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Trigeneration: an alternative process for energy savings

Aims and Objectives

With the increasing need for energy, there is a growing concern about its over-use and its impacts on the environment and natural resources. As a result, there is a vivid interest in finding alternative and sustainable energy sources as well as improving the efficiency of energy producing systems. While the debate on the net benefits of alternative energy sources on environment continues between many governments and industrialists, there seems to be no disagreement on developing energy efficient and sustainable energy systems to conserve depleting energy resources. This is the aim of this study, and more specific the investigation of trigeneration as a solution in global environmental pollution and the reduction of carbon dioxide emissions. The performance of energy utilizing systems plays a vital role in the consumption of energy as well as in the emissions of hazardous pollutants. The objective is the increase of the efficiency for the produced power. Through trigeneration the lost in the form of heat in the atmosphere are minimal and the percentages of fuel energy that can be converted into usable forms are very large in comparison with other conventional power plants. It seems to be a very attractive technology and the subject will be examined in an extensive point.

Background and Literature review

Curing the problems associated with inefficient electrical power generation begins with pollution prevention. The choices are clear, we must stop wasting energy and start increasing the efficiency of power generation facilities. Instead of building inefficient, wasteful, pollution-generating central power plants owned by utility companies, where the thermal energy is wasted, we need to start building efficient, onsite power plants where the heat energy can be utilized. These onsite cogeneration, trigeneration and quadgeneration power and energy systems are also referred to as "distributed generation" or "distributed energy" technologies. They can be installed easily, affordably and they operate economically throughout their life-cycle[5]. Trigeneration is an energy and power production technology that takes cogeneration one additional step. Cogeneration, also known as combined heat and power (CHP), is the simultaneous production of electricity and useful heat, usually in the form of either hot water or steam, from one primary fuel, such as natural gas. While not necessarily defined correctly, cogeneration has also been referred to as district energy, total energy, combined cycle and simply cogen. Cogeneration has been mostly a technology used in the industrial marketplace where these customers primarily require steam and power[6].

By ever-increasing numbers, more and more commercial, industrial and utility companies and businesses are seeking ways to use energy more efficiently. This is a direct result of dramatically increasing electric and natural gas rates, decreased power reliability (black-outs, brown-outs, rolling black-outs and other power interruptions) as well as competitive and economic pressures to cut expenses, increase air quality, and reduce emissions of air pollutants and greenhouse gasses. The Kyoto Protocol placed strict terms on the protection of planet. In Europe trigeneration is becoming a preferred method to produce a company's, building or facility's power and energy requirements[7]. Trigeneration is also providing a strategic competitive advantage for those companies who install an onsite trigeneration system. Another reason more companies are considering trigeneration is the ever-increasing expense of natural gas – which behoves commercial, industrial and even utility customers to extract as many of the available BTU's as possible[8].

When a trigeneration energy and power system is installed onsite, the electrical and thermal energy is needed by the customer, so that the electrical energy does not have to be transported hundreds of miles away, and the thermal energy is utilized, system efficiencies can reach and surpass 90%[9]. Onsite trigeneration plants are much more efficient, economically-sound and environmentally-friendly than typical (central) power plants. Because of this, customers have energy expenses that are significantly lower, and the associated pollution is also much less than if the customer had an energy system supplied with electricity from the grid, and had water heaters and boilers systems onsite. Trigeneration's superior efficiencies surpass even the latest state-of-the-art combined cycle cogeneration power plants by up to 50%[10]. Coupled with a 4-pipe system, these businesses can produce hot water/steam and chilled water simultaneously, for circulation throughout the building or campus – which would be referred to as a district energy system.

And size is not an impediment, since trigeneration systems can be installed, for example, in small commercial settings, such as restaurants, hotels, schools, office buildings and shopping centers to large petro-chemical plants, refineries and in a city's downtown area, providing the energy requirements for multiple buildings and still remaining at system efficiencies of 90%[11]. Trigeneration or trigen is the simultaneous production of mechanical power (often converted to electricity), heat and cooling from a single heat source such as fuel or solar energy. As with cogeneration, the "waste heat" byproduct that results from power generation is harnessed, thus increasing the overall efficiency of the system[12]. Usually space heating and hot water storage tanks serve as a heat sink for reasonable waste heat utilization. In summer, the heat demand is much lower but the heat of the electric generation process can be transformed into cooling energy by an absorption chiller. Trigeneration is sometimes referred to as *CCHP* (combined cooling, heating, and power generation)[13]. Conventional thermoelectric stations convert only about 1/3 of the fuel energy into electricity. The rest is lost in the form of heat. The adverse effect to the environment from this waste suggests a need to increase the efficiency of electricity production.

Across the world, there is a new emphasis on projects that combine climate protection and economical primary power generation. Absorption chiller technology represents an optimal solution for a year-round efficient source of cooling and heat, especially when used in conjunction with a gas engine cogeneration plant[14]. Trigeneration power plants, at up to 90% efficiency, are almost 300% more efficient at producing power than electric utility power plants. This means that Trigeneration power plants have a significantly greater return on investment and significantly fewer emissions compared to typical power plants[15]. Furthermore, when the Trigeneration power plants are fuelled with Biomethane or B100 Biodiesel, the emissions are reduced by about 95% and those that remain are "carbon neutral"[6]. One method for more efficient production of electricity is the Cogeneration of Heat and Power, where more than 4/5 of the fuels energy is converted in usable energy, resulting in both financial and environmental benefits.

Trigeneration, when compared to (combined-cycle) cogeneration, may be up to 50% more efficient than cogeneration. When found in a hospital, university, office-campus, military base, downtown or group of office buildings, trigeneration has also been referred to as a "district energy system" or "integrated energy system" and as previously mentioned, can be dramatically more efficient and environmentally friendly than cogeneration[17]. A trigeneration plant, defined in non-engineering terminology, is most often described as a cogeneration plant that has added absorption chillers - which takes the waste heat a cogeneration plant would have wasted, and converts this free energy that would have been wasted by cogeneration, into useful energy in the form of chilled water[6].

Since many industries and commercial buildings need combined power and heating and cooling, trigeneration plants have very high potentials for industrial and commercial application - with the associated energy and economic savings inherent with trigeneration. Trigeneration systems provide a solid basis for moving a potential renewable energy project forward. The cost for this depends on the type, location, amount of time we require, and any additional requirements that may be included by the owner-consumer[18]. Trigeneration can be considered as a special case of the application of cogeneration systems where a fraction of the shaft work or residual heat is used for running a refrigeration system. This work focused on trigeneration schemes where the turbine is used as a prime mover for power production and cooling is generated by a typical compression-refrigeration system. The turbine also could meet the heating needs, but it is unlikely that both cooling and heating would be satisfied simultaneously in the most efficient manner[19].

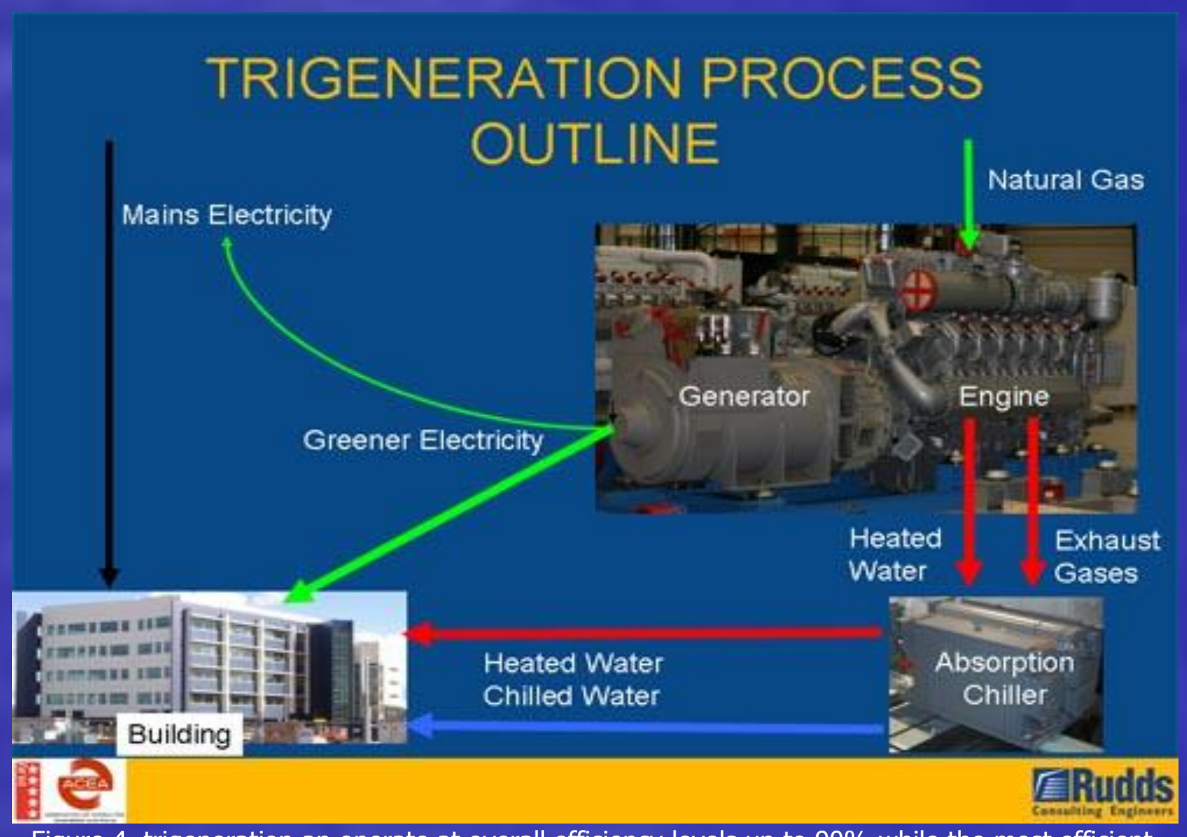


Figure 4. trigeneration an operate at overall efficiency levels up to 90% while the most efficient modern coal fired power is just 45% efficient. Trigeneration and associated technology can reduce CO_2 emissions from an office development by 50% or more.

Methodology

First of all, a large amount of bibliography and articles had been collected. After a detailed study, specific parts have been chosen in order to cover the issue of trigeneration systems.

Some of the issues that will be expected to study are:

♦ **The analysis of trigeneration systems and its performance from a thermodynamic point of view.**

The study begins with the applications, the methodology and the use of thermodynamic models. Furthermore, we are going to examine carefully the power requirements, the stream heat capacities, the mass flow rates, the target temperatures, the cold utility requirements and the operating conditions as well. It is expected to study some plants in different modes of operation. Also the energy balance of the plants will be calculated. Finally, as for the performance we will study the differences between the operation with some additional devices and the operation without using them.

♦ **The description of trigeneration schemes**

In this section not only a system based on a cogeneration-cycle but also a trigeneration-cycle system will be analyzed. For the analysis of the behaviours of both systems, a software program in Excel will be developed that allows a quick evaluation and comparison of data.

♦ **The kinds and combinations that could occur in order to improve**

In this part it is expected to study the incorporation of heat pumps to the traditional cogeneration systems in order to enhance its capacity, flexibility and overall performance. Furthermore, the addition of some specific auxiliary equipments will be expected to allow the system satisfy domestic energy demands, economically with no need of any other energy source.

♦ **The technology of trigeneration systems**

A review of the basic fundamentals for the components of trigeneration systems and the thermodynamic evaluation of these components with the design methodology for the trigeneration systems will be studied in this section.

♦ **The refrigeration techniques for possible use within the context of trigeneration.**

In this chapter we will study a hybrid refrigeration system that promises changes in thermal and electrical load profiles of a plant by shifting refrigeration from an electrical load to heating load during high cooling seasons and when high time of day electrical rates are enforced. This effective utilization of process energy seems to reduce, the energy production cost, the energy consumption and cuts down net emissions.

♦ **The environmental impact of trigeneration systems and a comparison on it with other existing techniques**

A research about the environmental impact from the trigeneration production of electricity, heating and cooling in comparison with other techniques such as cogeneration or conventional product like factories that burn lignite will take place as well.

♦ **The possible areas of application**

Here the field of application like hotels, restaurants, hospitals, schools, universities etc will be examined.

♦ **The applications in Greece and the possibility for new investments**

The applications in Greece are very limited but the case of a hospital in the central part of Greece will be studied.

♦ **The requirements for a computational modelling**

It is expected to give an analysis for the equipments and devices which are necessary in the computational modelling and a description of this.

♦ **The existing computational systems**

Here a reference and an analysis of the existing programs like TRNSYS, TESS and STEC will be made.

After the study and the choice of the appropriate bibliography we will start writing, aiming to cover all the above issues. Finally we will provide some directions and suggestions for future research on the topic.

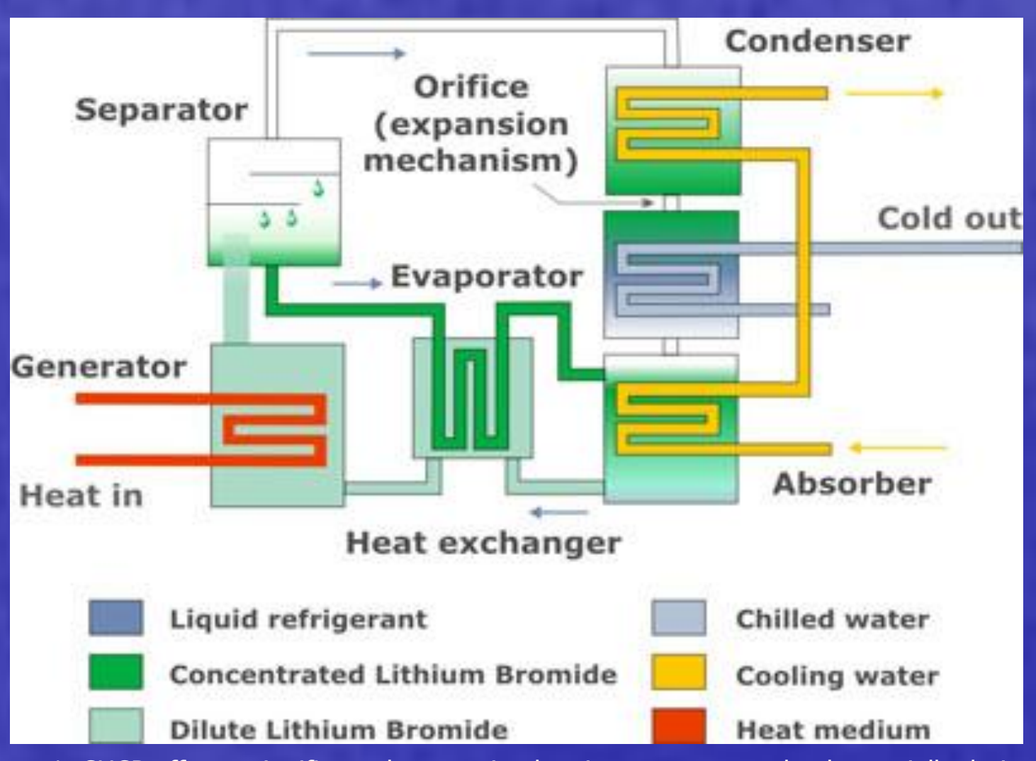


Figure 1. CHCP offers a significant decrease in electric power system load especially during hot summer months. CHCP advantages, in comparison with conventional cooling devices, are non-emission of harmful freons into the atmosphere and utilization of rejected heat produced in cogeneration facilities. However, CHCP is not used only for facility heating and cooling, but also for industrial processes demanding lower temperatures.

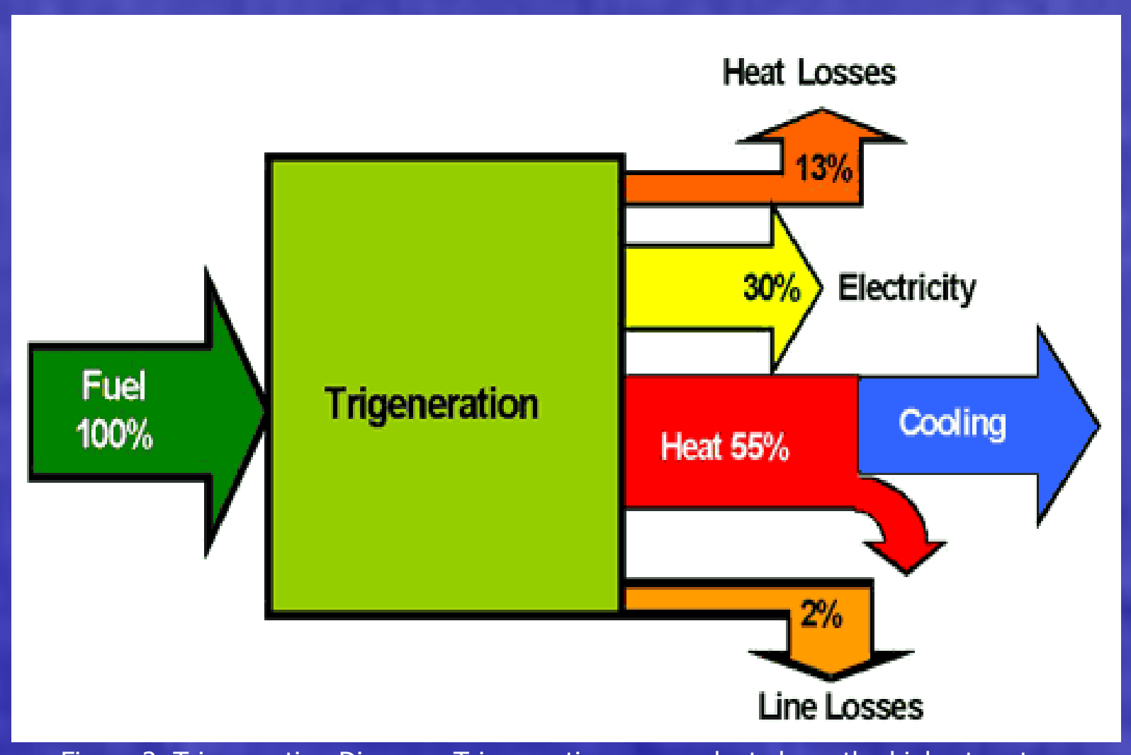


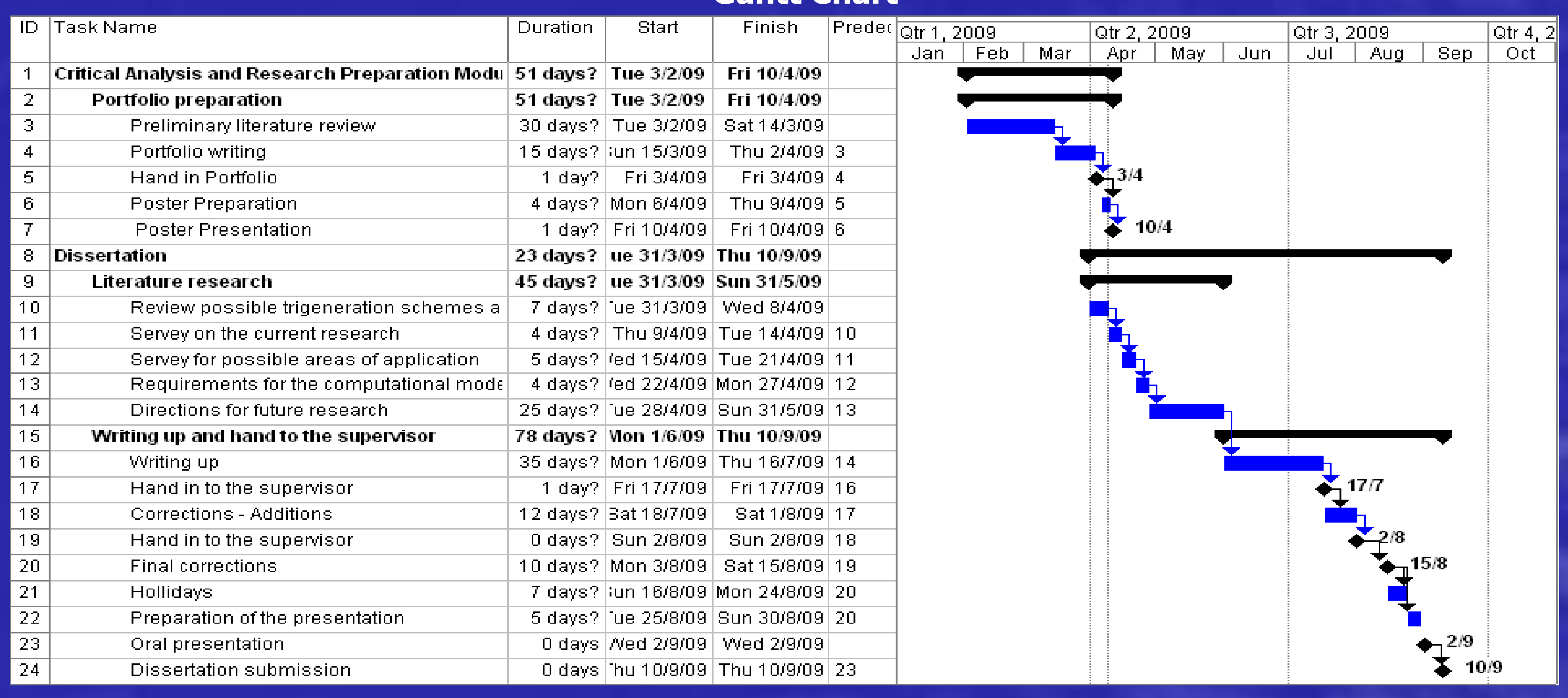
Figure 2. Trigeneration Diagram. Trigeneration power plants have the highest system efficiencies and are about 300 % more efficient than typical central power plants.

Figure 3. A 120 kWe Trigeneration system.

Expected Outcomes

This study is based on an alternative process of energy saving that is believed to have a widely application in the domestic and industrial section in the future. It is about the trigeneration systems, which can accomplish more efficient and economically the energy generated by conventional fuels. This study is focused on, the technology of new processes, the performance of applications and the kinds of trigeneration systems. A literature review is followed in order to extract directives about the improvements and changes of the applications, with a view to become more efficient and friendly to the environment. After that, a comparison of trigeneration systems with other existing techniques is made. Also comments are made about the impact assessment on the environment. An important point is the determination of possible application areas mainly for the Greek market. The results are very interesting and as it was expected there are big benefits for the consumers from trigeneration systems. Finally, some directions and recommendations for future research are made and some general conclusions are extracted.

Gantt Chart



ID	Task Name	Duration	Start	Finish	Predec
1	**Critical Analysis and Research Preparation Modu**	**51 days?**	**Tue 3/2/09**	**Fri 10/4/09**	
2	**Portfolio preparation**	**51 days?**	**Tue 3/2/09**	**Fri 10/4/09**	
3	Preliminary literature review	30 days?	Tue 3/2/09	Sat 14/3/09	
4	Portfolio writing	15 days?	un 15/3/09	Thu 2/4/09	3
5	Hand in Portfolio	1 day?	Fri 3/4/09	Fri 3/4/09	4
6	Poster Preparation	4 days?	Mon 6/4/09	Thu 9/4/09	5
7	Poster Presentation	1 day?	Fri 10/4/09	Fri 10/4/09	6
8	**Dissertation**	**23 days?**	**ue 31/3/09**	**Thu 10/9/09**	
9	**Literature research**	**45 days?**	**ue 31/3/09**	**Sun 31/5/09**	
10	Review possible trigeneration schemes a	7 days?	ue 31/3/09	Wed 8/4/09	
11	Servey on the current research	4 days?	Thu 9/4/09	Tue 14/4/09	10
12	Servey for possible areas of application	5 days?	ed 15/4/09	Tue 21/4/09	11
13	Requirements for the computational mode	4 days?	ed 22/4/09	Mon 27/4/09	12
14	Directions for future research	25 days?	ue 28/4/09	Sun 31/5/09	13
15	**Writing up and hand to the supervisor**	**78 days?**	**Mon 1/6/09**	**Thu 10/9/09**	
16	Writing up	35 days?	Mon 1/6/09	Thu 16/7/09	14
17	Hand in to the supervisor	1 day?	Fri 17/7/09	Fri 17/7/09	16
18	Corrections - Additions	12 days?	Sat 18/7/09	Sat 1/8/09	17
19	Hand in to the supervisor	0 days?	Sun 2/8/09	Sun 2/8/09	18
20	Final corrections	10 days?	Mon 3/8/09	Sat 15/8/09	19
21	Hollidays	7 days?	un 16/8/09	Mon 24/8/09	20
22	Preparation of the presentation	5 days?	ue 25/8/09	Sun 30/8/09	20
23	Oral presentation	0 days	Ved 2/9/09	Wed 2/9/09	
24	Dissertation submission	0 days	hu 10/9/09	Thu 10/9/09	23

References

[1] Active. Accelerating cross-fertilization and transfer of VIVE approach. Available from: http://www.vive-ig.net/projects/active/t_sheet.html; 2000
[2] CEC Commission of the European Communities, Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions – A Community strategy to promote combined heat-and-power (CHP) and to dismantle barriers to its development, COM 1997; 514 final, Brussels
[3] London Climate Change Agency, Allan Jones MBE, Chief Executive Officer
[4] http://www.greenpeace.org
[5] http ://en.wikipedia.org
[6] http ://www.Trigeneration.com
[7] Ziher, D. and A. Poredos, Cooling power costs froma trigeneration system in a hospital. Forsch Ingenieurwes 2006. 70: p. 105–113
[8] Journal of Engineering for Gas Turbines and Power JANUARY 2009, Vol. 131 / 012302-1, Copyright © 2009 by ASME, Design and Performance Evaluation of a Trigeneration System Incorporating Hydraulic Storage and an Inverted Brayton Cycle
[9] A. Piacentino, F. Cardona , An original multi-objective criterion for the design of small-scale polygeneration systems based on realistic operating conditions, Applied Thermal Engineering (2008) p. 146–182
[10] J.L. Mıguez, S. Murillo, J. Porteiro, L.M. Lopez, Feasibility of a new domestic CHP trigeneration with heat pump: I. Design and development, Applied Thermal Engineering 24 (2004) 1409–1419
[11] A. Piacentino, F. Cardona, On thermoeconomics of energy systems at variable load conditions: Integrated optimization of plant design and operation, Energy Conversion and Management 48 (2007) 2341–2355
[12] Aiying Rong , Risto Lahdelma, An efficient linear programming model and optimization algorithm for trigeneration, Applied Energy 82 (2005) 40–63
[13] Piero Colonna, Sandro Gabrielli, Industrial trigeneration using ammonia–water absorption refrigeration systems (AAR), Applied Thermal Engineering 23 (2003) 381–396
[14] Galip Temir, Durriye Bilge, Thermoeconomic analysis of a trigeneration system, Applied Thermal Engineering 24 (2004) 2689–2699
[15] Pappas, T., Thermodynamic analysis and optimization of the cogeneration power plant of BIOKARPET-EXALCO S.A., Master Thesis in Mechanical Engineering Department. 2006, University of Thessaly: Volos
[16] J. Porteiro, J.L. Mıguez, S. Murillo, L.M. Lopez, Feasibility of a new domestic CHP trigeneration with heat pump: II. Availability analysis, Applied Thermal Engineering 24 (2004) 1421–1429
[17] E. Cardona, A. Piacentino, A methodology for sizing a trigeneration plant in mediterranean areas, Applied Thermal Engineering 23 (2003) 1665–1680
[18] Joel Herna´ndez-Santoyo, Augusto Sa´nchez-Cifuentes, Trigeneration: an alternative for energy savings, Applied Energy 76 (2003) 219–227
[19] E. Teopa Calva, M. Pico´n Nu´n˜ez, M.A. Rodrı´guez Toral, Thermal integration of trigeneration systems, Applied Thermal Engineering 25 (2005) 973–984
[20] X.Q. Kong, R.Z. Wang, X.H. Huang, Energy efficiency and economic feasibility of CCHP driven by stirling engine, Energy Conversion and Management 45 (2004) 1433–1442
[21] Gianfranco Chicco, Pierluigi Mancarella, Assessment of the greenhouse gas emissions from cogeneration and trigeneration systems. Part I: Models and indicators, Energy 33 (2008) 410–417
[22] Pierluigi Mancarella, Gianfranco Chicco, Assessment of the greenhouse gas emissions from cogeneration and trigeneration systems. Part II: Analysis techniques and application cases, Energy 33 (2008) 418–430
[23] Editorial, Recent novel developments in heat integration—total site, trigeneration, utility systems and cost-effective decarbonisation. Case studies waste thermal processing, pulp and paper and fuel cells, Applied Thermal Engineering 25 (2005) 953–960
[24] J. Godefroy, R. Boukhanouf, S. Riffat, Design, testing and mathematical modelling of a small-scale CHP and cooling system (small CHP-ejector trigeneration), Applied Thermal Engineering 27 (2007) 68–77
[25] Cardona, E., et al., Energy saving in airports by trigeneration. Part II: Short and long term planning for the Malpensa 2000 CHCP plant. Applied Thermal Engineering 2006. 26: p. 1437–1447
[26] Chmielniak, T., W. Kosman, and G. Kosman, Simulation modules of thermal processes for performance control of CHP plant with a gas turbine unit. Applied Thermal Engineering, 2007. 27: p. 2181–2187
[27] Yilmaz, T., Optimization of cogeneration systems under alternative performance criteria. Energy Conversion and Management, 2004. 45: p. 7
[28] Industrial Application of Gas Turbine committee (IAGT) Paper No: 07-IAGT-2.4
[29] Zheng, L. and E. Furimsky, ASPEN simulation of cogeneration plants. Energy Conversion and Managment, 2002. 44 p. 7
[30] Zhen Huang, W., M. Zaheeruddin, and S.H. Cho, Dynamic simulation of energy management control functions for HVAC systems in buildings. Energy Conversion and Management, 2006. 47 p. 926–943
[31] Hinojosa, L.R., et al., A comparison of combined heat and power feasibility models. Applied Thermal Engineering 2007. 27: p. 2166–2172
[32] Ziher, D. and A. Poredos, Cooling power costs froma trigeneration system in a hospital. Forsch Ingenieurwes 2006. 70: p. 64–88