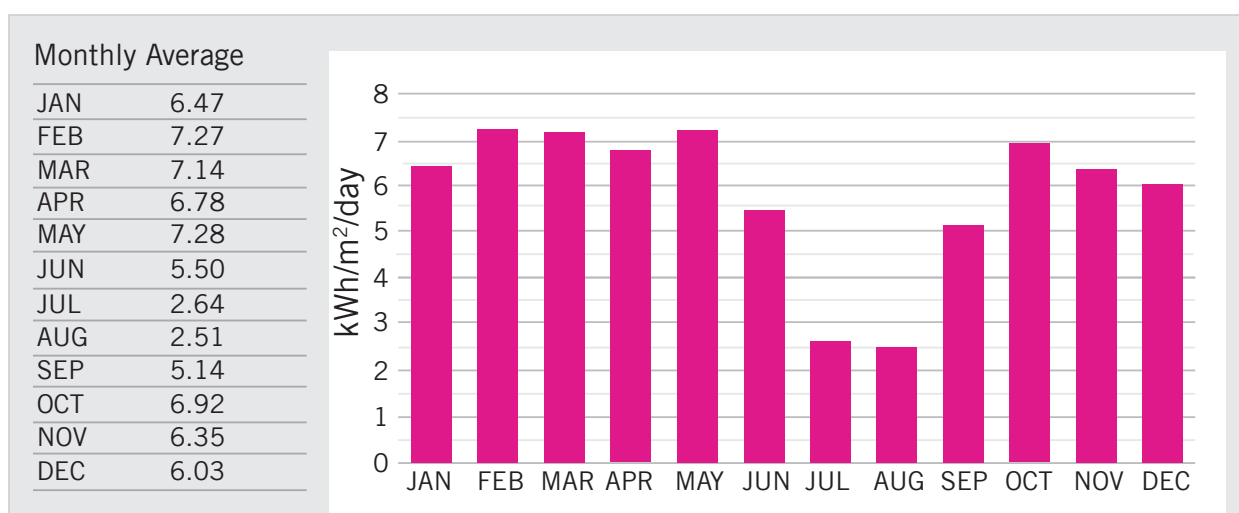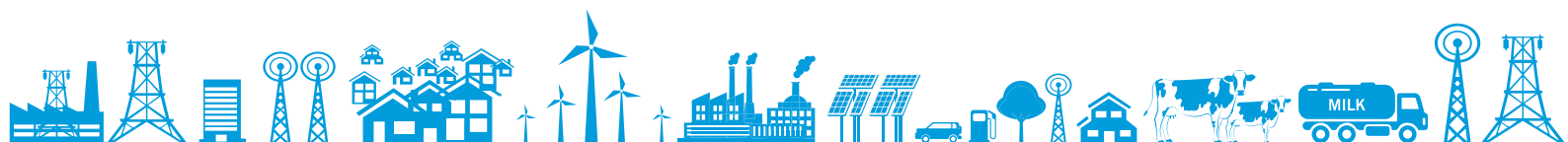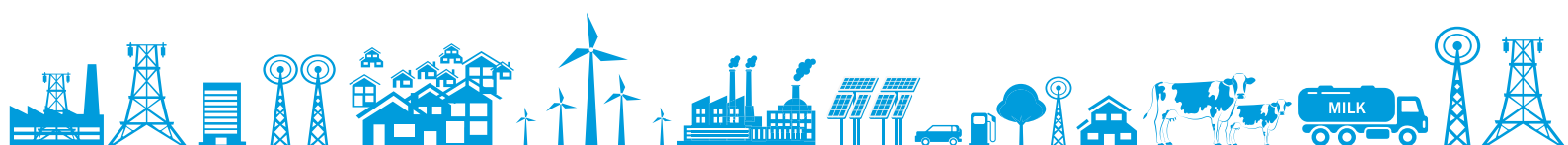As per the site specifications, the unit has a potential of installing 20 kWp solar rooftop which can generate around 0.40 lakh units of electricity annually. The proposed system will be an A Grid Tied Solar PV power plant consisting SPV array, Module Mounting Structure, Power Conditioning Unit (PCU) consisting of Maximum Power Point Tracker (MPPT), Inverter and Controls & Protections, interconnect cables, junction boxes, distribution boxes and switches. PV Array is mounted on a suitable structure. Grid tied SPV system is without battery and should be designed with necessary features to supplement the grid power during daytime. In grid-connected rooftop or small SPV system, the DC power generated from SPV panel is converted to AC power using power converter and is fed to the grid either of 33 kV/11 kV three phase lines or of 440V/220V three/single phase line, depending on the local technical and legal requirements. These systems generate power during the daytime, which is utilized by powering captive loads and feeding excess power to the grid. In case the power generated is not sufficient, the captive loads are served by drawing power from the grid.

Net Metering Business Model - The net metering-based rooftop solar projects facilitate the self-consumption of electricity generated by the rooftop project and allows for feeding the surplus into the grid network of the distribution by the licensee. The type of ownership structure for installation of such net metering-based rooftop solar systems becomes an important parameter for defining the different rooftop solar models. In a grid-connected rooftop photovoltaic power station, the generated electricity can sometimes be sold to the servicing electric utility for use elsewhere in the grid. This arrangement provides payback on the investment of the installer. Many consumers from across the world are switching to this mechanism owing to the revenue yield. A commission usually sets the rate that the utility pays for this electricity, which could be at the retail rate or the lower wholesale rate, greatly affecting solar power payback and installation demand. The features/ requirements for Grid Connected Rooftop Solar PV System are as follows:

Table 75: Features/requirements for Grid Connected Solar PV Systems (Rooftop)

S. No.	Features / Requirements	Values
1	Shadow free roof area required	10 m²/kWp or 100 ft²/kWp.
2	Roof suitable for Solar PV system	Concrete/ GI/ tin shed (Asbestos may not be suitable)
3	Orientation of the roof	❖ South facing roof is most suitable. ❖ Installation may not be feasible beyond 5 deg slope.
4	Module installation	❖ Modules are installed facing South. ❖ Inclination of modules should be equal closer to the latitude of the location for maximum energy generation.

S. No.	Features / Requirements	Values	
5	Cost of the rooftop solar PV system	MNRE issues benchmark cost for GCRT SPV system and the cost for general category states for 2019-20 are as follows. This includes cost of the equipment, installation and O&M services for a period of 5 years. ❖ Above 1 kWp and up to 10 kWp: INR 54,000/ kWp ❖ Above 10 kWp and up to 100 kWp: INR 48,000/ kWp ❖ Above 100 kWp and up to 500 kWp: /INR 45,000/ kWp Based on discussions with a few project developers, average cost of the system (as per market conditions) is as follows: ❖ For 10 kWp system, INR 49,000/ kWp ❖ For 50 kWp system, INR 42,500/ kWp ❖ For 100 kWp system, INR 37,000/ kWp	
6	Useful life of the system	25 years	

Merits

❖ PV panels provide clean & green energy. During electricity generation with PV panels, there is no harmful greenhouse gas emissions.

❖ Technology development in solar power industry is constantly advancing, which can result in lower installation costs in the future.

❖ PV panels have no mechanically moving parts, except in cases of sun-tracking mechanical bases; consequently, they have far less breakages or require less maintenance than other renewable energy systems (e.g. wind turbines).

Limitations

❖ The initial cost of purchasing a solar PV system is high, which includes paying for solar panels, inverter, batteries, wiring and for the installation.

❖ Although solar energy can be still collected during cloudy and rainy days, the efficiency of the system drops, which results in lower generation of energy.

❖ Installing a large PV system takes up a lot of space.

Cost Benefit Analysis

The expected savings by installation of 25 kWp solar rooftop is 40,000 units of electricity annually. The annual monetary saving for this project is **INR 2.60 lakh, with an investment of INR 19.00 lakh and a payback period of 7 years.**

Table 76: Cost Benefit Analysis – Solar PV Systems

Parameters	UOM	
Proposed Roof top Solar installation	kW	25
Annual units generation per kW of Solar PV	kWh per kW/year	1,600
Total Energy Generation Per Annum	kWh/year	40,000
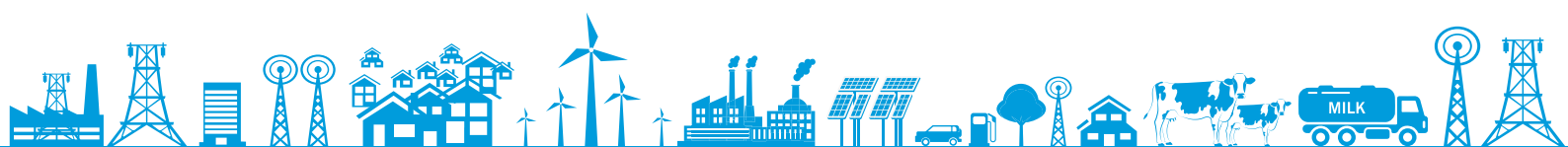
Parameters	UOM	
Electricity Cost	INR/kWh	7
Cost Savings	INR lakh	2.60
Investment	INR lakh	19.06
Payback period	years	7
IRR	%	19.81
NPV at 70 % Debt (12% rate)	INR lakh	4.45

Energy & GHG Savings

Annual Electricity Savings

40,000 kWh

Annual Energy Savings

3.44 TOE

Annual GHG Savings

32.80 T CO$_2$

Reference Plant Implementation

Table 77: Reference Plant Implementation – Solar PV Systems

Project Name	Installation of 170 kWp solar PV system
Objective	Installation of 170 kWp grid connected solar rooftop PV
Unit profile	Amul Fed Dairy is a large-scale dairy unit located at Gandhinagar, Gujarat. The various products manufactured in AFDG dairy are liquid milk, butter milk, flavored milk, lassi, ghee and ice cream with an average milk processing capacity of 32 lakh LPD
Installation Photo	

Project Name	Installation of 170 kWp solar PV system
Assumptions Made	❖ Power cost – INR 7.87/kWh ❖ Daily running hours - 8 ❖ Annual operating days – 320
Savings (INR lakh)	₹ 20.60
Investment (INR lakh)	₹ 76.50
Simple Payback Period	25 years
Replication potential	In all the dairy units irrespective of size and milk chilling centers
Outcomes	❖ 3.44 TOE of annual energy savings ❖ Better availability of power
Unit contact details	Mr. Prashant Seth Amul Fed Dairy Plot No 35, Gandhinagar Ahmedabad Road ,Bhat , Gujarat Phone: 07574802084 Email: prashant.sheth@amul.coop
Cluster Reference	Gujarat Dairy Cluster

Vendor Details

Table 78: Vendor Details – Solar PV

Equipment Detail	Solar PV System
Supplier Name	Varizone Solar Pvt. Ltd.
Address	Shop no. 2/3, Amrut Nagar, Hari Nagar-2, Opp. Swaminaryan Temple, Udhna, Surat
Contact Person	Mr. Parshwa Shah
Email Id	varizonesolar@gmail.com
Phone No	+91 9426111113
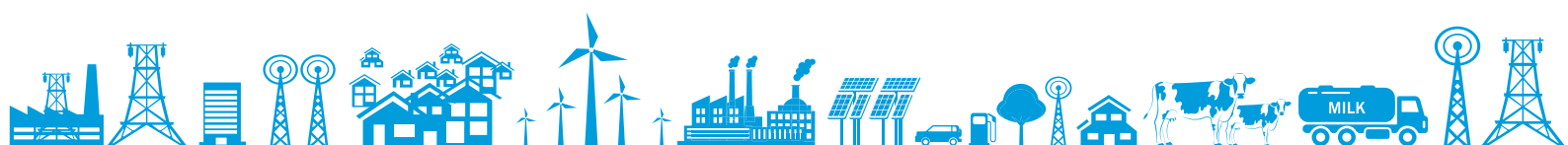
4.5.2 Solar Thermal System

Baseline Scenario

The unit has installed one FO-fired boiler for steam generation, which is used in process applications such as ghee, curd, ice cream section, etc. All the heating process in dairy is through indirect heating. The table below shows the details of the boiler installed in the plant:

Table 79: Boiler Details

Boiler	Fuel Type	Design Capacity (TPH)	Operating Pressure (kg/cm²)	Operating Condition	Operating hrs
Boiler	FO Fired	1 TPH	9	Running	8

Currently, the temperature of feed water was observed to be 25°C and there is no mechanism for preheating of feed water inside the plant. The average feed water requirement for the plant during normal running hours is 0.375 TPH and feed water is available at 25°C. The lower the temperature of feed water is, the higher is the fuel consumption inside the boiler to generate steam. For a conventional boiler, increasing the feed water temperature by 15°C will result in an increase in overall thermal efficiency of 3%. There is a good potential to install solar thermal inside the plant to harness solar energy and generate hot water. The site specifications are shown in the table below:

Table 80: Site specifications

Parameters	
Total area available	600 m².
Location	Latitude : 23.05 Longitude : 72.55
Altitude above sea level, m	58
Direct Normal Irradiance	5.82 kWh/m²/day

Proposed System

It is recommended to install 3.5 KL solar thermal system with evacuated tube technology for supplying hot water at 65°C to preheat boiler feed water. Convention solar thermal system consisting of flat plate collectors have the surface area flat and as a result, maximum efficiency occurs when the sun is directly overhead at midday. At other times, the sun's rays are striking the collector at varying angles, bouncing off the glazing material, thereby reducing their efficiency.

The evacuated tube collector mainly comprises of double glass-walled long evacuated tubes in which the outer surface of the inner tube is coated with a Selective Absorber Coating for solar heat collection. These glass tubes are cylindrical in shape. Therefore, the angle of the sunlight is always perpendicular to the heat absorbing tubes which enables these collectors
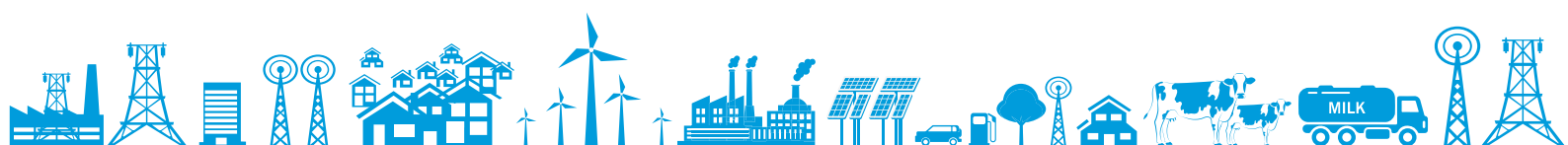
to perform well even when sunlight is low, such as when it is early in the morning or late in the afternoon, or when shaded by clouds.

Latitude : 23.05   Longitude : 72.55

Annual Average : 5.84 kWh/m^2/day

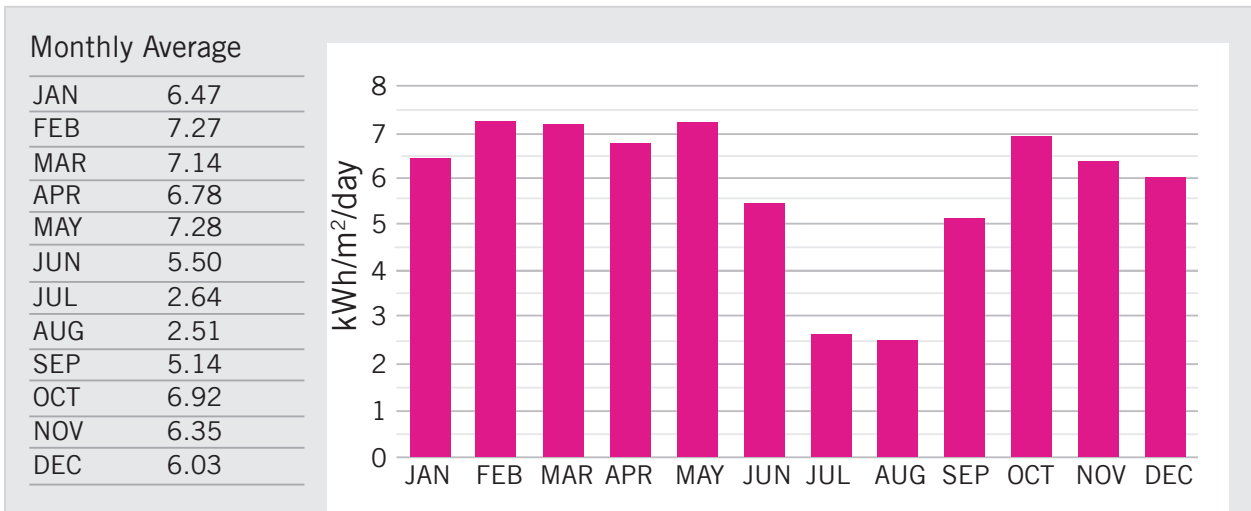| Monthly Average	
JAN	6.47
FEB	7.27
MAR	7.14
APR	6.78
MAY	7.28
JUN	5.50
JUL	2.64
AUG	2.51
SEP	5.14
OCT	6.92
NOV	6.35
DEC	6.03

Figure 41: Average Solar Irradiance

Air is removed, or evacuated, from the space between the two tubes to form a vacuum, which eliminates conductive, convective and radiation heat losses. The heat transfer fluid is systematically circulated into the inner tubes where it absorbs the heat from the selective coating – which in turn is continuously heated by the available solar radiation. ETC type is a more efficient solar heat collector (conversion efficiency of over 90%).
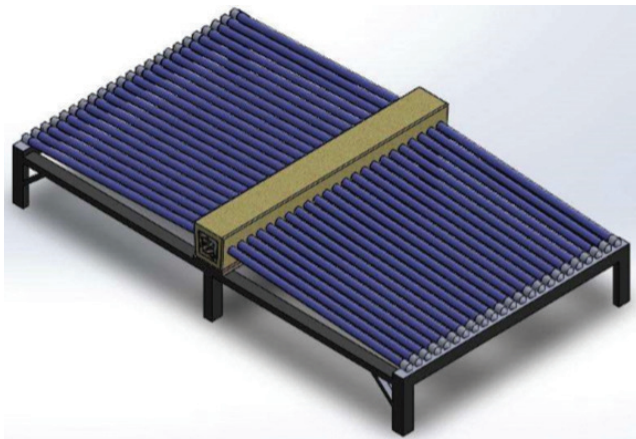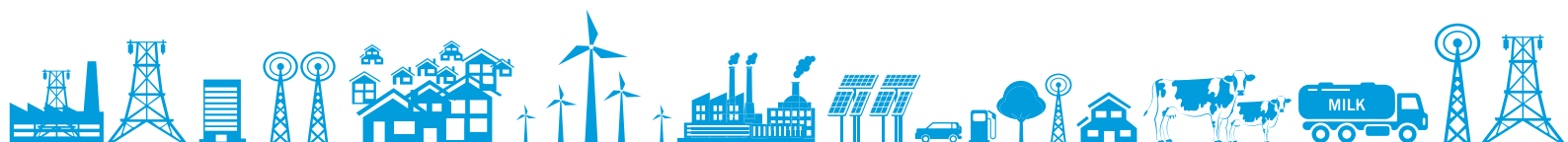
Figure 42: Evacuated Tube

Unlike flat panel collectors, evacuated tube collectors do not heat the water directly within the tubes. Instead, air is removed or evacuated from the space between the two tubes, forming a vacuum (hence the name evacuated tubes). This vacuum acts as an insulator reducing any heat loss significantly to the surrounding atmosphere either through convection or radiation making the collector much more efficient than the internal insulating that flat plate collectors have to offer. With the assistance of this vacuum, evacuated tube collectors generally produce higher fluid temperatures than their flat plate counterparts, so it may become very hot in summer.

The ETC type collector module is designed with an industrial-grade manifold header type consisting of 30 to 80 tubes. The average rated output of each module is 1 kW for every 12 ETC

tubes of 58 mm dia x 1,800 mm length. The average rated output of each module is 1 kW for every 12 ETC tubes of 58 mm dia x 1,800 mm length.

Features of Solar Thermal System

1. **Solar thermal Modules**

   a. ETC type Solar Thermal Modules.

   b. ETC Glass tubes: 1,800 mm length, OD: 58mm, ID: 48 mm

   c. Total weight of module including structure and filled-water = Approx. 40 kg/m².

   d. End Connection: Both ends of each manifold equipped with flanged end.

2. **Module structural Supports** – Made of MS L-angle, hot dip galvanized. (Suited for rooftop mounting).

3. **Interconnecting pipes between modules** – GI; Insulated with 50 mm thick rockwool and aluminum cladded.

4. **Area required** – Area required for the solar thermal modules: Approx. 4 m²/kW shade-free rooftop area is required for modules, including inter-spaces.

5. **Rooftop Load** – The distributed load of the ETC Type module and structure will be a maximum of 35 kg/m².

Desired water quality for a long running life of the system:

Table 81: Water Quality Requirement for Solar Thermal

Parameter	Unit	Specifications
Colour		Colourless
Odour		Unobjectionable
Turbidity	NTU	5
pH		6.5 to 8.5
Total Dissolved Solids	mg/l	50
Total Alkalinity	mg/l	20
Total Hardness	mg/l	30
Calcium	mg/l	7.5
Magnesium	mg/l	3
Chloride	mg/l	25
Sulphate	mg/l	20
Iron	mg/l	0.003
Nitrate	mg/l	4.5
Fluoride	mg/l	1
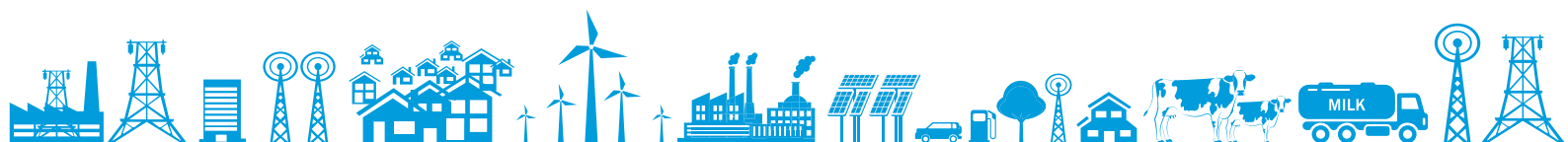
Merits

❖ Reduced dependence on fossil fuels.

❖ Solar thermal energy does not cause pollution.

❖ Technology development in solar power industry is constantly advancing, which can result in lower installation costs in the future.

Limitations

❖ The initial cost of purchasing a solar thermal system is high.

❖ Although solar energy can be collected during cloudy and rainy days, the efficiency of the system drops, which results in lesser generation of energy.

❖ The area required for installing for large PV system can take up a lot of space.

Cost Benefit Analysis

The expected fuel savings by installation of solar thermal is 4,922 litres of FO annually. The annual monetary saving for this project is **INR 2.21 lakh, with an investment of INR 6.89 lakh and a payback period of 3.1 years**.
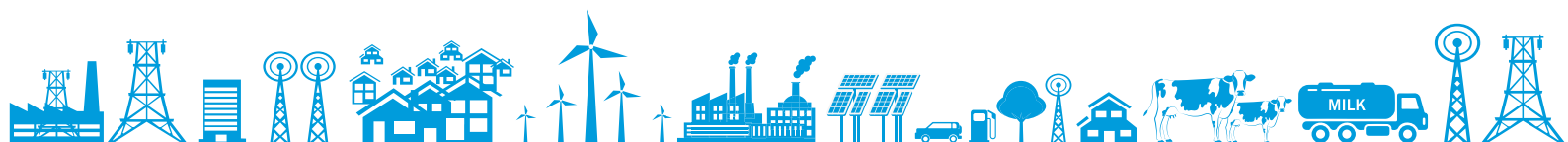
Table 82: Cost Benefit Analysis – Solar Thermal Systems

Parameters	UOM	
Hot water requirement	LPD	3,000
Total boiler operational hours	hrs	8
Temperature required	°C	65
Cost of Furnace Oil	INR/l	45
Boiler Capacity	TPH	1
Boiler Efficiency	%	75
GCV of fuel	kCal/kg	39,580
Hot water requirement per day	LPD	3,000
Feed water temperature	°C	25
Heat loss in pipeline	%	15%
Heat energy required to raise the temperature including losses	kCal	5,77,392
Heat energy required to raise the temperature including losses	kW	160.47
Effective sun shine hours	kW	6.00
Heat Energy to be produced per effective hour	kW	27
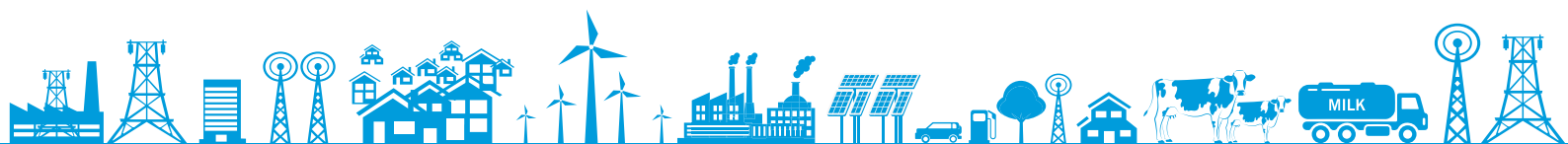
Parameters	UOM	
Selected System Capacity	kW	36
Shadow free roof area required	m²	144
Fuel saved per day	litres/day	16.41
No of operating days	days	300
Annual fuel savings	litres	4,922
Annual Cost Savings	INR lakh	2.21
Investment	INR lakh	6.88
Payback Period	years	3.1
IRR	%	48.24
NPV at 70% debt (at 12% rate)	INR lakh	8.07

Energy & GHG Savings

Annual Fuel Savings

4,922 litres of FO

Annual Energy Savings

59.06 TOE

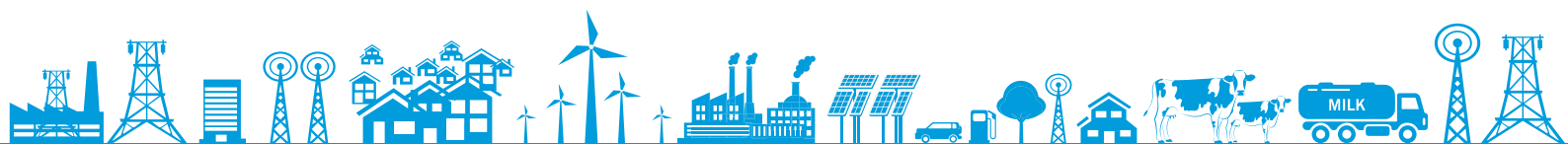**Annual GHG Savings**

13.78 T CO$_2$

Vendor Details

Table 83: Vendor Details – Solar Thermal Systems

Equipment Detail	Solar Thermal System
Supplier Name	Aspiration Energy
Address	Aspiration Energy Pvt ltd Mandaveli, Chennai - 600028
Contact Person	Mr. Logesh N
Email Id	logesh@aspirationenergy.com
Phone No	+91 9840409624

4.5.3 Solar-Wind Hybrid system

Baseline Scenario

The unit is purchasing electricity from grid for the electrical energy requirement. The contract demand of the plant is 450 kVA, with an electricity price of INR 6.5/kWh and average operating load is 260 kW to 300 kW.

Renewable energy is deemed to be the best substitute for conventional fossil fuel. Implementation of renewable energy posts various challenges, such as capital cost and consistency of power output, of which the latter can be solved by the installation of a Solar – Wind hybrid system. The plant has enough rooftop area which can be utilized to install a solar-wind hybrid system that can harness solar energy and wind energy to generate electricity.

Proposed System

The Solar – Wind Hybrid system is also known as solar mill. The solar mill generates:

❖ Daytime energy from the sun and wind.

❖ Day & night energy from the wind energy.

❖ Energy even on cloudy days.

❖ More energy on hot sunny days due to cooling effect on solar panels by wind.

Figure 43: Solar wind hybrid system

It consists of three vertical axis wind turbines coupled to three permanent magnet generators. Automatic mechanical braking is provided once the wind speed goes beyond the cut-off speed. On board smart electronics include dynamic Maximum Power Point Tracking (MPPT). It uses wind and solar resources on a 24/7/365 basis, allowing access to energy and very little interruption of services. The design life of solar mill is 25 years.
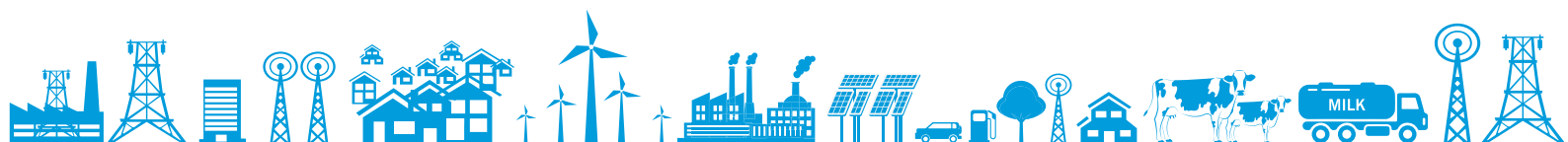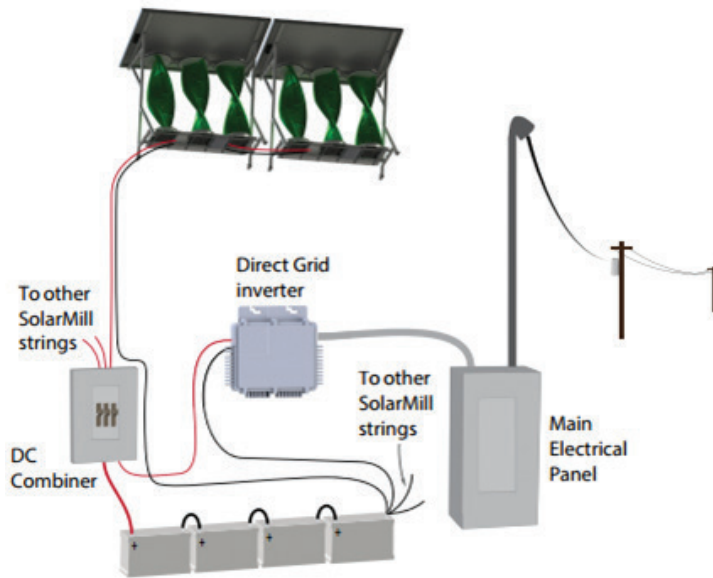
Specifications

Figure 44: Hybrid mill connected to supply

The increase of renewable power per square foot of roof is obtained by combining two power sources. For a rooftop installation, combining solar and wind power is a complementary combination. For example, many locations are less windy in the middle of the day when the sun is at its peak and the wind picks up after dusk. Other advantages are solar module providing protection for the wind portions of the mechanism from direct rain and hail and assisting with the direction of air into the turbines.

Since this compact installation is designed for rooftops and urban atmosphere, savonius type of wind turbine is chosen for its low running speed and relative insensitivity to turbulence. Power generation begins at a wind speed of 5 kmph. Independent MPPT for both wind and solar is calibrated. Maximum power point tracking (MPPT) is an algorithm included in charge controllers used for extracting maximum available power. The power from both wind and solar generation is routed into a common 48V DC bus which has built-in charge control for a lead acid battery bank.

Modes of Use

In grid tied system, the bank of batteries is connected to one or more Direct Grid micro-inverters, which connect to the user's electrical panel. The inverters push power back to the grid efficiently when the batteries become fully charged.

In off grid storage, the batteries can be used to supply power to electrical devices in off grid settings. This electrical energy can power DC powered devices through a voltage converter, or can power AC devices through an inverter.
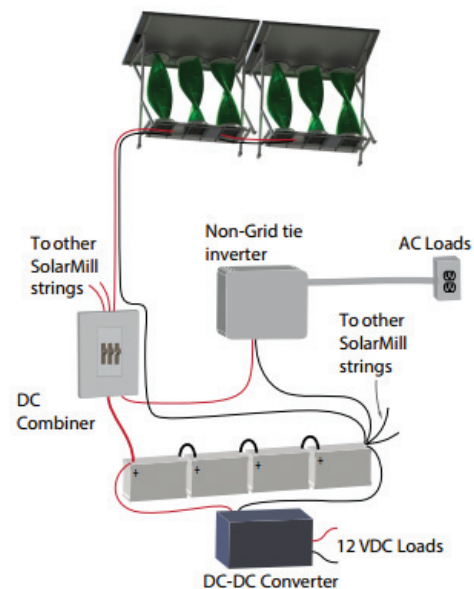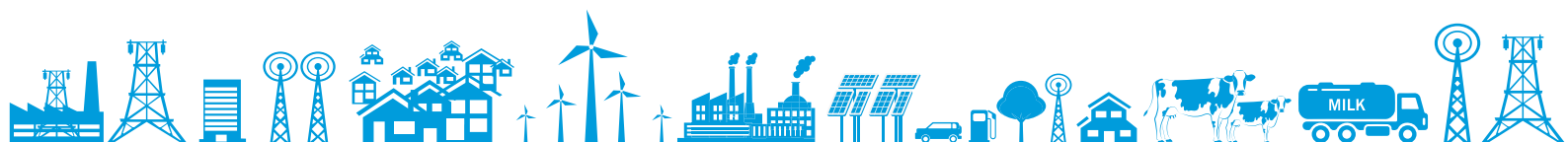

Figure 45: Hybrid mill connected to loads

Merits

❖ Power generation during daytime as well as nighttime.

❖ Reliable power generation even on cloudy days.

❖ A compact hybrid solar mill to meet a portion of the plant's load after detailed study with vendors.

❖ Power generation stats at 2-5 m/s and mechanical braking occur beyond 18 m/s.

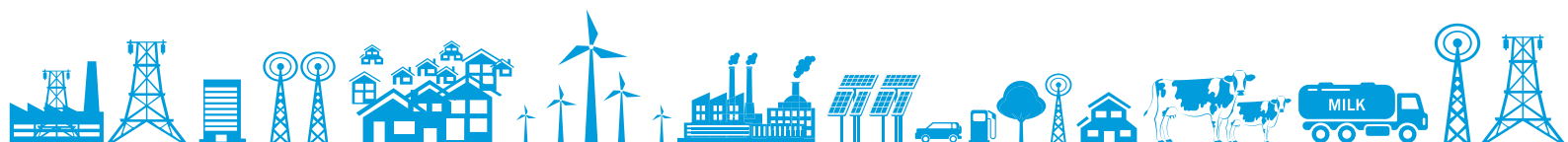❖ The power generation can be monitored online.

Limitations

❖ Higher investment.

Cost Benefit Analysis

The expected savings in electrical energy to be achieved by installation of a 50 kWp Solar - Wind hybrid system is 1,32,000 units annually. The annual monetary saving for this project is **INR 8.60 lakh, with an investment of INR 45.00 lakh and a payback period of 5.2 years**.

Table 84: Cost Benefit Analysis – Solar Wind Hybrid Systems

Parameters	UOM	
Installed Capacity of Solar wind Mill	kWp	50
Average generation per day per kWp	kWh	6.0
Area Required	m²	60
Annual operating days	Days	365
Electricity Tariff	INR/kWh	6.5
Average Annual Energy Generation	kWh	1,09,500
Annual cost savings	INR lakh	7.11
Investment	INR lakh	50
Simple Payback Period	Years	7
NPV at 70% Debt (12% rate)	INR lakh	13.15
IRR (%)	%	20.88

Energy & GHG Savings

Annual Electricity Savings
1,09,500 units

Annual Energy Savings
9.42 TOE

Annual GHG Savings
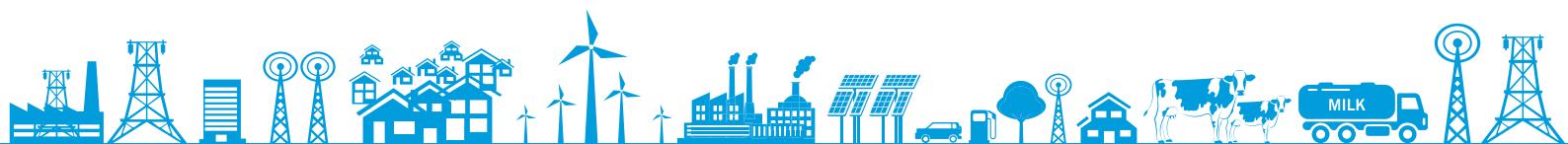89.79 T CO$_2$

Vendor Details

Table 85: Vendor Details – Solar-Wind Hybrid Systems

Equipment Detail	Solar - wind hybrid system
Supplier Name	Windstream Technologies
Address	G2-SSH Pride, Plot 273, Road No-78, Jubilee Hills, Hyderabad 500096
Contact Person	Mr. Bhaskar Sriram
Email Id	bhaskars@windstream-inc.com
Phone No	+91 99599 18782

5. Conclusion

In a typical dairy plant, heating and cooling operations are dominant energy users. Due to the wide variation in product mix among the dairy units, overall energy and specific energy consumption indicators vary significantly from plant to plant, making it extremely difficult to compare for performance or for identifying efficiency improvement opportunities. Other reasons for such wide variation also include level of technology adopted, vintage of these facilities, capacity utilization and fuel mix used in their operations. Significant energy efficiency improvement opportunities in dairy units exist in heating and cooling applications via adoption of co-generation technology, desuperheaters, evaporative cooling systems, utilization of renewable energy; biomass fired boilers and increased automation. Through this compendium, some of the key technologies that are highly replicable in the cluster have been identified and for these technologies the case examples are included.
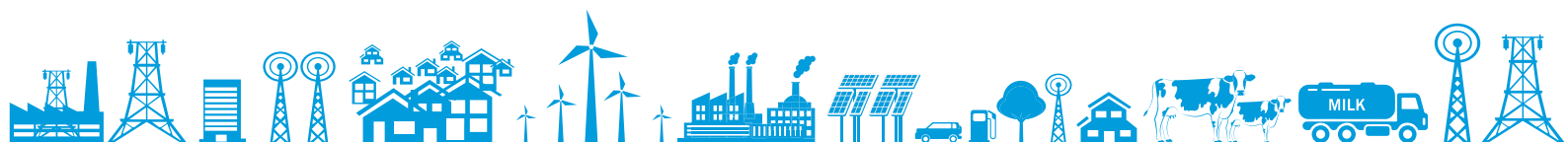
The identified technologies can be categorized into three heads, namely, Level 1, Level 2 and Level 3, based on the investment requirement and the payback, as follows:

- ❖ **Level 1**: Low investment
    - ✧ Condensate recovery system
    - ✧ Steam operated pumping traps
    - ✧ VFD in chiller compressor
    - ✧ Thermal energy storage for BMC
    - ✧ VFD for air compressor
    - ✧ Energy Efficient Pumps
    - ✧ Desuperheaters for chiller compressor
    - ✧ IoT for water management
- ❖ **Level 2**: Medium investment
    - ✧ Installation of screw refrigeration compressor
    - ✧ Evaporative condenser
    - ✧ Heat Pump
    - ✧ Demand side controller for air compressor
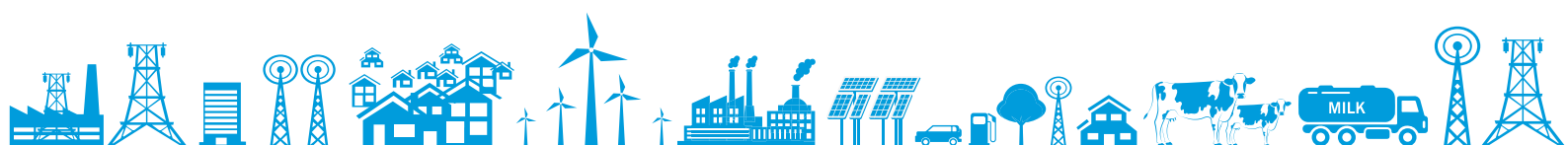   - ✧ Package type bio reactor

❖ **Level 3:** High investment

   ✧ Conversion of furnace oil fired boiler to fully automated biomass fired boiler

   ✧ Installation of micro-turbine

   ✧ Direct cooling method – IBT

   ✧ Methane capture from dairy effluents

   ✧ Solar rooftop system

   ✧ Solar thermal system

   ✧ Solar wind hybrid system

Table 86: Summary of Energy conservation measures

Sr. No.	Technologies	Ease of Implementation			Priority of activity (based on payback)		
		Easy	Moderate	Difficult	Short	Medium	Long
Steam Generation and Distribution							
1	Conversion of Furnace Oil Fired Boiler to						
	Fully Automated Biomass Fired Boiler		√			√	
2	Condensate Recovery System		√		√		
3	Steam Operated Pumping Traps	√			√		
4	Installation of Microturbine			√		√	
	Refrigeration Systems						
5	Installation of Screw Refrigeration Compressor		√				√
6	VFD in Chiller Compressor	√				√	
7	Evaporative Condenser		√			√	
8	Falling Film Chiller		√			√	
9	Direct Cooling Method – IBT			√			√
	Waste Heat Recovery						
10	Desuperheater for Compressors	√					√
11	Heat Pump		√		√		

Sr. No.	Technologies	Ease of Implementation			Priority of activity (based on payback)		
		Easy	Moderate	Difficult	Short	Medium	Long
12	Thermal Energy Storage for BMC	√			√		
Utilities							
13	VFD for Air Compressor	√			√		
14	Demand Side Controller for Compressed Air	√		√			
15	Energy Efficient Pumps	√				√	
16	Package Type Bio Gas Reactor		√				√
17	Methane Capture from dairy effluents			√			√
18	IoT based Water Management System		√			√	
Renewable Energy							
19	Solar rooftop system	√					√
20	Solar Thermal System		√				√
21	Solar-Wind Hybrid system	√					√

The energy efficiency/renewable energy projects detailed in the case studies in this compendium indicate that there is a good potential for benefits in both low hanging and medium-to-high investment options. The dairies can implement the low hanging fruits (with smaller investments) faster, as with minimum or no investments, several savings can be achieved. However, for the high investment projects, a detailed review in the form of DPR can be prepared. The attractiveness of the project can also be assessed from the unit abatement cost (UAC). The UAC is defined as the cost/investment of reducing one unit of energy or pollution. The options having lower UAC are attractive to reduce a unit of energy consumption as lower investments are required to achieve energy savings. The following graph highlights the comparison of Unit Abatement Cost as Investment (INR Lakh)/Energy Saving achieved (TOE), for the major proposals identified at the Gujarat Dairy cluster.
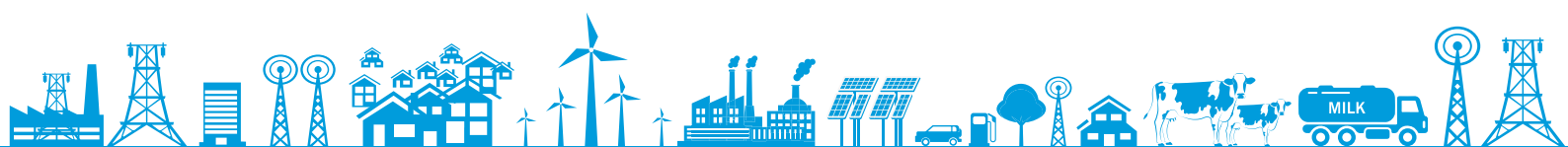
UAC: INVESTMENT (INR LAKH)/ENERGY SAVINGS (TOE)
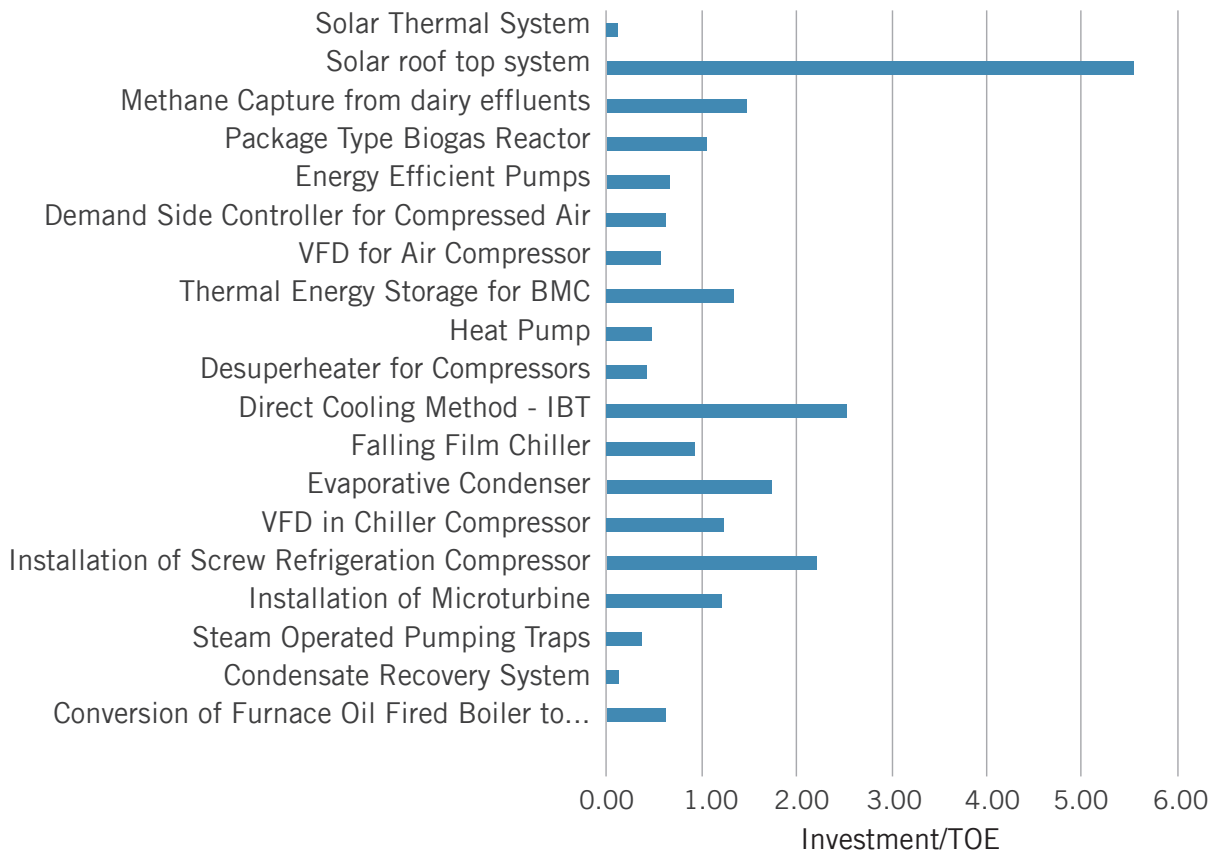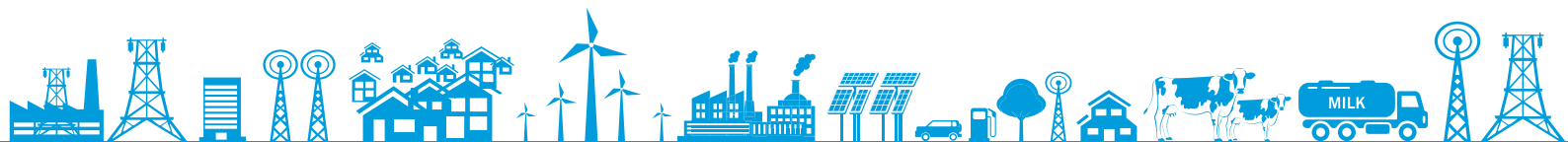

Figure 46: Unit Abatement Cost - Energy Efficient Technologies

The Gujarat dairy industry should view this manual positively and utilize this opportunity to implement the best operating practices and energy saving ideas during design and operation stages and thus move towards achieving world class energy efficiency.
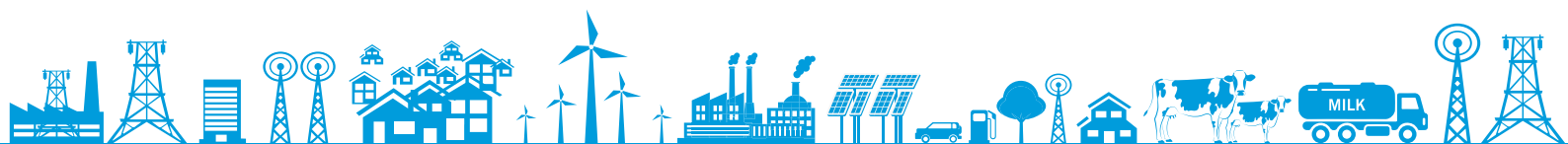
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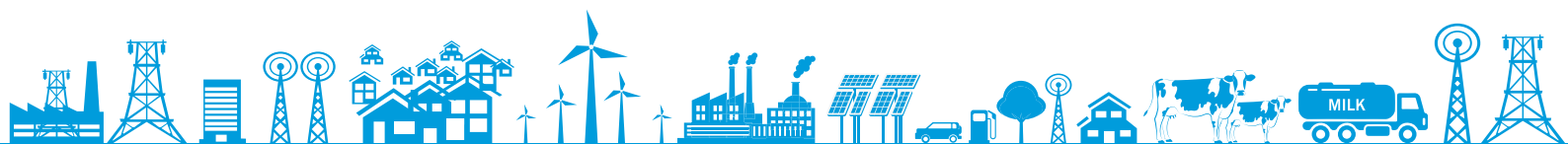
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