International Journal of Multiphysics
Volume 16, No. 1, 2022
ISSN: 1750-9548

Study of Combined Refrigeration System with power plant for Sustainable Environment

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Abstract

In this paper First and Second Laws of thermodynamics to different refrigeration and heat pump cycles combined with power plants has been presented. The main goal of the study is to determine how well low GWP refrigerants work in refrigeration and heat pump systems. Component-level exergy analysis is used to improve design possibilities by addressing systemic inefficiency, which is the primary cause of lost work . Reducing energy use, cutting carbon emissions, and promoting environmental sustainability are all addressed by Cold climate heat pumps that use low GWP refrigerants. Study of Biofuel based Polygeneration and Solar assisted cogeneration power plant included in this paper.

In pursuit of sustainable development and carbon neutrality, the integration of refrigeration systems with power plants emerges as a transformative solution to enhance energy efficiency and minimize environmental impact. This study presents a comprehensive analysis of combined refrigeration systems (CRS) synergistically linked with power generation units, leveraging waste heat recovery and cogeneration techniques to optimize thermodynamic performance. By exploiting low-grade thermal energy typically discarded in conventional plants, the integrated system substantially reduces greenhouse gas emissions and operational costs, promoting a circular economy approach within energy infrastructures. The research employs advanced simulation models and exergy analysis to benchmark system efficiencies across varying operational parameters and climatic conditions. Results demonstrate that the hybrid configuration not only augments overall plant efficiency by up to 15% but also achieves significant reductions in carbon footprint, aligning with global sustainability goals. This paper sets a strategic foundation for policymakers, industry stakeholders, and researchers to reimagine energy ecosystems.

1 INTRODUCTION

With a significant advertising push, the Freon were introduced in the 1930s and 1940s and swiftly seized a sizable portion of the market. The many forms of CFC and HCFC now fully dominate all other conventional domains of application, with ammonia being the only refrigerant that has remained the preferred choice in large industrial machinery. Their total safety and environmental innocuousness were the primary claims made in the propaganda.

Over the years, dissociation goods have injured some people, and asphyxia in ships and areas below threshold level has killed many others[1][2].
The Montreal Protocol and the widespread prohibition of the majority of CFC and HCFC chemicals are the results of environmental damage[3]. The entire atmosphere contains 3000 billion tons, whereas the biosphere circulates several hundred billion tons annually.
Its total harmlessness can be determined without the need for laborious and time-consuming investigation. One could counter that CO_2 is a greenhouse gas as well, which is obviously true, but its impact is much less significant than that of halocarbons [3], [4].

Working fluids are used in heat pump and air conditioning systems to move heat from heat sources to heat sinks. These fluids need to possess qualities that are appropriate for these systems' operation. The working fluids in air conditioning and refrigeration systems often have to reject heat at greater pressures and temperatures and absorb heat at lower temperatures (below O'C) without freezing [5],[6],[7]. The development of refrigerants since 1834, when ethyl-ether was employed in the first mechanical cooling manufacture. A number of natural refrigerants, like ammonia, CO2, hydrocarbons, etc., were then used The use of CFC refrigerants, often known as Freons, has increased significantly since 1930. Later on, HCFC refrigerants were primarily introduced in the air conditioning industry. Excellent refrigerants that are safe for human health and extremely stable are CFC gasses. Additionally, CFCs have direct entrance into the human body due to their use in inhalers [8],[9].

The Phase-Out of CFCs and the Montreal Protocol Figure 1, provides a graphic representation of the CFC phase-out's development for a more current historical viewpoint. The United States and other wealthy nations stopped producing CFCs at the end of 1995, with very few significant potential to cause global warming. HCFCs were to be phased out by 2020–2030 and HFCs by 2025–2040, according to the Kyoto Protocol (1997). CFC gases with extremely high GWP values have been released into the atmosphere over the exceptions [10],[11]. Natural refrigerants were first used in early refrigeration history (1800), but in 1929, synthetic refrigerants with better thermal performance, safety, and durability took their place. Chlorofluorocarbons (CFCs), a type of synthetic refrigerant, were prohibited by the 1987 Montreal Protocol because it was discovered that they depleted the stratosphere's ozone layer. In the 1980s, hydro fluorocarbons (HFCs) and hydro chlorofluorocarbons (HCFCs) were suggested as alternatives. It has been shown that HCFCs deplete the ozone layer and have a last 80 years, and to make matters worse, they have a lengthy half-life. The most common refrigerant, R12, for instance, has a lifetime of 102 years and a GWP of 10,300 (UNEP 2014). We are surrounded by these and other CFC gases, and although their percentage was estimated to be around 15% in 1990, their chemical stability still plays a significant role—certainly greater than that of HFC gases. Furthermore, it is a reality that certain developing nations continue to emit CFC chemicals into the atmosphere despite the fact that doing so is prohibited[8], [12] .

In order to mitigate the human impact on climate change, current research is shifting toward natural and low-GWP refrigerants[13][14].

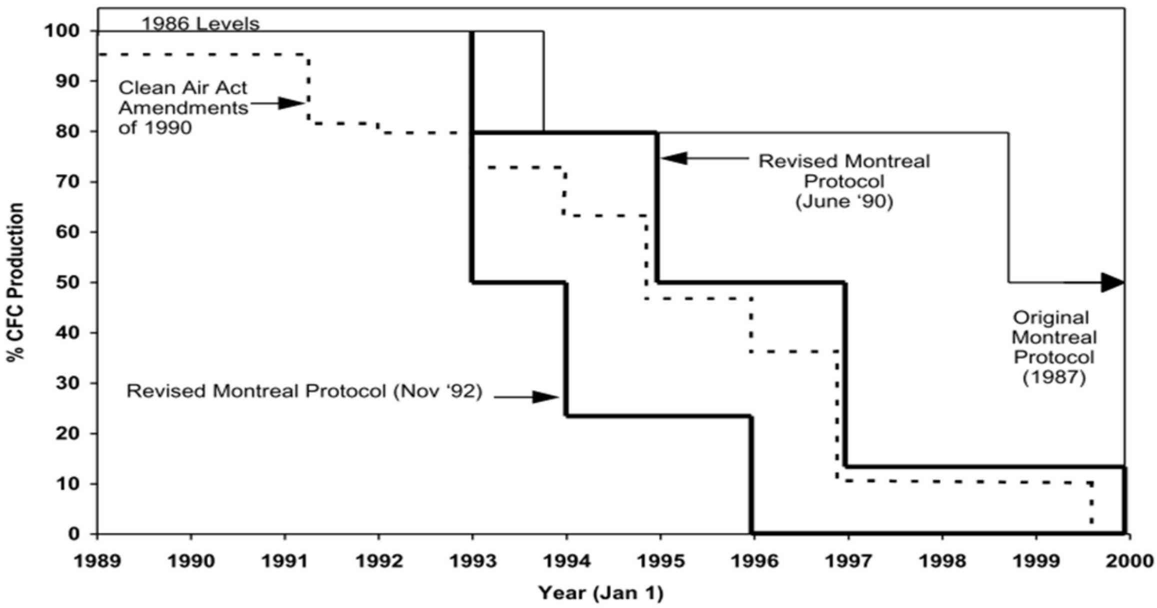


Fig. 1 Overview of CFC Phase Out in history [8].

(1987) Montreal Protocol.

(1992) UNFCCC (United Nations Framework Convention on Climate Change).

(1997) Kyoto Protocol (HFCs under control) 2007: Acceleration of HCFC phase-out (Montreal Protocol).

Climate friendly actions to be taken account (2015) Paris agreement on climate change accepted.

(2016) Kigali amendment to the Montreal Protocol ; HFCs phase-down Introduction of HFOs (unsaturated HFCs)[15][16] .

2 Combined power plant and Refrigeration sector

The primary goal of this article was to address the needs of combined cooling, heating, and power (CCHP). the sustainability and possibility of combining several cooling and desalination methods with solar-biomass hybrid power generation. This study was conducted in Indian. Polygeneration's function as a distributed, sustainable energy source[17]. The primary goal of this article was to address the needs of combined cooling, heating, and power CCHP[18], [19]. methods for generating several utilities in a distributed manner [20]. The potential and sustainability of solar-biomass hybrid power generation combined with several cooling[21].

2.1 Comparision of Energy scenario in power plant and Refrigeration sector.

Residential and commercial water heating is the fourth largest energy end use in households, accounting for around 10% of all residential and commercial site energy usage in the US. According to Fig. 2, water heating used between 15% and 20% of residential energy in both OEDC and non-OEDC countries worldwide in 2015 [22]. Globally, space heating demand in urban areas is the single-largest building end use, while cooking and water heating are still a large share of energy demand [4].

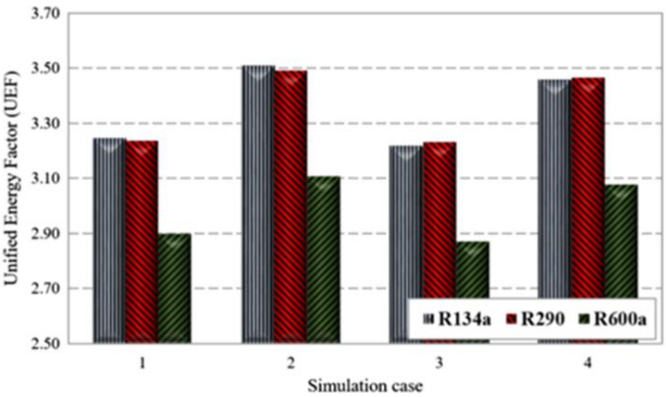


Fig. 2 . Last uses of residential power consumption in OECD and non-OECD countries[4] .

When tank insulation is 95% effective, the UEF is greater. However, as can be seen from the results in Fig. 3, the condenser wrap pattern has no discernible effect. R600a has the lowest UEF, while R134a and R290 have similar values [23].

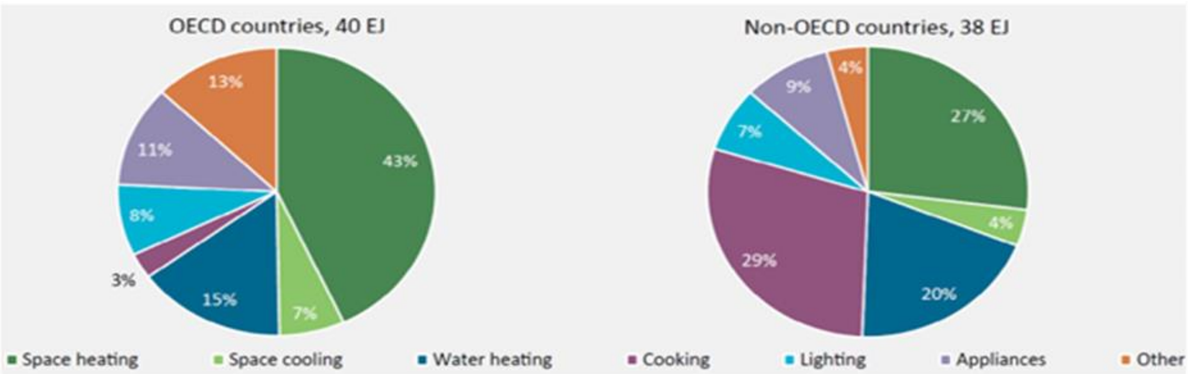
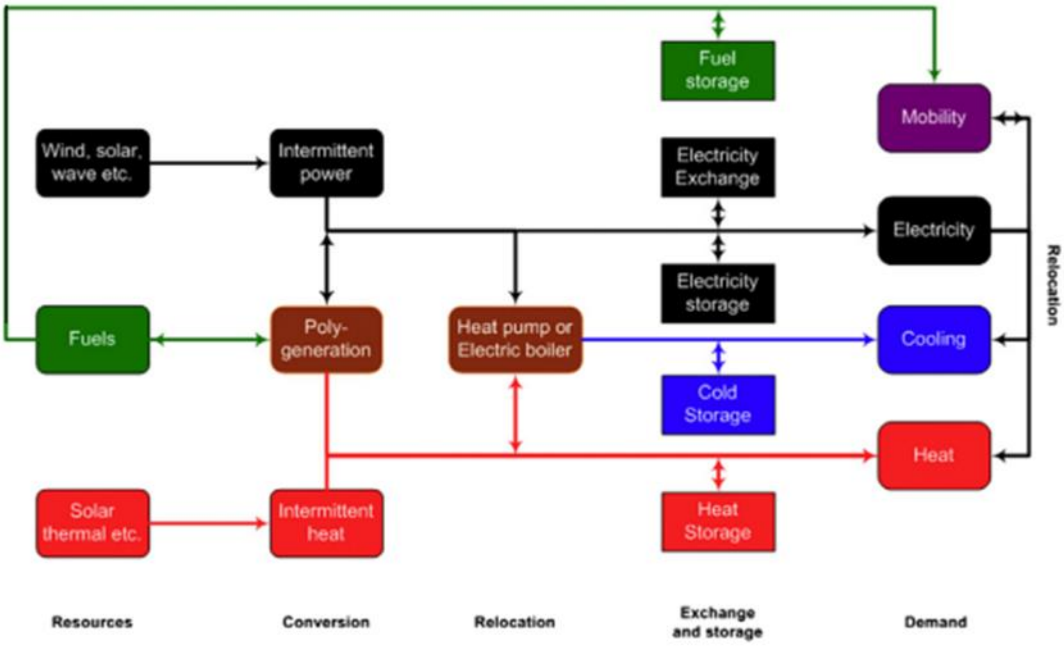


Fig. 3 . Unified energy factor for different refrigerants with varying design options [23].

The geometry of the temperature–entropy (T–S) phase border determines the route a refrigerant takes within the heat pump cycle as it crosses the saturation phase boundary and ultimately affects cycle performance and equipment. In order to screen refrigerants—particularly low GWP candidates—for the upcoming generation of ecologically friendly fluids, the phase boundary offers helpful information. Given the increased interest in natural and low-GWP refrigerants, it is illuminating and informative to evaluate these fluids for application in heat pumps and refrigeration cycles using the saturation phase boundary characteristics (Morrison, 1994)[24].

2.2 Strategies for an intermittency-friendly energy system for both power plant and refrigeration sector

Highlights the core technological elements of the energy system that is compatible with intermittent power. Heat pumps and poly-generation seem to be key components. Poly-generation, or multi-generation, refers to the evolution of cogeneration and trigeneration into supplying additional outputs such as hydrogen, ethanol, or other chemical compounds utilized in certain processes. Heat pumps, on the other hand, make it possible for energy carriers to couple by producing heat and/or cooling using electricity, which may then be subject to thermal storage. This helps to balance the supply of power by integrating intermittent renewables into the delivery of heating and cooling services while lessening the strain on poly-generators [24].



. **Fig.4** The intermittency energy friendly scenario[24] .

Cross-system interchange via transnational cabling in relation to the Super Grid is the dominant implementation strategy in Denmark and the EU. The European Commission has approved an energy infrastructure plan for 2020 that supports this policy by estimating that 200 billion euros will be needed to invest in transmission networks, primarily high voltage transmission lines.

By facilitating a more intermittency-friendly mode of operation, distributed cogenerators can more effectively coexist with intermittent renewable energy sources. Reductions in emissions and a decreased reliance on fossil fuels are among the anticipated advantages of the energy system. Other advantages include increased support for distributed and local energy solutions, power system dependability, and lower operating costs in distributed generation.

Initiatives focused on the smart grid to boost intermittent renewable energy systems penetration rates. The possibilities are examined within West Denmark's paradigmatic framework[24] . The ocean thermal energy conversion (OTEC) system, also known as the Kalina cycle, is the basis for the proposed combined power and refrigeration cycle. Solar energy is used in this coupled cycle to increase the temperature of the heat source. The ejector refrigeration cycle (ERC), which uses the exhaust heat taken from the turbine in the Kalina cycle, simultaneously generates cooling capacity. The ERC uses isobutane as its working fluid, while the Kalina cycle uses ammonia-water. The proposed cycle, which is a suitable combination of the Kalina cycle and ejector refrigeration cycle (ERC), is schematically shown in Fig.5. It uses OTEC technology to simultaneously create power and refrigeration. In the Kalina cycle, it is evident that the refrigeration cycle works by absorbing the heat emitted by the turbine's exhaust gas[25]. Some techniques have been used to raise the seawater's temperature. A Rankine solar system that integrated solar energy and warm seawater was proposed by Faming Sun. OTEC system-assisted solar energy was examined by Hakan Aydin et al. Two approaches were taken into consideration: first, the surface saltwater was immediately heated by solar radiation, and second, the working fluid was superheated before it entered the turbine. According to their findings, the relative net power generation might rise by 20–25% using either approach. To increase the system's overall performance, U. Sahoo et al. incorporated solar and biomass energy sources into their work[26] .

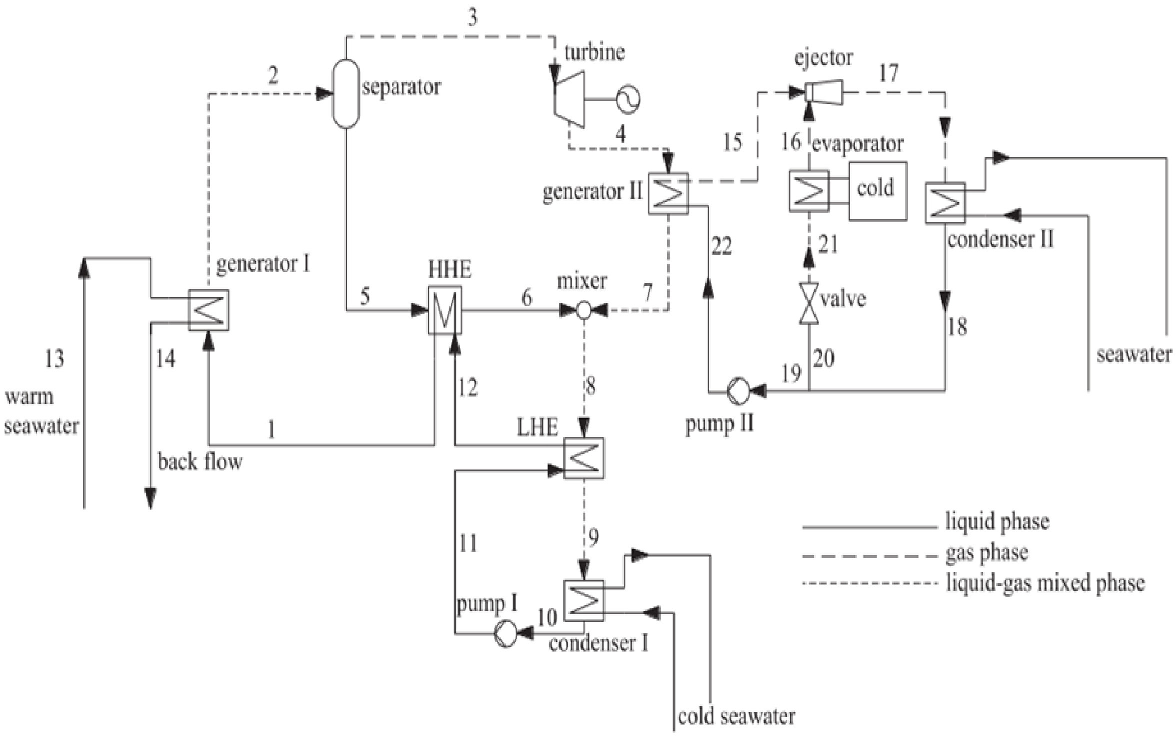


Fig. 5 Line diagram of the combined cycle [25].

Hybrid solar thermal power plant's polygeneration process (energy & exergy) for combined electricity, cooling, and desalination is created to meet the energy demand from renewable energy sources. The system's performance is examined in Fig. 6. It is a technique for producing energy of the future generation that has the ability to overcome the intermittent nature of renewable energy [26]. In order to meet power requirements, solar thermal power plant (STPP) hybridization is crucial. One alternative for helping with partial and full load energy requirements during periods of low or no sunshine is biomass, which can be supplemented seasonally [27]. In various Indian states, more than 500 million tons (MT) of biomass are produced annually. Biomass heat drives in brief bursts during the day and at night to produce steady power, while solar thermal technology powers the thermal power system during the hours of greatest sunshine[26]. In many sectors, the polygeneration process offers enormous potential for integrated power, cooling, and process

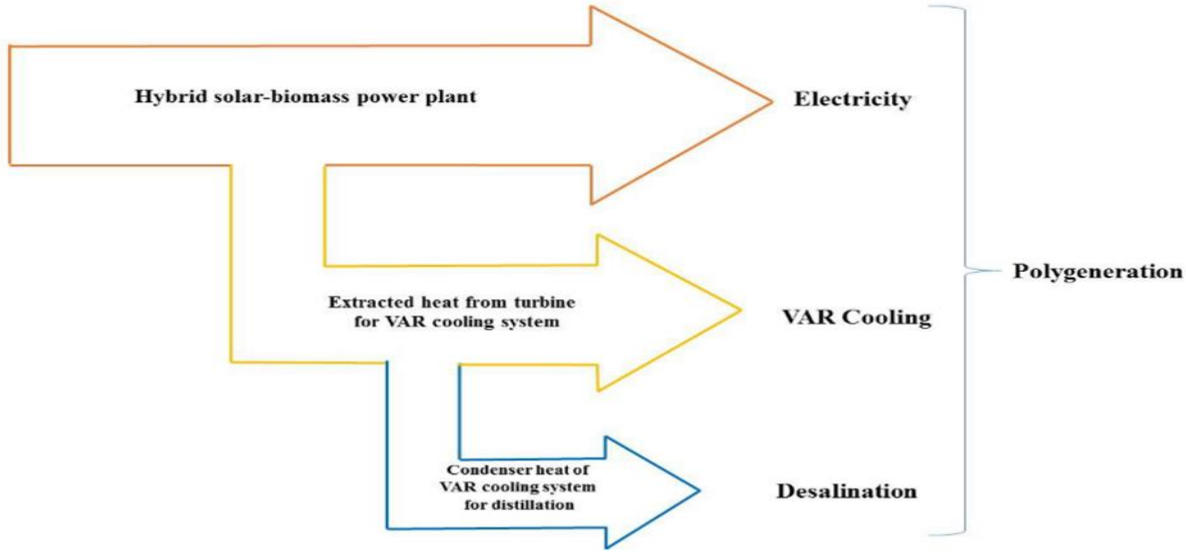


Fig. 6 Line diagram of cooling system with process heat methods[26].

Figure 7, illustrates how fuel energy can be used to power the power producing system. Simultaneously, the waste is released into the environment as hot water waste, exhaust gasses, etc. Furthermore, as illustrated in Figure 8, the cogeneration plant generates electric heat and utility, and as illustrated in Figure 9, the plant's product is a truthful factory. These outputs include cooling, energy, and heating. As seen in Figure 10, production outcomes from multiple utilities from a single facility or from multiple resources might be referred to as polygenerational or multigenerational [27].

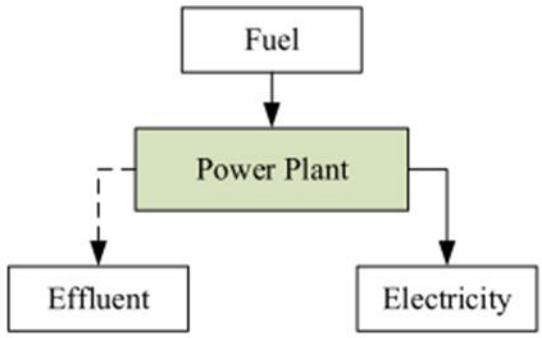


Fig. 7 Line diagram of Simple power plant .

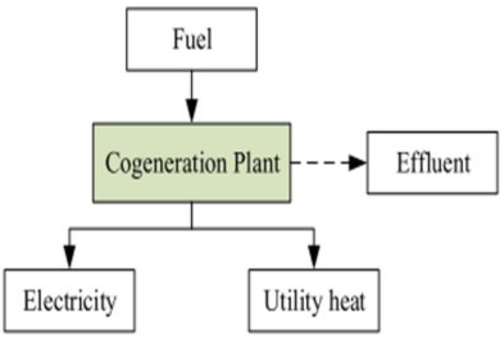


Fig. 8 Line diagram of Cogeneration plant.

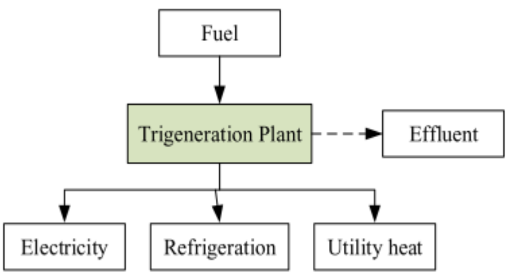


Fig. 9 Line diagram of Trigeneration plant .

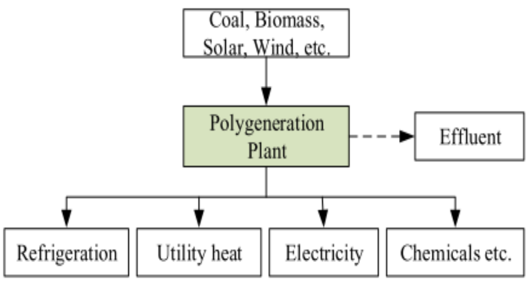


Fig. 10 Line diagram of Polygeneration Plant.

2.3 Type of Fuel used for Polygeneration

Although renewable-based polygeneration has a higher capacity, polygeneration plant design has so far solely addressed the usage of coal [17]. Because polygeneration produces the intended results, it has been selected and applied in certain situations. The term "inputs" refers to the process of producing liquid fuels that utilize coal or biomass as an input [28]. Furthermore, some inputs, as those in [29], A hybrid solar thermal power plant's polygeneration process (energy & exergy) for combined power, cooling, and desalination is created to meet the energy demand from renewable energy sources. The system's performance is examined in Fig. 11. It is a technique for producing energy of the future generation that has the ability to overcome the intermittent nature of renewable energy. This technology can deliver electricity with reduced impact on environment compare to conventional fossil fuel based power generating system. It could increase network efficiency and provide electricity to a sizable portion of the population. Expanding the use of this cutting-edge system also improves a country's energy security [27][26].

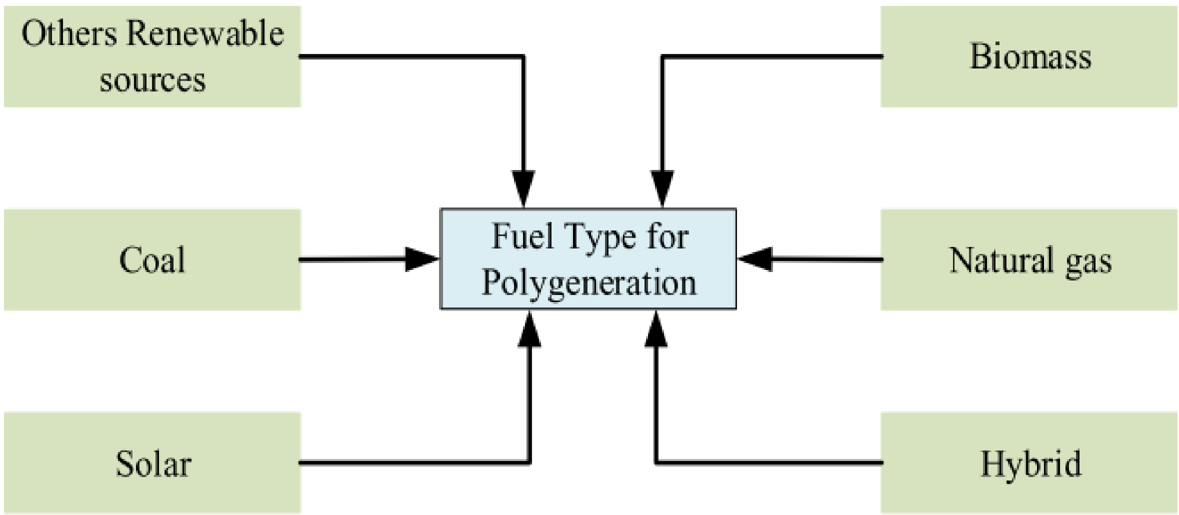


Fig. 11 Type of Fuel for Polygeneration[26].

A polygeneration's fuel inputs might vary greatly. The majority of the input energy sources for decentralized plants are accessible locally . Nevertheless, centralized polygeneration plants have a larger capacity than polygeneration based on renewable energy and are primarily coal-based . In certain situations, the input or inputs of a polygeneration are chosen according on the intended outputs[1].

2.3.1 Biofuel based Polygeneration

As an alternative to coal, solar energy, and other energy sources, methanol made from biomass is very suitable for use in polygeneration. A study by has been conducted on the manufacturing of methanol for polygeneration. Nonetheless, the study is a coal-based polygeneration system designed to generate power and methanol. The use of natural gas-based polygeneration systems to produce electricity and methanol from renewable energy sources has also been assessed. According to their study's findings, the new system can save roughly 6% more energy than a system that just uses one product [30][31]. In order to address the issues with the energy system and the chemical production process, polygeneration systems—which combine the processes of chemical manufacturing and power generation—are currently viewed as one promising trend [1,2]. Compared to single product systems, polygeneration systems with several outputs offer greater flexibility in system integration, potentially leading to additional options for increased efficiency and reduced environmental consequences. A number of programs, such as "Vision 21" and "Syngas Park," take serious issues. With syngas from coal, natural gas, coke, heavy oil, or biomass, polygeneration systems—which can be utilised [32].

2.3.2 Solar assisted cogeneration power plant

The suggested polygeneration plant, depicted in Fig. 12, may produce cooling, energy, and drinkable water by connecting a solar power system (SPS) to a Multi-Effect Distillation (MED) unit and an Absorption Refrigeration

System (ARS). Both steam and solar field Rankine cycles (SRC) are part of the SPS unit. Because it can stay in the liquid phase up to 400 degrees Celsius, thermal oil (Therminol-VP1) is utilized as the working fluid for the solar field loop [33].

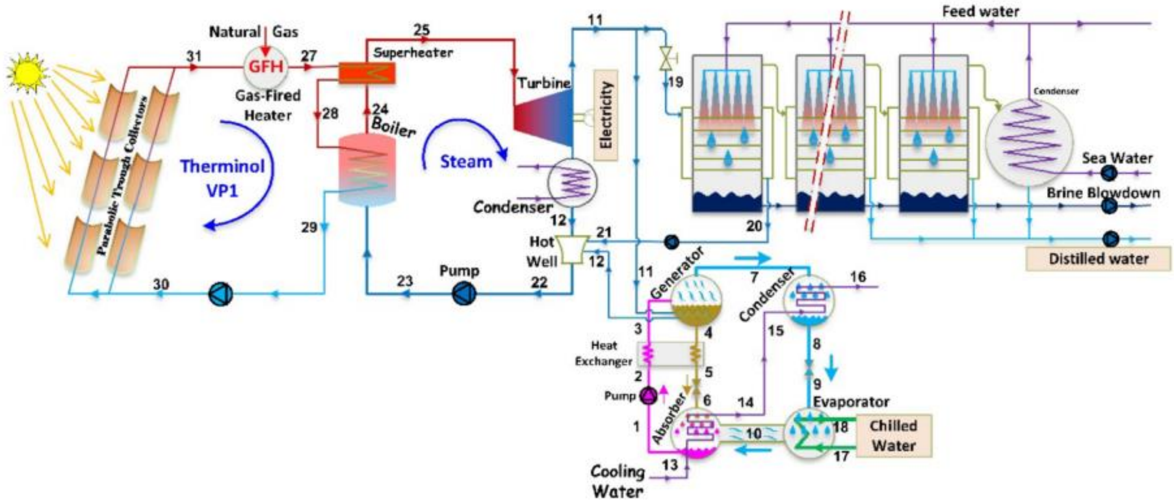


Fig. 12 Layout of the hybrid SPS - ARS - MED system[21]

3 Methodology

A techno-economic analysis of a novel process to co-produce ethylene and electricity using a recently developed methane oxidative coupling catalyst is presented. Several design variants are considered, featuring the use of traditional gas turbines, chemical looping combustion, and 100% carbon dioxide capture. Mass and energy balance simulations were carried out using Aspen Plus simulations, and particle swarm optimization was used to determine the optimal process design under a variety of market scenarios. The simplified schematic of this process is shown in Fig. 14. It consists mainly of six sub-sections: direct ethylene synthesis from shale gas using an OCM

$$2CH_4 + 0.5O_2 \longrightarrow C_2H_6 + H_2O$$

$$C_2H_6 + 0.5O_2 \longrightarrow C_2H_4 + H_2O$$

$$C_2H_6 \longrightarrow C_2H_4 + H_2$$

$$CH_4 + 1.5O_2 \longrightarrow CO + 2H_2O$$

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

$$CO + H_2O \longrightarrow CO_2 + H_2$$

reactor, compression, CO2 removal, prod- uct recovery (a demethanizer and C2 splitter), power generation, and CO2 compression (optional). The OCM reactor is a gaseous flu- idized bed reactor that uses a La2O3 (27 wt.%)/CaO (73 wt.%) cata- lyst at about 800 °C. The contact time (mass of catalyst divided by volumetric gas flow rate) should be also less than 250 kg s/ m3) . The main OCM reactions and side reactions over the La2O3/CaO catalyst at 750– 900 °C are as follows, noting that (C2H6) and ethylene (C2H4) are the primary components[30].

The most crucial factor influencing the reactor's selectivity and conversion is the ratio of inlet methane to oxygen; increasing the CH4/O2 ratio promotes the production of ethylene by increasing the catalyst selectivity while decreasing the conversion rate; hence, this ratio should be chosen to maximize net present value[34] .

Basis for shale gas Even while shale gas and conventional gases typically have comparable compositions, they are not the same and differ not just across various wells in the same area but also between distinct areas. Typical composition ranges of six shale gas reservoirs. Because it contains the most methane, the Fayetteville shale is most suited for this process. Despite having a high ethane content, the shale gases from Haynesville, Marcellus, and New Albany might still work well for the OCM process. However, the presence of N2 will reduce the amount of unreacted gases recycled to the OCM reactor, lowering its potential yield[35][36].

$$C_mH_n + [(4m+n)/2]NiO \rightarrow mCO_2 + n/2H_2O + [(4m+n)/2]Ni$$

$$CO + NiO \rightarrow CO_2 + Ni$$

$$H_2 + NiO \rightarrow H_2O + Ni$$

The main reaction for the air reactor is:

$$Ni + 1/2O_2 \rightarrow NiO$$

The air and fuel reactors were modelled in Aspen Plus using standard RGIBBS reactor models, as explained by Fan, because there was a dearth of published kinetic data. Both of these reactors did not require any external heat. The design of the CO2 compression and liquefaction portion is based on a method that Adams and Barton[37] devised. This method separates water, condenses CO2, and pumps it to 153 bar (supercritical pressure) using a multi-stage compression and a sequence of cascading flash drums. For those process units, simulations were conducted using standard Aspen Plus models; for further information, the reader is directed to the source reference. Optimization Each process was subject to optimization considering two degrees of freedom: (i) the inlet molar ratio of methane to oxygen routed to the OCM reactor (CH4/O2 of stream 4 shown in Fig.13 with feasibility bounds between 2 and 8 based on and (ii) the recycle ratio of unreacted gas to OCM reactor (with bounds between 0% and 100%) as identified in Fig.13. A "coarse grain exhaustive search" approach was employed, which involved equally spaced combinations of the decision variables, due to the fact that there were only two. It was visually clear that there was only one local optimum in each case examined, and this 1440 simulations were trial based taken[37].

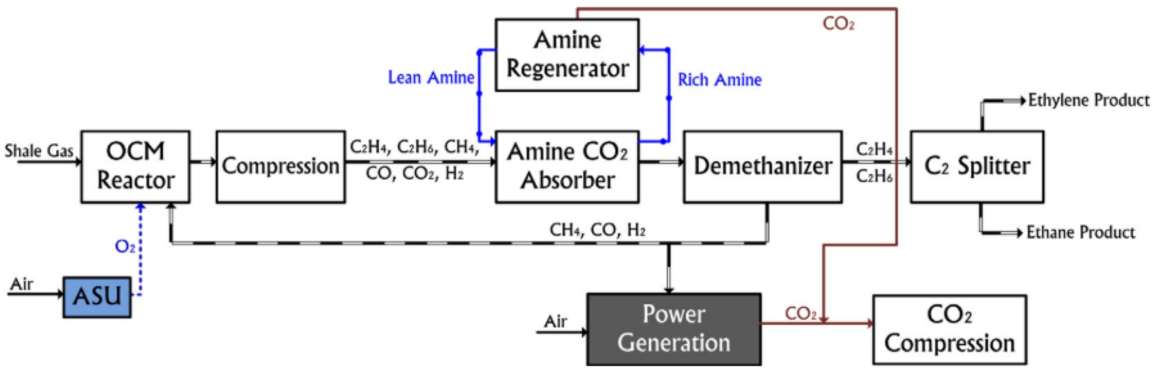


Fig.13 OCM polygeneration process[30].

3.1 Exergy analysis

The majority of thermal systems have been concerned with energy efficiency in order to increase system efficiency [11–13]. This paper analyzes the energy destruction by utilizing the REFPROP database to perform thermodynamic properties of refrigerant [14]. Fig. 14 shows the refrigeration system scheme employed in this study [11].

Using a cascade condenser, HTC and LTC are integrated into a single system. Heat (Qc) is discharged into the atmosphere by the condenser at temperature Tc after heat (Qe) from the chilled area is absorbed by the evaporator at temperature Te. Tme is the temperature at which C3H8 evaporates, and Tmc is the temperature at which the mixture of C2H6 and CO2 condenses.

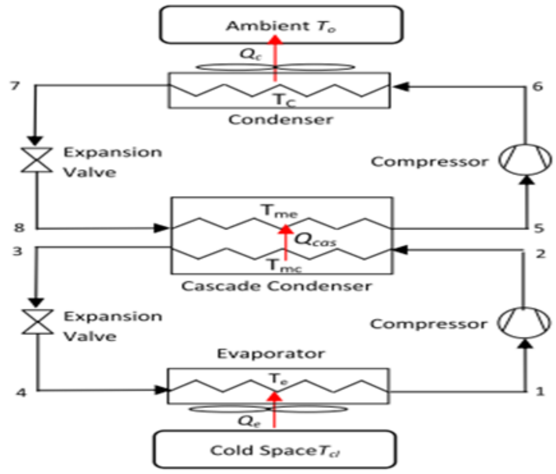


Fig.14 Flow diagram of cascade refrigeration system.

Table 1
Calculation of exergy and thermodynamics analysis.

Component	Mass	Energy	Exergy destruction
HTC			
Compressor	$\dot{m}_6 = \dot{m}_5$	$\dot{W}_H = \frac{\dot{m}_5(h_6-h_5)}{\eta_H}$	$\dot{X}_{des} = \dot{W}_H - \dot{m}_5(\psi_6 - \psi_5)$
Condenser	$\dot{m}_7 = \dot{m}_6$	$\dot{Q}_c = \dot{m}_7(h_6 - h_7)$	$\dot{X}_{des} = \dot{m}_7(\psi_6 - \psi_7) - \left[1 - \frac{T_{amb}}{T_0}\right]\dot{Q}_c$
Expansion valve	$\dot{m}_8 = \dot{m}_7$	$h_8 = h_7$	$\dot{X}_{des} = \dot{m}_8(\psi_7 - \psi_8)$
Cascade condenser	$\dot{m}_5 = \dot{m}_8$ $\dot{m}_3 = \dot{m}_2$	$\dot{Q}_{cas} = \dot{m}_3(h_2 - h_3)$ $= \dot{m}_5(h_5 - h_8)$	$\dot{X}_{des} = \dot{m}_5(\psi_8 - \psi_5) - \dot{m}_3(\psi_3 - \psi_2)$
LTC			
Compressor	$\dot{m}_2 = \dot{m}_1$	$\dot{W}_L = \frac{\dot{m}_1(h_2-h_1)}{\eta_L}$	$\dot{X}_{des} = \dot{W}_L - \dot{m}_1(\psi_2 - \psi_1)$
Evaporator	$\dot{m}_1 = \dot{m}_4$	$\dot{Q}_c = \dot{m}_7(h_1 - h_4)$	$\dot{X}_{des} = \dot{m}_1(\psi_4 - \psi_1) + \left[1 - \frac{T_{amb}}{T_d}\right]\dot{Q}_E$
Expansion valve	$\dot{m}_4 = \dot{m}_3$	$h_4 = h_3$	$\dot{X}_{des} = \dot{m}_4(\psi_3 - \psi_4)$

Energy and mass balance equations from Table 1[38]were used to model the thermodynamics and characteristics of the transformation the refrigerant achieved.The pressure ratio of the refrigerant that flows through the compressor affects the efficiency of the HTC compressor (Eq. (1)) and the LTC compressor (Eq. (2)) [10]. Isentropic Efficiency for HTC compressor is equal to

$$\eta = 1 - \frac{\dot{X}_{des,total}}{\dot{X}_{in}} \qquad h_b = F(1-x)^{0.8}\frac{Nu\ k}{d_i}$$

$$h_c = 0.023\frac{k}{d_i}Re^{0.8}Pr^{0.4}\left[(1-x)^{0.8} + \frac{3.8x^{0.76}(1-x)^{0.04}}{(P_{sat}/P_{cr})^{0.38}}\right]$$

3.1.1 Heat exchanger design It is believed that the refrigerant going through the condenser and evaporator is in a two-phase flow configuration. The Chen and Shah equation, which may

be stated as above Eq., is used to calculate the heat transfer coefficient of two-phase flow for boiling(hb). Furthermore, the Shah and Kandlikar approach Eq. is used to estimate the heat transfer coefficient (hc) for condensing processes.
Heat exchanger specifications used in this simulation are shown in Tables 2 and 3 ,4 [7][39].

Table 2
Specifications of compact heat exchanger in the evaporator and condenser.

Specifications	Evaporator	Condenser
Length of pass (m)	0.35	1
Lateral pitch (m)	0.02	0.02
Longitudinal pitch (m)	0.057	0.057
Air inlet density (kg/m^3)	1.547	1.147
Air outlet density (kg/m^3)	1.582	1.124
Outlet diameter tube (m)	0.0159	0.0217
Tube thickness (m)	0.889	0.889
Free flow area/frontal area	0.057	0.057
Hydraulic diameter	0.00484	0.00484
Fin density (fin/m)	354	354
Fin thickness (in)	0.012	0.012
Inlet air viscocity (Pa s)	1.8462×10^{-5}	1.569×10^{-5}
Outlet air viscocity (Pa s)	1.569×10^{-5}	1.8462×10^{-5}
Thermal conductivity of tube (W/m K)	389	52

The goal of the study is to ascertain the ideal operating temperature and CO2 fraction to create a system that is optimal from an economic and thermodynamic standpoint. The system's overall cost and energy consumption should be kept to a minimum in order to maximize its performance[14].

Table 3
Specifications of shell and tube heat exchanger in cascade condenser.

Specification	Cascade condenser
Outlet diameter of tube (m)	0.025
Tube thickness (m)	0.00165
Entrance diameter of shell (m)	0.0195
Number of tubes	16
Number of passes	2
Shell diameter (m)	0.2
Baffle spacing(m)	0.35
Square pitch (m)	0.0254
Thermal conductivity of tube (W/m K)	52

4 Results and discussion

The relationship between the system's overall cost and energy destruction is depicted in Fig. 15. The multi-objective optimization result is Pareto optimum. The system's COP is expressed through energy destruction. A low COP is indicated by high exergy destruction. More energy destruction results in a reduced system total cost, as seen in Fig. 15. The outcomes of an optimal system based on economics and thermodynamics are displayed in Table 4 and 5's multi-objective optimization results. The maximum COP system can be obtained from a single objective optimization of the system thermodynamic transformations[6][40].

Table 4
Constraints of the system.

Cooling capacity	40 kW
Ambient temperature	25 °C
Cold space temperature	−45 °C
Air inlet temperature on evaporator	−42 °C
Air outlet temperature on evaporator	−47 °C
Air inlet temperature on condenser	25 °C
Air outlet temperature on condenser	30 °C
Operating period	15 years
Period of operation per year	6570 h
Annual interest rate	8%
Electricity cost	0.07$/kW h

Table 5
Result of multi-objective optimization.

	Thermodynamics	Multi-objective	Economics
Optimized parameter			
T_e (°C)	−48	−49	−49.91
T_c (°C)	56	56	56
T_{mc} (°C)	−9.95	−9.96	−9.99
ΔT (°C)	3	3.37	4.68
CO_2 fraction	0.68	0.68	0.67
System			
COP	0.82	0.79	0.79
Evaporator area (m^2)	71.12	47.39	47.38
Condenser area (m^2)	18.62	18.96	18.96
Cascade condenser area (m^2)	127	113.93	113.88
Compressor power HTC (W)	31382.62	31966.37	31967.16
Compressor power LTC (W)	17444.07	18543.74	18545.26
Exergy destruction			
Ex. des condenser (W)	11092.24	11297.15	11297.43
Ex. des cascade condenser (W)	2230.19	2495.92	2487.27
Ex. des evaporator (W)	1285.83	1524.32	1527.76
Ex. des compressor HTC (W)	8529.71	8689.33	8689.54
Ex. des compressor LTC (W)	6891.91	7431.59	7432.82
Ex. des expansion valve HTC (W)	7036.82	7168.65	7168.82
Ex. des expansion valve LTC (W)	2809.35	3002.79	3008.47
Total Ex destruction (W)	39876.04	41609.75	41612.13
Component cost			
$C_{comp\ HTC}$ ($)	37876.7	38956.95	38958.42
$C_{comp\ LTC}$ ($)	46972.29	47372.2	47372.74
C_c ($)	20212.91	20536.46	20536.91
C_e ($)	62568.44	43721.23	43717.59
C_{cas} ($)	64223.85	59649.86	59634.17
Total annual cost ($)	51070.59	49342.36	49341.49

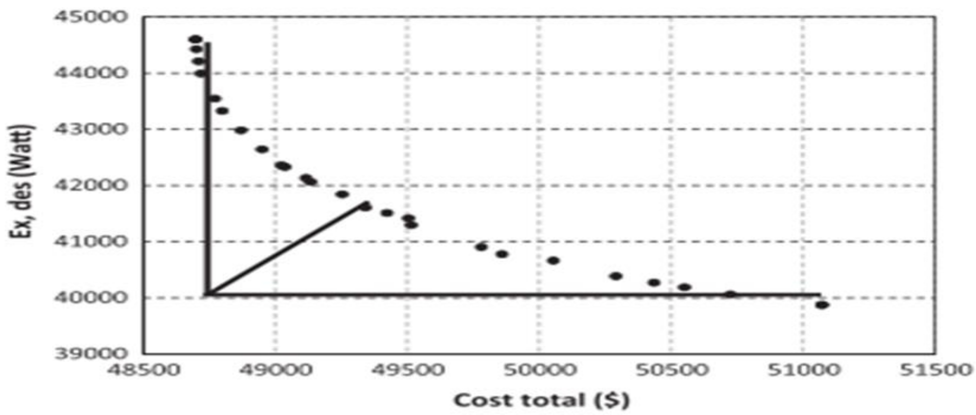


Fig.15 Multi-objective optimization result[38].

A cascade vapor refrigeration system comprising two singlestage systems and heat exchan

er was part of the experimental setup.
In LTS, one of the two refrigerants served as a working medium, while the other was utilized in HTS.Fig. 16 dis plays the schematic circuit design of an experimental setup for cascade refrigeration [40]. The best refrigerant is chosen based on consideration of the compressor work,

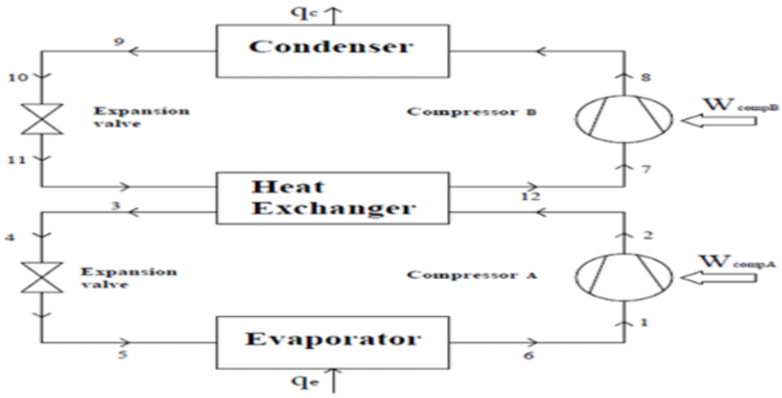


Fig.16 Line diagram of a Cascade refrigeration[40].

rate of flow, and coefficient of performance. The combined action of both refrigerants was responsible for the compressors increased output[39][40]. In results many conclusions were obtained in which one of the result was Coefficient of performance decreases with rise in temperature for different refrigerants[25].

5 Conclusion

As hydro chlorofluorocarbons are phased out and replacement of refrigerants has been done. A better understanding of refrigerant discrimination required both an energy and exergy analysis of potential cycles has been considered. There was less error between the results obtained from our study of newly designed setup conditions and those from manufacturer's data and tables. In Cogeneration and polygeneration some of the triggers was employed as sustainable solutions, enabling the most economical, effective, and ecologically friendly use of resources. Since the working system has been well welcomed theoretically, as reported in certain publications, polygeneration can be imagined in a variety of ways. Waste heat from many power plants was used in boiler of Ammonia absorption refrigeration system in Cogeneration power plants. Analytical modelling and simulation results underscore the potential for substantial reductions in primary fuel consumption and operational carbon footprint. The study also explores innovative configurations utilizing waste heat recovery and renewable energy augmentation to bolster system resilience and sustainability metrics. Findings affirm that such integrated systems not only align with global decarbonisation objectives but also offer a compelling value proposition for next-generation smart energy infrastructures. This work aims to serve as a blueprint for industry stakeholders seeking to future-proof their operations through sustainable technological convergence.

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