Open Journal of Applied Sciences, 2022, 12, 672-687
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Application Model of Energy Management and Emissions Control to Limit Environmental Risks of Fossil Fuel

Eman M. Gabr

Processes Development, Egyptian Petroleum Research Institute, EPRI, Cairo, Egypt
Email: dremangabr@Gmail.com

How to cite this paper: Gabr, E.M. (2022) Application Model of Energy Management and Emissions Control to Limit Environmental Risks of Fossil Fuel. *Open Journal of Applied Sciences*, **12**, 672-687.
https://doi.org/10.4236/ojapps.2022.125046

Received: March 26, 2022
Accepted: May 7, 2022
Published: May 10, 2022

Abstract

Around the world energy sustainability and environment protection face many challenges due to the continuously increasing population and energy demands, where the demanding rate of energy increases by at least 2.3% per year. According to statistical data, until 2035, fossil fuels still are the main source of energy consumption. Burning fossil fuels produces the greenhouse gas of carbon dioxide as a byproduct. CO_2 emissions have a dangerous effect on both human health and the natural environmental balance. There are many types of clean energy like solar, biofuel, and wind energy. The major limitations of using these types, their availability depends on climate conditions and their production rate is inadequate for energy demand. For any country, energy resources' availability and economic conditions imposed on projects' prioritization. Application of energy management and emissions control techniques for industrial unit can limit fuel combustion environmental effects and transfer this fossil fuel to an eco-friendly type. In this work, we applied Green Energy Model GEM to the Hydrotreater Unit of the refinery, GEM is composed of four techniques. Which are Heat Exchangers Networks Synthesis [HENS], Fuel Switching, Thermal Insulation application, and Carbon Captures Storage [CCS]. Where they reduce energy consumption by the rate of 3% - 34% and control CO_2 emissions by the rate of 26% - 90%. This model is a radical way to face climate change challenges and practical solutions for both energy and environmental crises.

Keywords

Energy Management, Greenhouse Gases, Heat Exchangers Networks, Fuel Switching, Thermal Insulation, Carbon Capture

1. Introduction

As technology development takes place, more energy consumes with high rates of greenhouse gases. Although concerted efforts for renewable sources of energy, fossil fuel will be the prime energy source for the next 20 years [1] [2]. The industrial sector and power stations consume 60% of the annual required energy, so they are responsible for 70% of CO_2 emissions. For example: if a fired heater load of uniting is decreased by approximately 5%, that leads to a reduction of carbon dioxide (CO_2) emissions by a rate of 1700 tons/year, which can realize in presence of 4150 trees. Over the next decade, we have difficult challenges to save our nature life and humanity. Real cooperation among governments, communities, and businesses can synthesize a more sustainable world [3] [4] [5] [6].

In Egypt's statistical analysis from 2014 to 2030, robust economic growth with GDP increasing by 4% is expected. This growth includes increasing energy demand by 117%, where 92% of this energy is a fossil fuel. Coal demand for power stations rises from 1 Mtoe to 53 Mtoe. These energy consumption rates are responsible for increasing CO_2 emissions by 126% and increasing air pollution costs by 117% [7].

Global gas consumption has nearly tripled since 1985 and now accounts for a fifth of global primary energy. An estimated 6 million people are currently employed in oil and gas extraction worldwide. Egypt has ambitious plans to increase renewable energy's share of generation, but its development has been put on hold in order to prioritize gas, rather than recent discoveries of natural gas fields. The current situation in Egypt requires expansion of natural gas switching, taking into consideration the environmental precautions [8] [9] [10].

The rapid solution is limiting environmental risks of fossil fuel consumption by emissions control and energy management of industrial units. In this work, Green Energy Model GEM for energy & emissions reduction is applied. The model is composed of 4 practical technologies: energy recovery using [HENS], fuel switching, thermal insulation technology, and carbon capture storage [11] [12].

Last four decades, HENS proved its energy recovery ability for industrial units. Where, excess hot stream loads transfer to cold streams through heat exchangers' matches. By these matching, demand utilities such as steam and cooling fans are reduced. Reduction of utilities has economic and eco-impacts. HEN can achieve the reduction of utilities and CO_2 emissions by at least 20% [13] [14] [15] [16].

As the quantity of combusted fuel has a strong effect on GHG emissions, although fuel type affects pollutants released. The common industrial fuels are Coal, Fuel Oil, and Natural gas, where their rates of CO_2 emissions are 6300, 5200, and 3600 kg/h respectively. Switching coal and diesel oil to natural gas, reduces emissions by the percentage of 43% and 31% respectively [17] [18] [19] [20].

Zero energy loss is an important goal to save demand utilities and control emissions. Thermal insulation application for industrial units with periodic maintenance is the best way for minimizing energy losses. Insulation has many benefits rather than saving costs, such as increasing process productivity, providing a safer and more productive work environment, and controlling condensation. Industrial insulations can share to solve energy and emissions crises by at least reduction percentage of 20% [21] [22] [23] [24] [25].

According to the BP Statistical Review of World Energy 2020, the volume of global carbon dioxide emissions through fossil fuel consumption was 34,169 billion tons in 2019. CO_2 emissions in 2019 were about 60.1% higher than in 1990 and 44.3% higher than in 2000.

According to Emissions Gap Report 2021, a global temperature rising of 2.7˚C will happen by the end of the century. This rising would lead to catastrophic changes in the Earth's climate. The world needs to halve annual greenhouse gas emissions in the next eight years to limit climate temperature rising [26] [27] [28].

Carbon Capture Sequestration CCS & Carbon Capture Utilization CCU is a rapid solution to minimize the CO_2 rate of flue gases emitted from power stations or the chemical industry. Post Combustion Capture is the most mature CO_2 capture technology, a major advantage of this technology is that it can be retrofitted to the many emission sources that already exist [29] [30] [31].

In this work, the GEM model has been applied to an industrial unit as a case study. This case study is a naphtha hydrotreater united with a petroleum refinery. In the industrial sector, petroleum refineries consume the largest quantity of premium fuels. In refinery, many processes for rising product grades as reformer units require catalytic protection. This is the hydrotreater role, where besides sulfur removal it eliminates nitrogen and metal contaminants. It needs about 20% of refinery energy consumption [32] [33] [34] [35]. Application of the four techniques of energy management and minimizing GHG emissions realize the reduction of energy consumption by the rate of 3% - 34% and control CO_2 emissions by the rate of 26% - 90%.

2. Energy Crisis

All these conditions: the shortage of resources, increasing rate of demand energy, and the restricted production of renewable energy sources lead to complicating energy crises. Fossil fuels with harmful environmental impact are still a prime source of energy for the next 20 years as shown in **Figure 1**. Coal which is the highest emitter fuel produces 35% of global electricity. Economic conditions especially for development countries rearrange priorities [36] [37] [38] [39].

3. GHG Emissions

As shown in Equation (1)-(3), the rate of pollutants and harmful emissions ($M_{pol.}$) is affected by the amount of fuel combusted (Q_{fuel}) and fuel type physical properties. As shown in **Table 2**, emissions indicators (β & ϕ) of Fuel oil are higher than Natural Gas. While the net heating value NHV of Fuel oil is lower than Natural Gas, so Natural Gas is the least emitting of CO_2. These emissions are the main reasons for severe climate change and its appurtenances of Global Warming, Desertification, Forest Fire, Flood, Drought, Disturbance of Natural Balance, Deterioration of Human Health, and Bad Impact on Economic.

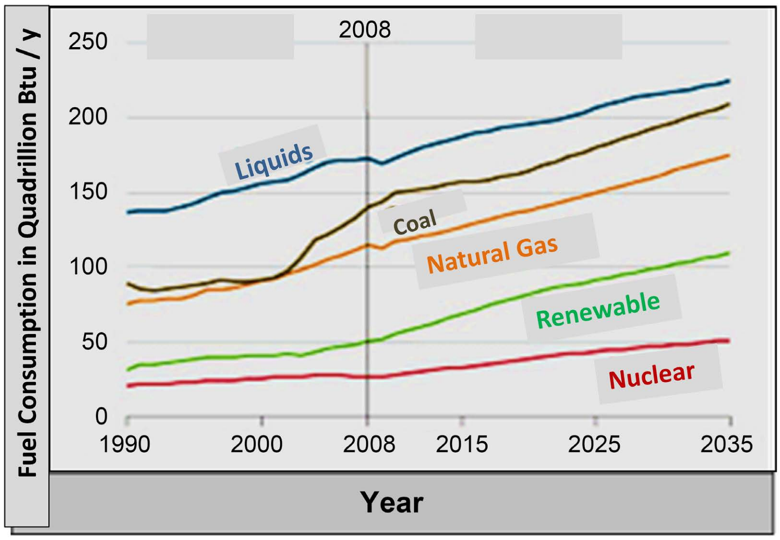


Figure 1. Historical and projected world energy consumption by fuel type, in units of quadrillion Btu [37].

$$\eta_{furn.} = \frac{T_{TFT-T_{STCK}}}{T_{TFT-T_a}} \tag{1}$$

$$Q_{fuel} = Q_{proc.} / \eta_{furn.} \tag{2}$$

$$M_{pol.} = Q_{fuel \times \beta \times \varnothing} / \text{NHV} \tag{3}$$

4. Experiment

4.1. Green Energy Model GEM for Energy & Emissions Reduction

A model composed of four technologies can be applied to any industrial unit to maximize its energy efficiency and reduce released CO_2.

4.1.1. Heat Exchangers Networks Synthesis [HENS]

HENS' theory depends on energy integration by transferring energy load from hot streams to cold streams through heat exchangers. These matches can minimize required hot and cold utilities. See Figure 2, where matching E1 & E2 reduced loads of both the heating system and cooling system by 54% & 52% respectively. This reduction has economic and environmental benefits due to minimizing fuel combusted and emissions released.

4.1.2. Fuel Switching

Natural gas (N.G) is a fossil fuel with the least emissions rate compared to oil and coal as shown in Figure 3. In Egypt, sustainable development and recent N.G discoveries require expansion of N.G switching through environmental precautions. Where switching of both Coal & Oil to N.G reduces emissions by at least 43% & 31% respectively [15].

4.1.3. Application of Thermal Insulation

The global goal for governments and communities is zero value for both emissions

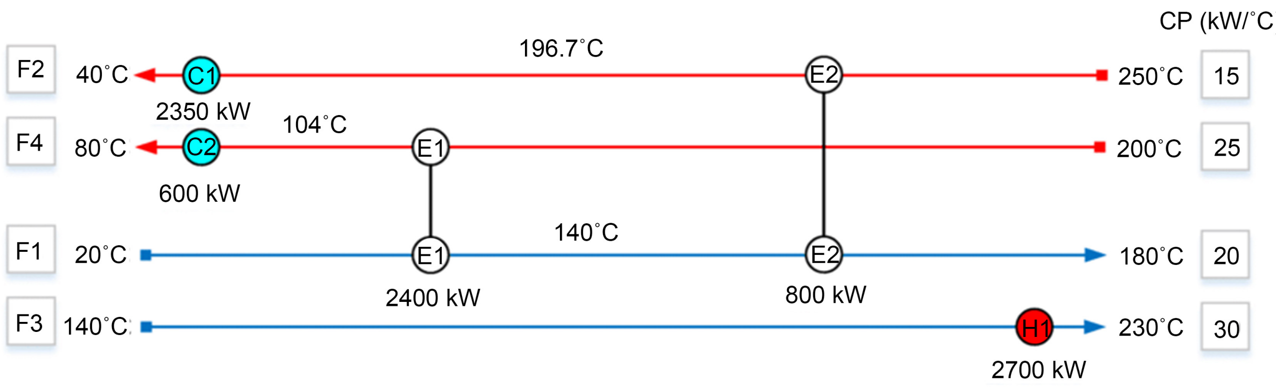


Figure 2. Simple example of HEN (2 hot streams & 2 cold streams).

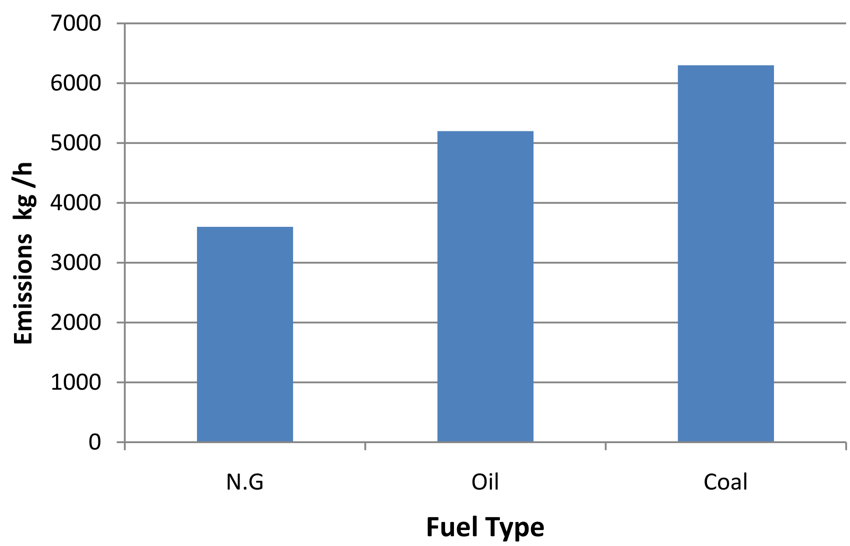


Figure 3. CO_2 emissions rates of the three types of fossil fuels [15].

and energy losses by 2050. Thermal insulation application is a fast direct way of energy loss reduction. Besides the economic and environmental benefits of energy-saving, insulation realizes more safety and adjustment of processes control as shown in Figure 4. Energy losses can be estimated using Equations (4)-(6) [21].

$$S = \left[10 + (T_s - T_a)/20\right] * (T_s - T_a) \tag{4}$$

$$Hs = S * A \tag{5}$$

$$A = 2\pi * r * L \tag{6}$$

4.1.4. Carbon Capture Technology

Flue gasses of industrial unit and power stations are the main source of CO_2 emissions. Approximately annual emissions of industrial units are 400,000 ton/year, which equals 180,000 cars' emissions. Therefore elimination of CO_2 of different flue gas types through CCS or CCU helps to avoid the dangerous effects of fossil fuel combustion. Where, 90% of exhaust gasses CO_2 can be collected and stored geologically in great depth through CCS or utilized through CCU. CO_2 utilization without conversion is used for oil and gas enhanced recovery. While CO_2

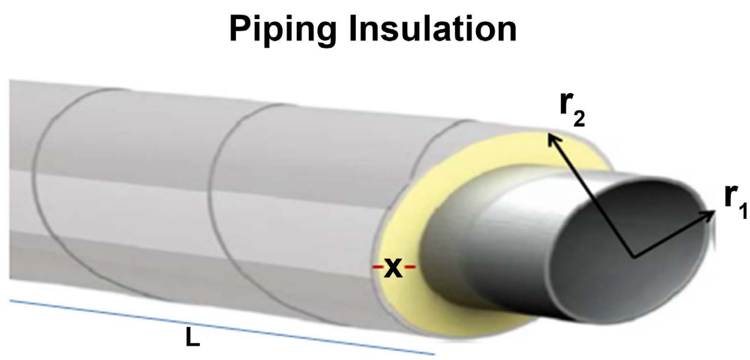


Figure 4. Scheme of piping thermal insulation [21].

utilization with conversion is used for chemical synthesis, carbon mineralization, and algae cultivation. Three types of CCS, Post-combustion, Pre-combustion & Oxy-fuel can be applied to the industrial sector. Recent design of Post Combustion type is defined by its small size, high efficiency, and flexible operability conditions. In post-combustion type, CO_2 is absorbed firstly by amine solvent in scrubber column then regeneration and recycling of solvent take place. Finally, stage is the transportation of CO_2 and clean exhaust gas. See Figure 5(a) & Figure 5(b).

5. Discussion and Results

The first step to examine the model validity is choosing a case study where application results can prove the model's applicability.

5.1. Application GEM Model on a Case Study

Egypt has the greatest refining capacity in Africa. On the other side, refineries, steel, and cement are the prime source of GHG in the industrial sector. We take the hydrotreater to unit of a refinery as a case study due to its important role and high fuel consumption. The hydrotreating unit removes sulphur, nitrogen, and metal contaminants, it consumes about 20% of refinery energy consumption. Removal of sulfur is essential for protecting the catalyst in subsequent processes and for meeting product specifications.

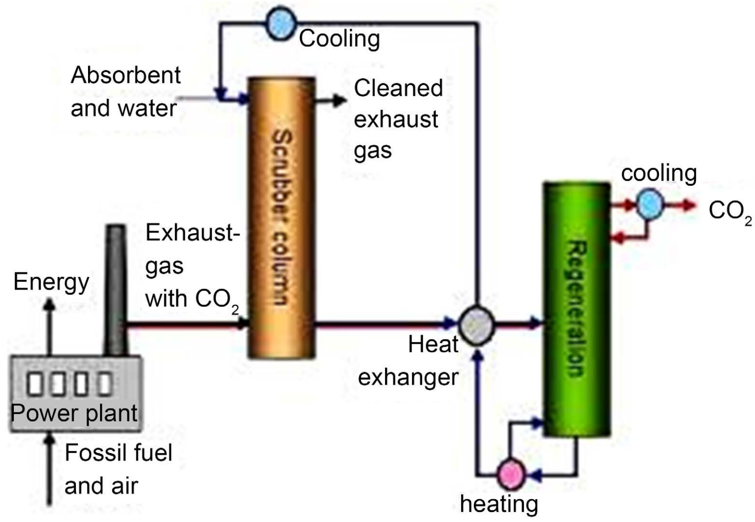
Description of Naphtha Hydrotreater Unit

Naphtha feed and hydrogen introduce to the fired heater then the catalytic reactor. Reaction product cools and separates. Where, the mixture of naphtha and light hydrocarbon is transferred to the stripper column and H2 recycled to the feed stream. Treated naphtha is the outcome of the column. A flowsheet of the process is shown in Figure 6.

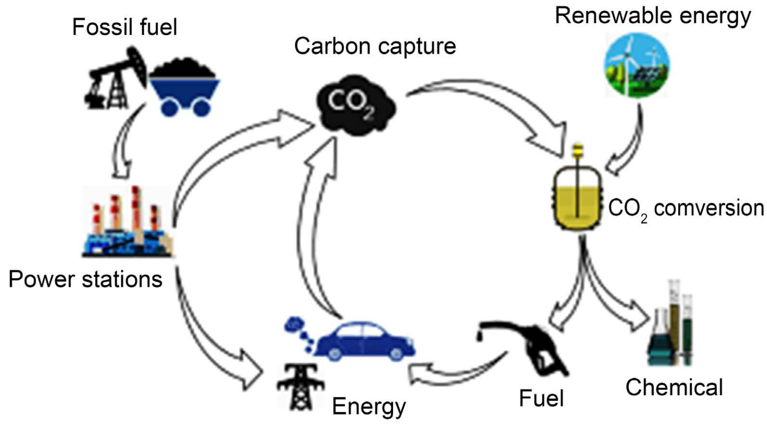
5.2. Energy Recovery using HEN Technology for Naphtha Hydrotreater

1) Classification of the process into two groups of hot and cold streams is listed in Table 1.

2) Many HENs at different temperature differences (ΔT_{min}) are designed.



(a)



(b)

Figure 5. Post-combustion CCS & figure scheme of CO_2 capturing and utilization.

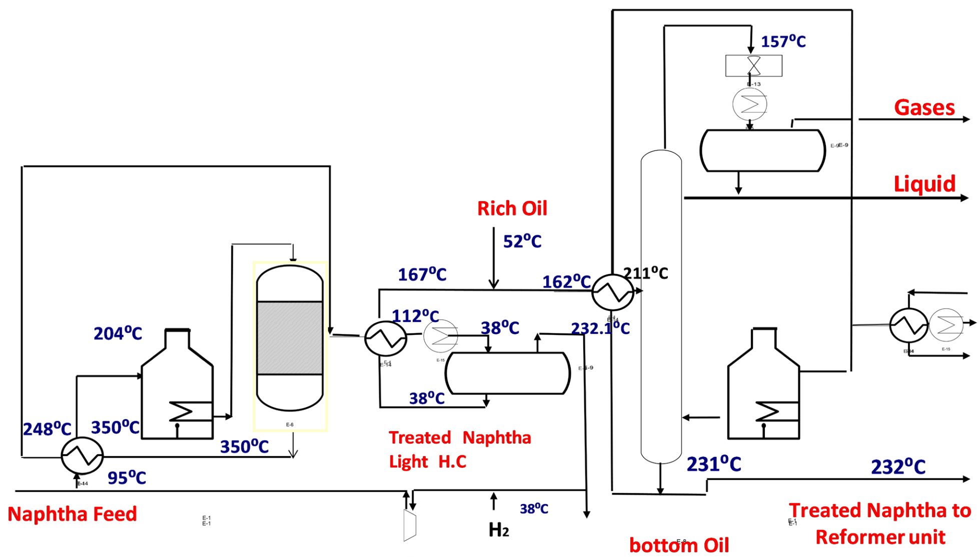


Figure 6. Flowsheet of naphtha hydrotreater unit [32].

Table 1. Streams data of hydotreater unit.

Stream	T_{in} ˚C	T_{out} ˚C	CP MJ/h ˚C	H MJ/m^2 ˚C
Reactor Effluent (h1)	350	38	165.6	2.02
Lean Oil (h2)	232	38	13.5	1.7
Stripper Condenser (h3)	157	38	273.9	2.02
Reactor Feed (C1)	95	350	167.3	2.02
Stripper Feed (C2)	38	167	117.8	2.02
Stripper Feed 2 (C3)	52	130	12.0	2.02
Mixed Stripper Feed (C4)	162	211	212.6	2.02
Stripper Reboiler (C5)	231.9	232	249690.0	2.02

3) Estimation of utilities and added cost of every network design, then CO_2 emissions corresponding to every design are assigned.

4) Optimum ΔT_{min} is defined as 18˚C. See Figure 7.

5) Comparing between optimum & existing HENs (Figure 8(a)) is done. According to this comparison, revamping of the existing HEN design took place by relocating exchanger 4 and adding a fired heater to cold stream C4. See Figure 8(b). The results of these modifications are percentage reduction of hot & cold utilities as 25% & 28% respectively beside reduction of CO_2 emissions as 25%. Revamped Hydrotreater flowsheet is shown in Figure 9.

5.3. Application of Fuel Switching Technology for Hydrotreater Unit

The fuel used in this refinery is fuel oil which is highly emitter of CO_2 by at least 30% than N.G. Recent Egyptian discoveries of N.G resources and Egypt's location as a crossway trade of liquefied N.G, expanded N.G projects. So replacement fuel oil with N.G is recommended for hydrotreater unit. This switching realized satisfying results for reduction of cost and CO_2 emissions by 34%. Specifications and application results of the two fuel types are listed in Table 2.

5.4. Application of Thermal Insulation Technology for Hydrotreater Unit

The target is to minimize both energy losses and CO_2 emissions of hydrotreater unit by applying thermal insulation. There are two classifications of insulator types, according to temperature range and according to construction material. See Figure 10. The Candidate type for the case study is Mineral Wool, which is an inorganic material and applicable to high temperatures. This insulator is defined by its flexibility and availability in many forms besides its low thermal conductivity (0.044 W/m^{2}K). The insulator thickness is 10 mm and expecting surface temperature is 60˚C.

The hydrotreater unit conditions before and after Insulation is listed in Table 3. Where, this technology realized great results in minimizing both energy losses

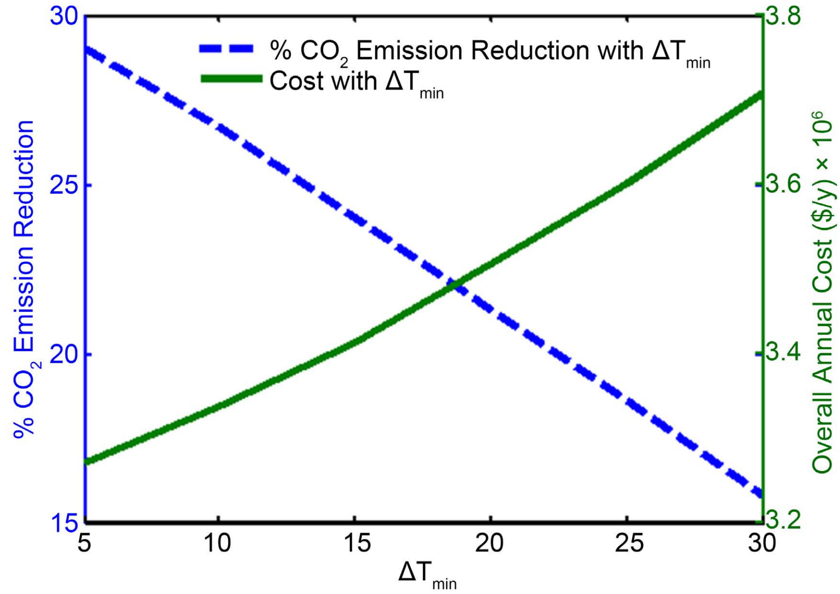


Figure 7. Optimum $\Delta T_{\min}$ [32].

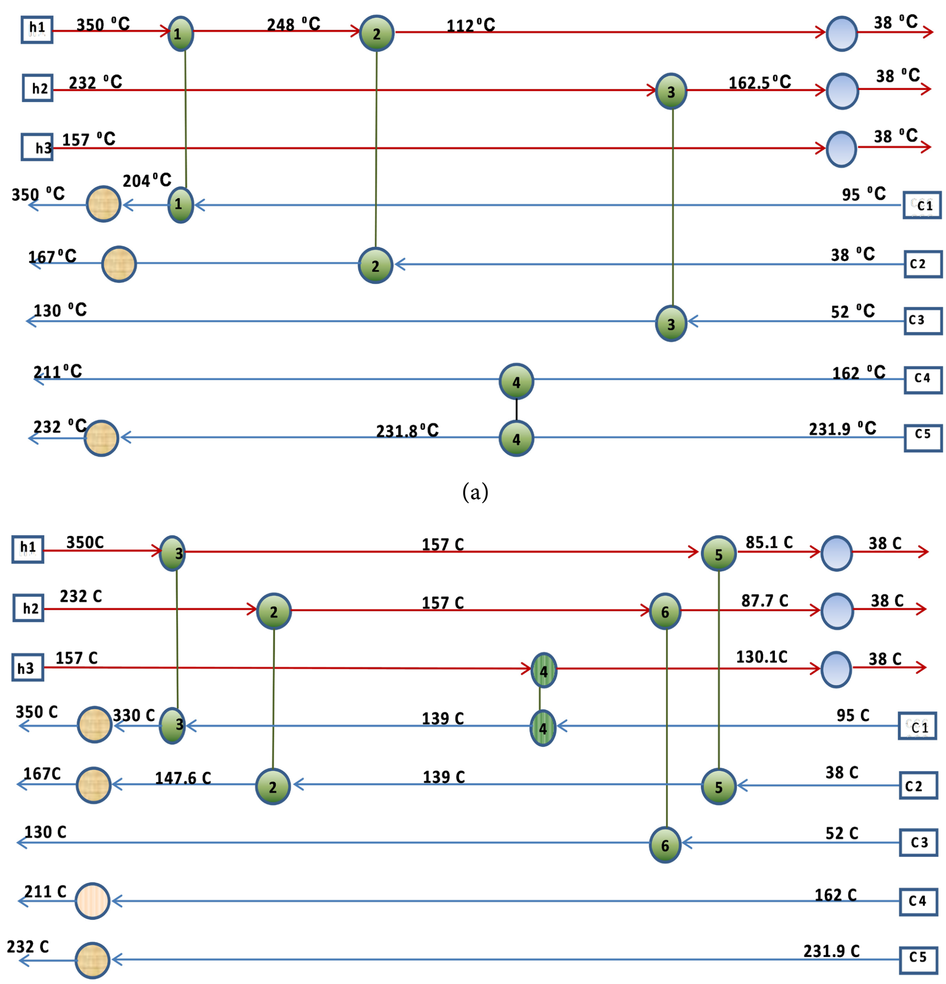


Figure 8. (a) HEN of existing design [32], (b) Existing HEN design after modifications.

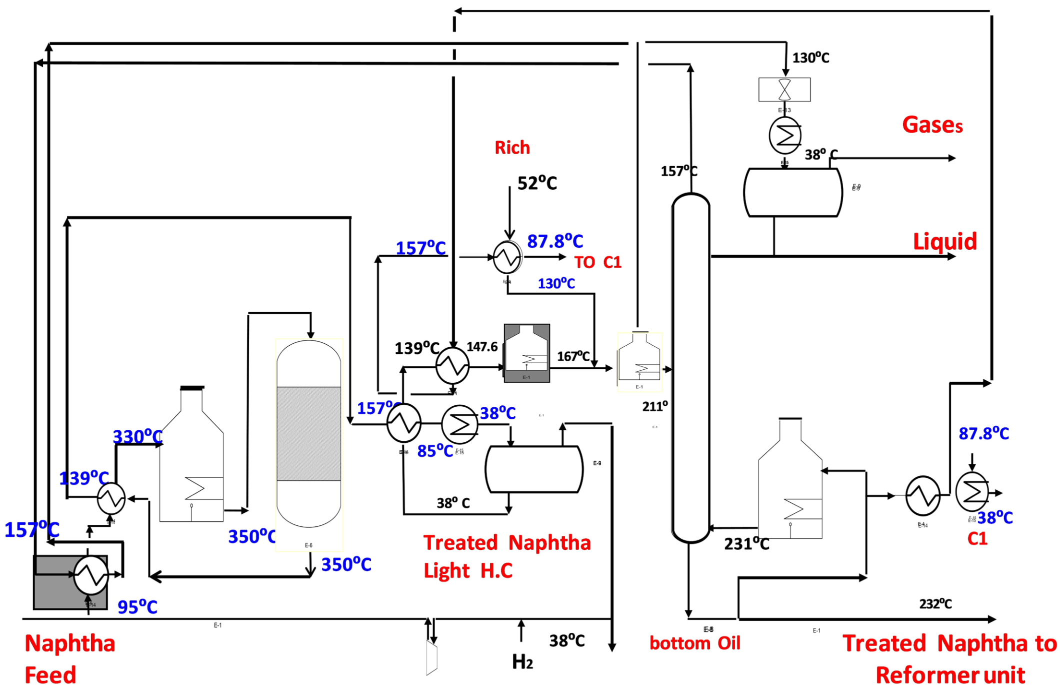


Figure 9. Revamped design of Hydrotreater Unit [32].

Table 2. Specifications & results of 2 fuel types for hydrotreater unit.

Fuel Specification	Natural Gas	Fuel Oil
NHV MJ/kg	51.2	40
β	0.76	0.85
ϕ	3.5	3.7
CER	0.052	0.079
Cost $/kg	0.34	0.4
Q_{fuel} MJ/h	54803.1	54803.1
Operating Cost $/y	2,882,373	4,340,475
Pollutant Emission ton/y	25,055	37,919

Table 3. Hydrotreater unit conditions before and after insulation.

	Before Insulation	After Insulation
Energy Losses kCal/h	431,907	54,354
Excess Fuel Combusted ton/y	421	53
Cost of Excess Fuel $/y	168,370	21,188
Insulation Cost $/y	--	1600
Net Saving of Operating Cost $/y	--	125,516
% Energy Losses reduction	--	89%
% CO_2 emissions reduction	--	26%
% Demand Utility reduction	--	3%

Figure 10. Insulation types.

and emissions. Taking into consideration the construction and maintenance of Insulators, the Net annual saving is 125,516 $/y and the percentage reduction of CO_2 emissions reaches 26%.

5.5. Application of Carbon Capture Technology for Hydrotreater Unit

In February 2022, The European Council's latest report endorsed the objective of achieving a climate-neutral by 2050 through drastic reduction of greenhouse gas emissions, on the other hand finding ways for facing the remaining, and unavoidable emissions. The circular carbon economy is projected to capture and reuse 9.3 billion metric tons of CO_2 by 2050 to control climate temperature rising by 1.5˚C. Carbon Capture Storage CCS and Carbon Capture Utilization CCU are the better alternatives for facilitating a less costly reduction in carbon emissions with the continued use of fossil fuels. While carbon capture is a high-cost application it can provide a good return on investment (ROI) by avoiding penalty regulations and protecting the environment. The benchmark of CO_2 Taxes is 30 $/ton which expected to rise by gradually 2% to face climate damages and human health deterioration caused by every CO_2 ton [39].

Many factors, including infrastructure, CO_2 transportation, geological data, and storage capacity are defining contemporary costs of CCS in the range of 50 - 60 $/ton.

Post-combustion CCS is suitable to apply for refineries including Hydrotreater units, whatever the fuel used coal, fuel-oil, or N.G as shown in **Figure 11**. Where emissions' sources of refinery are loads of both furnaces and reboilers (30% - 60%), production of electricity and steam (20% - 50%), products upgrading unit (20% - 35%) and Hydrogen manufacturing unit (5% - 20%).

Expecting results of adding CCS to hydrotreater unit is 90% CO_2 elimination from exhaust gasses & 95% solvent regeneration. Where, the adding cost is 100,000 $/y in case of using N.G and 140,000 $/y in case of F.O.

6. Results of Application Green Energy Model on Hydrotreater Unit

Green Energy Model GEM proved its ability to apply to any industrial unit to minimize energy consumption and reduce CO_2 emissions. Application of the four technologies: HEN, Fuel Switching, Thermal Insulation, and CCS got great results

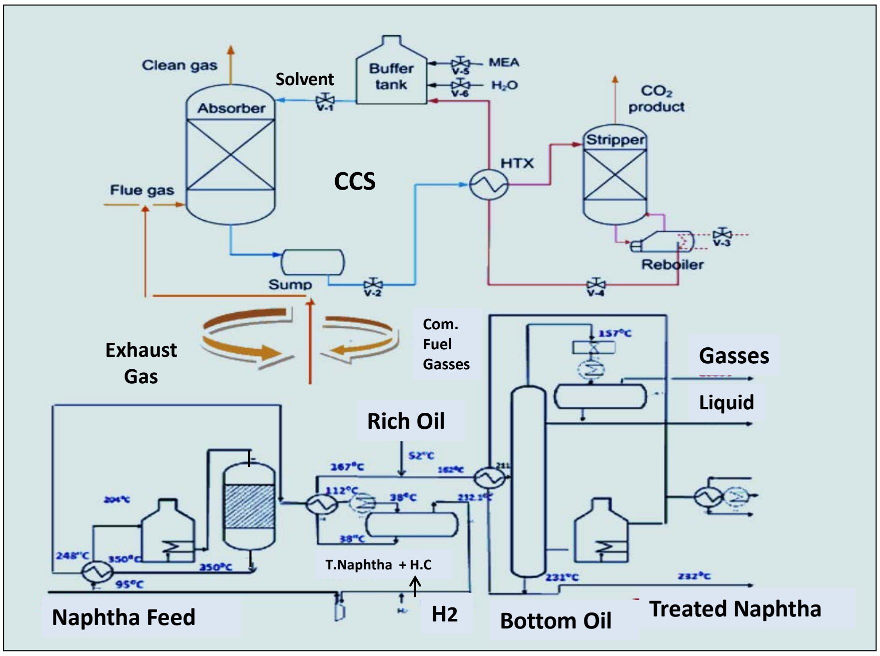


Figure 11. Flowsheet of hydrotreater unit attached to carbon capture storage CCS.

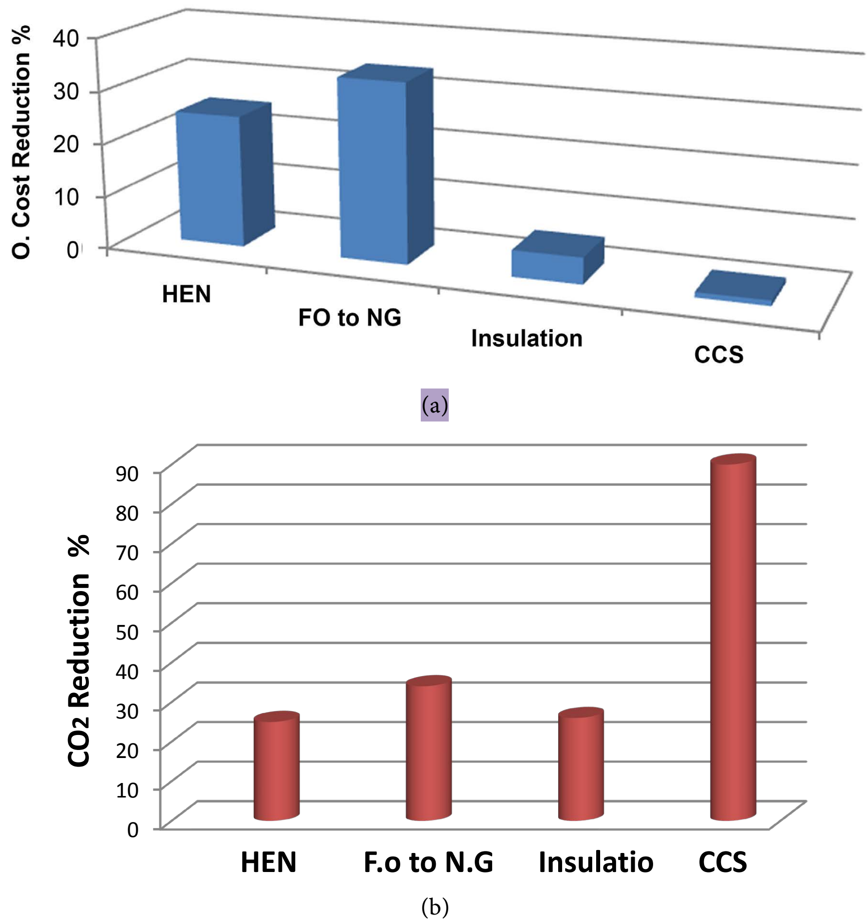


Figure 12. (a) % of operating cost reduction, (b) % of CO_2 reduction. Through application of GEM model with its four techniques.

as shown in **Figure 12(a)** & **Figure 12(b)**.

This model is a radical solution to using fossil fuels with avoiding their dangerous effects on the environment and human health.

7. Conclusion

The current situation of energy crisis and environmental pollution rather than climate change, require radical solutions to mitigate negative consequences. Global temperature rising requires real cooperation among governments, communities, and businesses to reduce GHG and so on halving rising. Due to fossil fuel standing as prime fuel for the next decades with continuous CO_2 emissions, GEM with four techniques can be applied for industrial unit. This model used for Hydrotreater units and realized great results of energy integration and emissions control. Where the four techniques are energy recovery by HEN, Fuel switching from fuel oil to natural gas, application of thermal insulation, and Carbon Captures reduce energy consumption and CO_2 at a good rate. Demand utility of the case study recedes in the range of 3% - 34% and elimination of exhaust CO_2 reached 90%. More effort is required to innovate and apply new techniques for facing climate change and sustainable development.

Acknowledgements

The author acknowledges the administration of the Egyptian Petroleum Research Institute [EPRI] for their continuous support. The author acknowledges the administration and operation engineers of the Cairo refining company for their cooperation.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Gaia Greentech Organization (2021) Gaia Greentech Ventures into Green Technology. https://gaiagreentech.com.my/articles/gaia-greentech-ventures-into-green-technology

[2] Al-juboori, S.S. (2017) Chapter 12. Green Energy—An Introduction. In: Prasad, R., Shivakumar and Sharma, U.C., Eds., *Energy Science and Technology Opportunities and Challenges*, Stadium Press LLC, Kirkuk, 316-340.

[3] Dınçer, A.R., Özsağiroğlu, E., Iseri, F., Dogan, G., Yavuz, G.D., Andaş, G.Ş., Aka, O., Mutlu, S., *et al.* (2021) CO_2 Emissions Reduction via a Pinch Study in a Vacuum Distillation Unit. *Hydrocabon Processing*, Izmir, 15.

[4] Kalyani, V.L., Dudy, M.K. and Pareek, S. (2015) Green Energy: The Need of the World. *Journal of Management Engineering and Information Technology*, **2**, 18-26.

[5] Kumari, S. (2021) Clean Energy: Key to a Sustainable Future. *ENVIS Resource Partner on Geodiversity & Impact on Environment*, **25**, 14-17.

[6] Barnard, *et al.* (2021) World Scientists' Warnings into Action, Local to Global. *Science Progress*, **104**, 1-32. https://doi.org/10.1177/00368504211056290

[7] IRENA, Intergovernmental Organization (2018) Renewable Energy Outlook. IRENA, International Renewable Energy Agency, Abu Dhabi.

[8] Muttitt, G., Sharma, S., Mostafa, M., Kühne, K., Doukas, A., Gerasimchuk, I. and Roth, J. (2021) Step off the Gas. International Institute for Sustainable Development. IISD Report.

[9] Dulal, A., Yao, X., Barker-Gibb, M., Tachega, M., Ge, S. and Li, H. (2021) Impact of Renewable Energy on Carbon Dioxide Emission Reduction in Bangladesh. *Journal of Power and Energy Engineering*, **9**, 134-165. https://doi.org/10.4236/jpee.2021.95009

[10] Biseri, Z.A. and Bugari, U.S. (2021) Reliability of Base load Electricity Generation from Fossil and Renewable Energy Sources. *Energy and Power Engineering*, **13**, 190-206. https://doi.org/10.4236/epe.2021.135013

[11] Moran, M.J., Shapiro, H.N., Munson, B.R. and DeWitt, D.P. (2003) Introduction to Thermal Systems Engineering. John Wiley & Sons, Inc., Hoboken.

[12] Rabah, A.A. and Abbas, M.A. (2013) Emissions of Local Heavy Fuel Oils. *University of Khartoum Engineering Journal*, **3**, 46-50.

[13] Svensson, E., Eriksson, K., Bengtsson, F. and Wik, T. (2018) Design of Heat Exchanger Networks with Good Controllability. Project Report. CIT Industrial Energy AB.

[14] Kono, T. and Tsuge, Y. (2020) Heat Exchanger Networks (HEN) Are Extensively Used to Recover Energy. Computer Aided Chemical Engineering.

[15] Chen, J.X., Yang, Q.G., Cui, G.M., Bao, Z.K. and Zhang, G.H. (2021) Synthesis of Cost-Optimal Heat Exchanger Networks Using a Novel Stochastic Algorithm and a Modified Stage-Wised Superstructure. *Processes*, **9**, Article 2060. https://doi.org/10.3390/pr9112060

[16] Gabr Eman, M. (2018) Step by Step for Designing an Optimum Heat Exchanger Network. *International Journal of Scientific & Engineering Research*, **9**, 827-845.

[17] Gota, K.R. and Khanam, S. (2011) Selection of Utility System and Fuels for Emission Targeting of Chemical Industries. *International Journal of Recent Research and Applied Studies*, **9**, 427-433.

[18] Mahmoud, A., Shuhaimi, M. and AbdelSamed, M. (2009) A Combined Process Integration and Fuel Switching Strategy for Emissions Reduction in Chemical Process Plants. *Energy*, **34**, 190-195. https://doi.org/10.1016/j.energy.2008.11.007

[19] Tiew, B.J., Shuhaimi, M. and Hashim, H. (2012) Carbon Emission Reduction Targeting through Process Integration and Fuel Switching with Mathematical Modeling. *Applied Energy*, **92**, 686-693. https://doi.org/10.1016/j.apenergy.2011.07.048

[20] Hashim, H., Mahadzir, S., Sin, W.K. and Ahmed, M. (2012) Operation System Optimization. In: *Handbook of* CO_2 *in Power Systems*, *Energy Systems*, Springer, Berlin, 373-391. https://doi.org/10.1007/978-3-642-27431-2_17

[21] Sova, D., Stanciu, M.D. and Georgescu, S.V. (2021) Design of Thermal Insulation Materials with Different Geometries of Channels. *Polymers*, **13**, Article 2217. https://doi.org/10.3390/polym13132217

[22] Keçebas, A., Mehmet, A. and Bayhan, M. (2011) Thermo-Economic Analysis of Pipe Insulation for District Heating Piping Systems. *Applied Thermal Engineering*, **31**, 3929-3937. https://doi.org/10.1016/j.applthermaleng.2011.07.042

[23] Jailani, S. (2019) PPT Course, Syllabus. Syllabus, Insulation and Refractories, Bureau of Energy Efficiency. https://beeindia.gov.in/sites/default/files/2Ch5.pdf

[24] Ucar (2018) A Thermo-Economic Approach for Determination of Optimum Thickness of Thermal Insulation Applied to Piping System. *Journal of Renewable and Sustainable Energy*, **10**, Article ID: 035102. https://doi.org/10.1063/1.5004086

[25] Gabr Eman, M. and Mohamed Soad, M. (2020) Energy Management Model to Minimize Fuel Consumption and Control Harmful Gas Emissions. *International Journal of Energy and Water Resources*, **4**, 453-463. https://doi.org/10.1007/s42108-020-00085-2

[26] Liu, Y., Jiao, R.T., Zhao, L.Y. and Liu, K. (2021) Impact of Greenization on the Marginal Utility of Intensity of Carbon Emissions and Factors Affecting It in China. *Energy Engineering*, **118**, 363-378. https://doi.org/10.32604/EE.2021.013472

[27] World Meteorological Organization (2021) Climate Change Triggers Mounting Food Insecurity, Poverty and Displacement in Africa.

[28] UNEP, UNEP Copenhagen Climate Centre (UNEP-CCC) (2021) Emissions Gap Report 2021. UN Environment Program.

[29] Das, S. and Kumar, J. (2016) Carbon Capture and Storage. *International Journal of Scientific & Engineering Research*, **7**, 1385-1388. https://doi.org/10.14299/ijser.2016.10.006

[30] Cherepovitsyn, A., Chvileva, T. and Fedoseev, S. (2020) Popularization of Carbon Capture and Storage Technology in Society: Principles and Methods. *International Journal of Environmental Research and Public Health*, **17**, Article 8368. https://doi.org/10.3390/ijerph17228368

[31] Shreyash, N., Sonker, M., Bajpai, S., Tiwary, S.K., Raj, M.A.K.S., Sharma, T. and Biswas, S. (2021) The Review of Carbon Capture-Storage Technologies and Developing Fuel Cells for Enhancing Utilization. *Energies*, **14**, Article 4978. https://doi.org/10.3390/en14164978

[32] Gabr Eman, M., Mohamed Soad, M., El-Temtamy Seham, A. and Gendy Tahani, S. (2016) Application of Energy Management Coupled with Fuel Switching on a Hydrotreater Unit. *Egyptian Journal of Petroleum*, **25**, 65-74. http://creativecommons.org/licenses/by-nc-nd/4.0 https://doi.org/10.1016/j.ejpe.2015.03.012

[33] Hirshfeld, D.S. (2016) Petroleum Refining. In: Gass, S.I. and Fu, M.C., Eds., *Encyclopedia of Operations Research and Management Science*, Springer, Boston, 43-64. https://doi.org/10.1007/978-1-4419-1153-7_1268

[34] Bergh, C. (2012) Energy Efficiency in the South African Crude Oil Refining Industry: Drivers, Barriers and Opportunities. M.Sc., Sustainable Energy Engineering, University of Cape Town, Cape Town.

[35] Worrell, E. and Galitsky, C. (2005) Energy Efficiency Improvement and Cost Saving Opportunities for Petroleum Refineries. Lawrence Berkeley National Laboratory, Berkeley. https://doi.org/10.2172/862119

[36] Pyle, T.J. (2022) Coal Is Still King. *Power Magazine*. https://www.powermag.com

[37] United States Energy Information Administration (2011) International Energy Outlook. http://www.eia.gov/forecasts/ieo

[38] United States Energy Information Administration (2012) Annual Energy Review

2011. http://www.eia.gov/totalenergy/data/annual/archive/038411.pdf

[39] Elshennawy, A. and Willenbockel, D. (2021) The Effect of a Carbon Tax on the Egyptian Economy: A General Equilibrium Analysis. Working Paper No. 1525, The American University, Cairo.

Abbreviations

GEM	Green Energy Model	**CCS**	Carbon Captures Storage
GDP	Gross Domestic Product	$\eta_{furn.}$	Efficiency of fired heater (dimensionless)
S	Surface heat loss in kCal/hr m^2	**NHV**	Net heating value of fuel kCal/kg
T_s	Hot surface temperature in ˚C	η_b	Boiler efficiency in %
T_a	Ambient temperature in ˚C	r_1	Radius of pipe m
H_s	Total heat loss kCal/hr	r_2	Radius of pipe after insulation m
β	The mass percentage of the pollutant in monoxides form	L	Pipe length m
ϕ	The molar mass ratio of the oxidized to the non-oxidized form of the pollutant	x	Insulation thickness m
T_{TFT}	Flame temperature ≈ 1800˚C	M_{pol}	Rate of pollutants released kg/h
T_{STACK}	Stack temperature ≈ 160˚C	Q_{fuel}	Actual rate of combusted fuelkCal/h
CCU	Carbon Captures Utilization	$Q_{proc.}$	Estimated rate of combusted fuel kCal/h
O.C.	Annual Operating Cost $/y		