Chapter 4
Research Methodology for Crude Oil Heating in Conjunction with PV, CSP and Microalgae

4.1. Introduction

The previous chapter dealt with the 'Utilization of Solar Energy and Bio-energy' for optimization of free solar energy and crude oil heating purpose respectively. The case studies have been evolved on 'Despatcher control system' besides 'Utilization of CSP technologies for crude oil heating'. In this connection, the third study has been targeted for 'Carbon mitigation utilizing microalgae biomass' with sun light.

This work has been conceptualized for a unique hybrid solution for 'Crude Oil Heating' at industrial site in conjunction with PV system, CSP technology and microalgae carbon capture concept. A prototype of CSP based hybrid system has been developed and analyzed. Within this scope, two hybrid solutions have been proposed for crude oil heating as:

1) CSP technology and Natural Gas system.
2) Algal biomass, Solar and NG system.

Both hybrid systems have been studied using established research methodologies and compared for most efficient, environmental friendly and cost effective solution. The chapter concludes that the hybrid system utilizing CSP and algal biomass has been reported as effective solution.

4.2. CSP technology and Natural Gas system

The prototype has been conceptualized in hybrid combination with existing natural gas fired crude oil heating facility. The work has been targeted to be used for typical Group Gathering System[6] (GGS) as shown in Figure 3.13.

Using CSP technology concentrated heat has been used for pre-heating of the emulsion to the required temperature range of 80-85˚C. Emulsion breaks by an action of demulsified & water separates and drained. Variable solar radiation due to dynamic weather conditions suggest for the hybrid system with the present crude oil heating system to maintain the crude production [81]. The pre-heating of emulsion for the desired temperature range has been targeted under dynamic weather conditions.

[6] Group Gathering System: flow line networks as well as the process facilities

4.2.1. Research Methodologies

The proposed schematic for the CSP based heater treater hybrid system has been shown in the Fig. 4.1 [76]

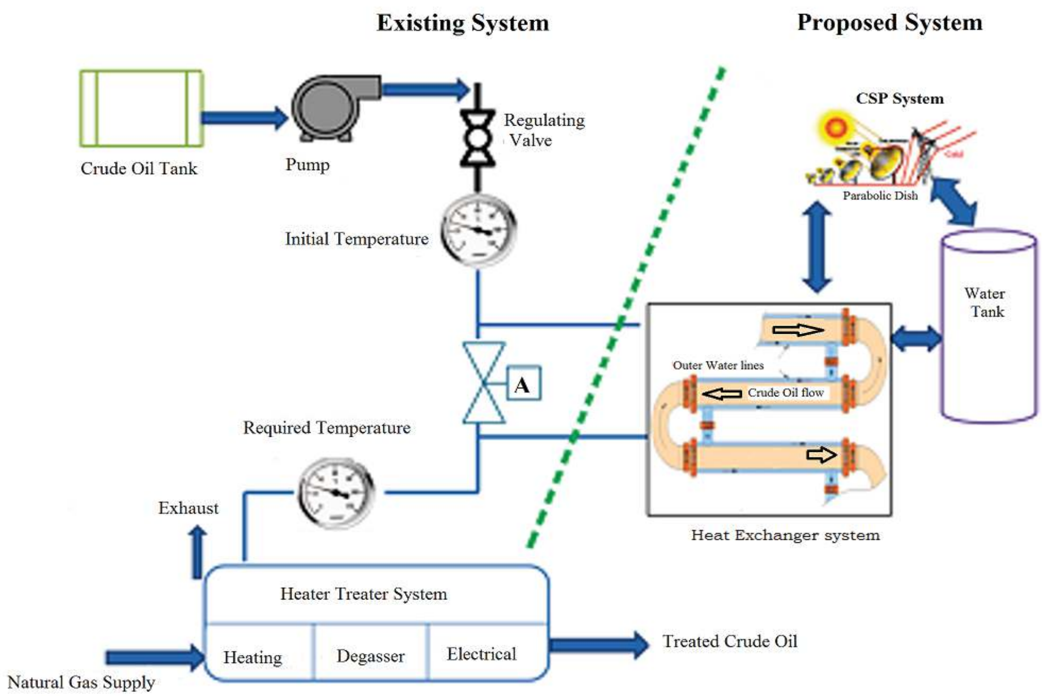

Figure. 4.1. Schematic of the hybrid prototype crude oil heating system

With the help of a by–pass valve 'A' as shown in Figure 4.1, the crude oil will pass through heat exchanger, which receives the concentrated solar heat by CSP system. Solar incoming rays being reflected from the concentrator's surfaces on the receiver and through heat exchange with circulating water, crude emulsion has been heated up to required temperature range. Heat exchanged water circulates in the solar thermal receiver-heat exchanger expansion tank system. During a definite initial time period of around 30-60 minutes it comes into the coiling pipe in the heat exchanger, further demulsifier[7] is added to make the emulsion cleaner [82]. The heat exchanging process between oil and water to achieve the desired temperature and oil begins to drain to the sedimentation tank [81]. After keeping it for 24 hours, the water is separated and treated oil has been sent to storage tanks. Heating helps to reduce viscosity, increased droplets, dissolves paraffin, and increases density between oil and water [83].

[7] Demulsifier: specialty chemicals used to separate emulsions, for example, water in oil

(a) Solar dish (b) With mirror (C) Thermal reciever

Figure. 4.2. Snapshot of developed dish and associated system

The remaining oil, gas and water mixture goes into treating process unit where thermal heating further supports to break up the mixture so that oil separates from denser water. Natural gas being less dense than oil rises to top of the chamber and extracted separately. The gas has been removed by processing and water has been stored for treatment.

Table 4.1. Design parameters for prototype system [76]

Total flow of crude	10 m^3/hr
Pressure of crude	4 kg/sq cm
Use of natural gas for crude heating	70m^3/hr
Specific heat of crude	0.5
Specific gravity of crude at 15°C	0.85
Desired temperature of crude	80°C
Natural gas density into calculation	0.8 kg/m^3
1 kg of natural gas will generate heat equivalent	13.5 kWh

The design parameters for the solar dish depends on the temperature rise, crude specific gravity, the water content in the oil, and crude flow rate. HT contains three chambers, first as the heating chamber, second as degassing chamber and third as electrical chamber, as shown in Figure 3.14.

Compared to other RE sources, CSP has been expected to generate energy 24 X 7, utilizing advanced stage storage technologies solutions. The study on storage technologies are beyond the scope of present work. The CSP technologies, such as point-focusing parabolic dish may extend the ability to provide the major industrial applications of solar heat energy [33][84].

The performance of the prototype has been evaluated, and economic feasibility has been explained in the Chapter 5.

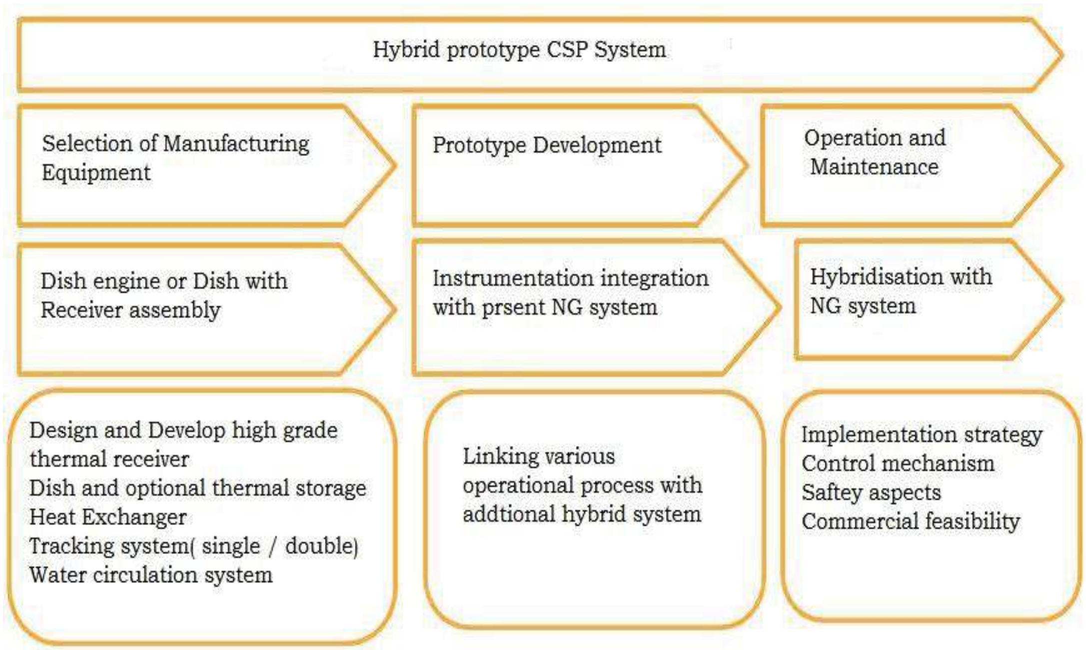

Figure. 4.3. Flow diagram for developing the Hybrid Prototype system

4.3. Algal- Solar (PV & CSP)-NG hybrid system

Bio-methane (Biogas) has been a co-product of microalgae supply chain as shown in Figure 3.15 is targeted to be produced after carbon capture of industrial vent gas. The potential of biogas has been evaluated for hybrid module for producing electricity or heat at site through combustion. Accordingly, a hybrid module with Algal, PV, CSP and NG has been proposed with existing heater treater system at oil and gas facility, as shown in Figure 4.4. The hybrid system attracts following three major integrated factors:

1. Carbon sequestration using emerging microalgae renewable sources and production of biogas for direct conversion to heat or electrical power.
2. Substitution or blending of biogas with natural gas being used for crude oil heating and reduce emissions.
3. Cost effective and environmental friendly hybrid process would be improved with anaerobic digestion under controlled conditions.

Figure 4.4 shows an integrated system of Bio-Solar-NG, at oil and gas location for crude oil heating application.

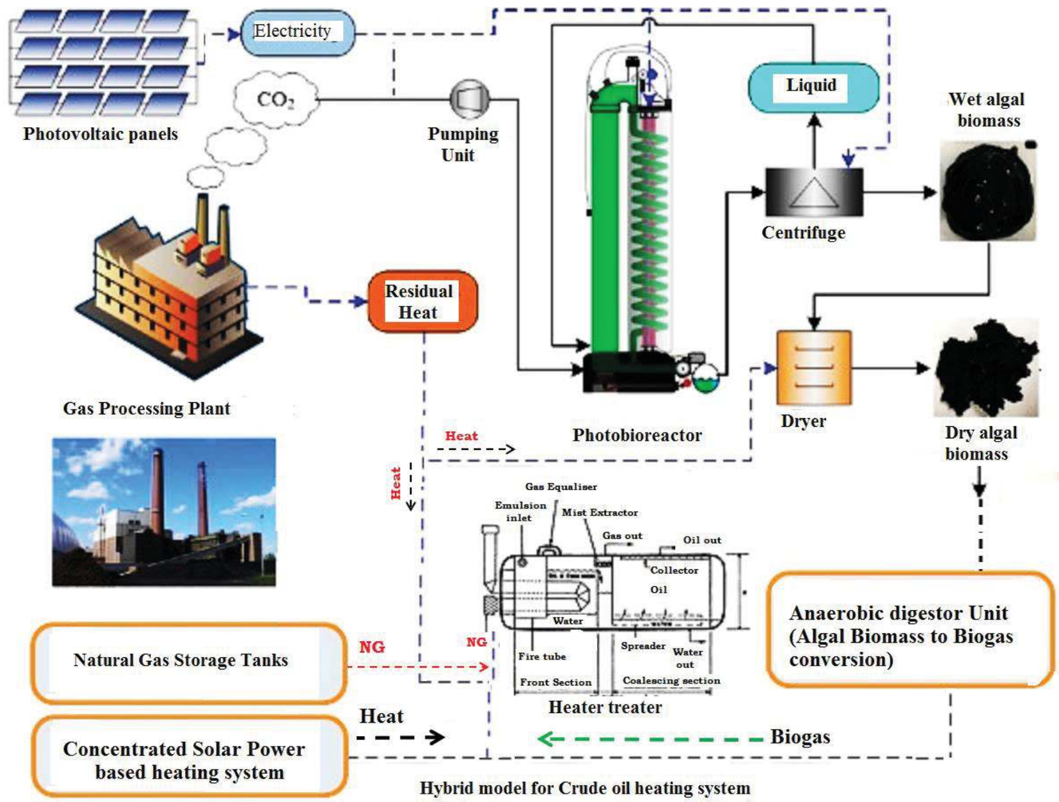

Figure. 4.4. Proposed hybrid system for crude oil heating system

Biomass has been cultivated, harvested, settled down and centrifuged. The algal biomass stream is then injected into anaerobic digesters for its conversion into biogas. The recovered CO_2 is further re-injected into the column system dissolved in water and will support algae biomass growth. The methane produced has been reported to be utilized for combustion purpose. The flexibility of blending of biogas with NG has been analyzed for the crude heating. The viability and improved carbon sequestration has been also suggested by using LED lamps during low solar illumination as well as night time.

The objectives briefed at Section 4.3 have been conducted to demonstrate at a pilot scale, the sequestration of carbon dioxide and biogas production from algal biomass. Factors like the availability of sun or artificial light, pH, O_2 removal, a suitable design of the photo bioreactor with agitation process, were required to start the pilot scale research bench [79]. The agitator based bioreactor has been able to improve the sunlight presence and accelerate the capture of CO_2 with Micro-Algae medium. The industrial vent gas was collected and directly fed to the column as shown in the Figure 4.4, where algae culture is being pumped into the column for the Carbon capture.

Robust algae species or screening of microalgae has been also integrated with this research work. Lab scale experiments have been conducted at location 3. Table 4.2 briefed the screening experiment results for species selection [79].

Table 4.2. Results of Preliminary CO_2 tolerance with Microalgae culture

Type of Microalgae	**Cell Density ($x\ 10^4$/ml)-Range**	**Growth rate (divisions /day)**	**Time taken for pH to drop from 8 to 7**
Chlorella vulgaris	100-500	0.66-0.70	15-25
Scenedesmus quadricauda	100-500	0.80-0.82	15-26
Desmococcus olivaceous	100-500	0.61-0.52	10-15
Chlorococcum humicola	100-500	0.84-0.91	15-30
Chroococcus turgidus	100-500	0.75-0.70	10-14
Dactylococcopsis raphioides	100-500	0.70-0.69	10-12
Consortium selected micro algae	Avg : 200	0.87	45

During the pilot studies, a specially designed PhotoBioReactor(PBR) with a 20 L capacity has been connected to an aerator for mixing and an outlet and inlet connected to a carbonation column which works with a motor, non-return valve, regulator and CO_2 meter as shown in Figure 4.5. The CO_2 pressure has been maintained at 0.3 L/min throughout the experiments. The culture was maintained in a semi-continuous mode removing 30% to a maximum 50% of culture every day to maintain required cell numbers and adding fresh medium. CO_2 tolerance of various species of selected microalgae was studied by sparging CO_2 and measuring pH every minute using a handheld Eutech pH meter. Time taken for the pH(<7=acidic, > 7 alkaline) to reach 7 from the initial pH of around 8 was noted for every species. The experiments were repeated by maintaining different levels of cell density (100 to 500 X 10^4/ml) as shown in Figure 4.5. Selected species of micro algae were mixed in to a consortium and growth and pH were monitored. Cell counts were made before and after every time the culture was harvested/ diluted for calculating the average growth rate. The biomass has been harvested and anaerobically digested for biogas production. The bio-methane production potential of Chlorella species has been assessed by biochemical methane potential. Each day, the algal growth in the pond has been monitored by measuring the optical density (OD[8]).

[8] Optical density : the degree to which a refractive medium retards transmitted rays of light.

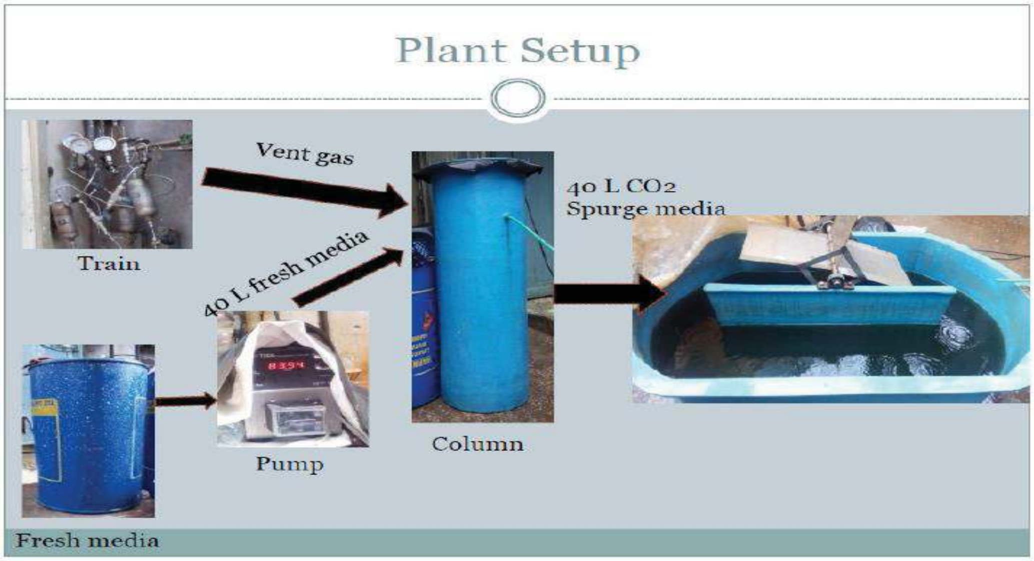

Figure. 4.5. CO_2 sequestration by algae experimental set up.

Based on these experiments a consortium of micro algae *Chlorella vulgaris, Scenedesmus quadricauda and Chlorococcum humicola,* which exhibited rapid growth and better tolerance to reach pH 7, has been selected for pilot trials at location 3. Plant set-up consisting of gas train, fresh media column, pumping solutions and raceway pond has been shown in the Figure 4.5 and 4.6.

(a) Raceway Pond

(b) Fabricated column

(c) Algae Growth purged with vent gas.

Figure. 4.6. Components of experimental set up (a), (b) and (c)

Two sets of experiments has been conducted, one by using Chlorella and the other by using the consortium of microalgae. The alga has been harvested on-site at location 3 during the small-scale pilot studies for anaerobic digestion studies. Sludge from an already existing anaerobic pilot reactor enriched on ethanol and was used as inoculum[9] with 3 g volatile solids per litre before carrying out the anaerobic digestion studies.

The reactors has been provided with synthetic growth medium containing major nutrients (NH_4Cl 26.6 g/l, KH_2PO_4 10 g/l, specific micronutrients: $FeCl_2 \cdot 4H_2O$ 2 g/l, $CoCl_2 \cdot 6H_20$, $Na_2MoO_4 \cdot 2H_2O$ 0.01 g/l) and bicarbonate (50 g/l)[85]. The column has been mixed manually once a day and biogas production was measured continuously for 21 days. The biogas composition has been measured by gas chromatography.

It has been found that the pilot-scale carbonation column has been able to bring down the CO_2 concentration from an initial 33% to 15 %, using a capture media with 55 % of CO_2 capture efficiency. In addition, the algal biomass has been found high contents of oil and nutrients as value-added products. The algae are advantageous, as they do not require agricultural land and can be grown by using wastewater, which have all the nutrient content required for their growth. These characteristics make CO_2 fixation by microalgae a promising route to carbon capture and utilization.

The discussions and results of this research are elaborated in results in Chapter 5. The research work has been conducted under International collaboration with Government of Finland.

4.4. Research Partners & Funding

[1] Oil and Natural Gas Corporation, India
[2] VTT, Technical Research Centre of Finland, Government of Finland
[3] CLEEN (Now Clicinnovation), Research Wing of Govt of Finland
[4] BITS Pilani, Goa Campus and PERC Chennai

Finnish partners were funded by Government of Finland and Indian part was borne by ONGC and DST-Government of India [86].

Since the Bio-Solar-NG hybrid system has been conceptualized for crude oil heating purpose incorporating the carbon sequestration, it has been also attempted to conduct a commercial viability of the system. This would improve the costing and help to reduce carbon emissions effectively.

[9] Inoculum: a substance introduced into algae to create or increase the resistance or immunity.

4.5. Techno-commercial analysis of Bio-Solar-NG hybrid system

Algal biomass has been concluded for dual purpose, the biogas generation as well as direct combustion. It has been reported that biomass based power plants generally have conversion efficiency in the range of 18-24% and major part of biomass couldn't be converted to electricity [87]. Hence concept of Combined Heat and Power (CHP) has been derived for efficient use.

The heat required for drying the wet algal biomass is in the range of 30-50%. The power requirement is in the range of 450 kWh at location 2 and the hybrid model has been modeled based on these inputs. The power requirement of hybrid system has been considered as 500 kWh, and hybrid model has been designed in such a way that 200 kWh units from solar and 300 kWh from algal biomass system. Since this system has been based on hybrid concept, the original NG method would act as back up source for heat requirement.

Another step is algal biomass harvesting with two major ways 1) natural settling and 2) concentration by centrifuge mechanism. Further, during the process, biogas is pressurized in water and CO_2 being highly soluble, the rest of gas composed of CH_4 comes out [88]. There is net energy consumption for this biogas up-gradation and leads the remaining gas with 96% content of CH_4.

The mass-weight study for the hybrid solution has been based on energy calculations and it was assumed that 75% of biomass is converted into biogas with 60% of methane content. In general the Biogas estimated to have thermal value of approximately 22 MJm^{-3} and electrical conversion efficiency of minimum 35%. It is now concluded that for 1 m^3 of biogas, it requires 2.14 kWh of electrical power. The growth rate of algal biomass leads to better quality of daily productivity with better concentration at the rate of 0.5 kg/m^3. Further, Table 4.3 summaries the various assumption and process parameters for the energy mass balance study[89].

The commericial viability of the hybrid system also depends upon the prevalinibg pricing of natural gas, land cost, Operation and Maintenance (O&M) cost etc in ONGC. The summary of these parameters has been summarised in Table 4.4. based on 450kWh power requirement at location 2. A techno-commercial study is important for determining cost-effective implementation at gas processing complex to fix environmental carbon and grow algal biomass.

The biogas generated at site has been utilized and major capital cost incurred on Photo-bioreactors, anaerobic digesters and feedstock collection unit.

The techno-commercial analysis has carried out and proposed the feasibility of Bio-Solar-NG hybrid system. The data inputs are proprietary values within the organization.

Table 4.3. Algal Energy-Mass balance for the conversion

Assumption and Process Parameters	**Value**
Algae biomass concentration	0.25 kg/m^3 (g/L)
Harvesting rate	25%
Biomass productivity rate	17 kg/m^2 /day
CO_2 utilized	15%
Electrical energy consumed for CO_2 injection	458 kWh
Energy for settling the culture	126 kWh
Electricity for centrifugation	76 kWh
Biogas production by anaerobic digestion	386 L CH_4/g fed
Electricity efficiency/ heat efficiency	30% / 55%
Water consumption	1256 m^3
Electricity consumption for other purpose	65 kWh
Combustion (Biogas-Methane)	34 kWh

The hybrid system has been analyzed and compared with three independent scenarios of NG heating, Biogas heating and Solar PV electricity requirement. Finally the hybrid system has been utilized for crude oil heating and found that the required temperature for heating has been achieved by the hybrid system.

Table 4.4. Costing of NG based Crude Oil Heating system at ONGC

Total natural gas used: 1226640 SCM (at ONGC location) per day	
Cost of natural gas @ INR 8.2 per SCM(Standard Cubic Meter)	
Parameters	Costing[10]
Cost of natural gas	Rs 8.2 X 1226640=A
Manpower cost	@ 25% of A
Land requirement	@20% of A (One time cost)
Operation and Maintenance cost(O&M)	@40% of A (Highest and variable after life cycle of various equipment's)

[10] Prevailing government established costing and estimation of parameters and adopted by ONGC

Table 4.5 has summarized on the design estimation for hybrid system. *PVsyst*[11] software has been used for PV array sizing [90].

Table 4.5. Design of Solar and Biomass hybrid system

Parameters	**Calculation and Results**
Solar PV system-Design perspectives	
Total watt hours required	200 kWh
System efficiency factor	Approximately 66%, assuming losses
Solar panel capacity required	=200*100/System efficiency factor * Solar irradiance=60606 Watts
Selected solar panel rating	240-250 W
PV array selection	60606/250=242 modules
Cost of PV system	Approx INR 19 lakhs
Biomass Requirement and Resource Availability	
Target watt hours	300 kWh
Hours of operation	12-14 hours
System efficiency	16-18 %
Calorific value	4000 Kilocalorie/kg=16800KJ/kg
Requirement of biomass for 1 KWh	1.19 kg
300 kWh need biomass	Aprrox 340 kg
Cost of biomass System	Approx INR 24 lakhs
Payback of hybrid system	7.5 years

4.6. Conclusion

The phase wise mandatory shift from fossil fuels to renewable energy resources has been the guidelines and regulation of Government of India. This research study has been emerged as that Bio-Solar–NG hybrid crude oil heating prototype model, which is expected to change the scenario in ONGC as well as related industrial sectors. It is also reported that microalgae has close connection with Environmental Sustainability and the CO_2 sequestration process is scalable to industrially significant values.

In continuation of these opportunities, the next chapter is focused on SIMULINK Model validation, MATLAB Simulation and Results.

[11] PVsyst software is commonly being used for design of PV system