A Comparative Study of Green Technology in Cement Industry

Restu Kholifatul Ummi
Civil Engineering
North China University of Water Resources and Electric Power (NCWU)
PPI DUNIA (Indonesian Student Association of the World)
Zhengzhou, China
restu_ummi@yahoo.com

ABSTRACT
The insufficiency of infrastructure is the main bottlenecks in Indonesian society that prevent higher economic growth, as it weakens connectivity hence increasing logistics costs, making businesses less competitive, and also initiating social problems. Then the Indonesian government has given more attention to infrastructure development in order to enhance the economic growth. Cement industry is one of the industries that are very important in supporting the development of infrastructure and property. However, a large number of demonstrations against the operation of a cement factory have been arising from some protest and communities (Civil Society Organization/LSM) due to the environmental issues. In general, every ton of Ordinary Portland Cement (OPC) that is manufactured releases on a similar amount of CO$_2$ into the atmosphere, or for roughly 6% of all human-generated greenhouse gas emissions. A developed production method that minimizes or eliminates CO$_2$ emissions from cement manufacturing process is essential. Innovation on green or environmentally technology in cement industry with the focus on green energy (use of renewable energy sources or alternative fuel and higher energy efficiency), green products (use of an industrial waste as raw material), and green processes (reducing waste generation and conserving water, hence improving operational efficiency and lowering costs) become the global trends. In this study, the latest developments in eco-friendly technologies of the mining/quarrying operations and cement manufacturing that will be operated in Rembang by PT Semen Indonesia will be described and compared with the other countries. Existing technologies in the European cement industry has made significant progress in reducing the environmental impact of the industry. It is including the rehabilitation of the quarry to protect and promote biodiversity, more efficient clinker and cement production processes that reduce greenhouse emissions, provide waste utilization, and produce innovative concrete which can reduce the energy consumption of buildings and roads. Cement factory that will be operated in Rembang by PT Semen Indonesia is applying a modern environmentally friendly plant with the latest technology and a higher efficiency than another cement factory in Asia (more efficient use of water, chemicals, fuel and electricity). Quarrying methods will be used a Zero Run Off concepts, in which the ground water is carefully managed to prevent the discharge from the mine area, then the amount of ground water is increased. In addition to the utilization of renewable energy biomass as an alternative fuel, they also developed technology that converts the hot exhaust gasses into electrical energy through the Waste Heat Recovery Power Generation (WHRPG) project. Then, these technologies will become a pioneer and a standard for the construction of a new cement industry in Indonesia. Direct effect of the cement factory operation to the local communities will also be discussed.

Keywords: Cement industry, green technology, Zero Run Off concepts, Waste Heat Recovery Power Generation (WHRPG) project.
I. INTRODUCTION

The lack of quality and quantity of infrastructure is the main bottlenecks in Indonesian society that prevent higher economic growth, as it weakens connectivity hence increasing logistics costs, making businesses less competitive. It also can initiate social problems because access to healthcare can be difficult in the rural regions. Then the Indonesian government has given more attention to infrastructure development in order to enhance the economic growth. Cement industry is one of the industries that are very important in supporting the development of infrastructure and property. Many programs that launched by the government, for example, “one million houses program”, the 35,000 MW power plant program, the 2,700 kilometers-long Trans-Sumatra toll road, and the construction of smelters, will require plenty of cement [1]. However, a large number of demonstrations against the operation of a cement factory have been arising from some protest and communities (Civil Society Organization/LSM) due to the environmental issues, especially with the operation of a new cement plant in Rembang.

The cement industry is facing unprecedented challenges relating to energy resources, CO$_2$ emissions and the use of alternative materials. In general, every ton of Ordinary Portland Cement (OPC) that is manufactured releases on a similar amount of CO$_2$ into the atmosphere, or for roughly 6% of all human-generated greenhouse gas emissions [2]. OPC is a vital construction material and also a strategic commodity. A developed production method that minimizes or eliminates CO$_2$ emissions from cement manufacturing process is essential. Then, innovation on green or environmentally technology in cement industry with the focus on green energy (use of renewable energy sources or alternative fuel and higher energy efficiency), green products (use of an industrial waste as raw material), and green processes (reducing waste generation and conserving water, hence improving operational efficiency and lowering costs) become the global trends [2-15]. Existing technologies in the European cement industry has made significant progress in reducing the environmental impact of the industry. It is including the rehabilitation of the quarry to protect and promote biodiversity, more efficient clinker and cement production processes that reduce greenhouse emissions, provide waste utilization, and produce innovative concrete which can reduce the energy consumption of buildings and roads. Cement factory that will be operated in Rembang by PT Semen Indonesia is also will apply a modern green technology plant. In this study, the latest developments in eco-friendly technologies of the mining/quarrying operations and cement manufacturing in existing plant PT Semen Indonesia and new Rembang plant will be described and compared with the European cement industry. Direct effect of the cement factory operation to the local communities will also be discussed.

II. LITERATURE REVIEW

There are many studies about green technology in cement industry that have been published, but the comparison study of the latest technology is still limited. Imbabi et al. have been investigated about trend and development in green cement and concrete technology [2]. They conclude that locally recycled materials and waste from industry may be suitable for blending with OPC as a substitute both in laboratory tests and in practice. They also presented the economics of cement production and the trends in the UK and USA to inform future developments in cement production based on maximizing the value of carbon reduction. Benhelal et al. have been reviewed about global strategies and potentials to curb CO$_2$ emissions in cement industry [3]. They described three strategies of CO$_2$ reduction including energy saving, carbon separation and storage as well as utilizing alternative materials.

Recent studies and potentials to mitigate CO$_2$ emissions in cement plant are developed in Europe. In UK, Popescu et al. compared the energy consumption and carbon dioxide emission during production of belite cement and OPC [4]. It was concluded that the energy consumed during production of belite cement was 500-540 kJ/kg less than producing the OPC. In Spain, Rodriguez et al. were proposed a new process to produce carbon dioxide in pure form [5]. As a result, it was possible to reduce 50% of carbon dioxide emission as compared to the conventional process. In France, Cazacliu and Ventura have compared a dry batch and a central mixed plant in terms of technical, environmental and economic aspects [6]. Results indicated that the Environmental Amortization Duration Time (EADT) for CO$_2$ and particles were below 6 years. Moya et al. have been carried out the cost-effectiveness analysis of some of the Best Available Technologies (BAT) that could result in energy consumption and CO$_2$ emissions reduction in the European Union’s (EU27) cement industry [7]. The results indicated that the possible thermal energy improvement in the clinker production was 10%. Valderrama et al. have been studied the potential improvements of a cement plant in Catalonia (Spain) by upgrading the cement production lines [8]. It was shown that 5% of the impact of global warming could be reduced by implementing new production line.

Several studies have been carried out aimed to utilized alternative materials and alternative fuel in European cement industry. In Portugal, Kikuchi has
reported a technology for producing cement from incineration ash of municipal solid waste, incineration ash of sewage sludge and other wastes such as aluminum dross and copper slag [9]. Mokrzycki et al. were studied the ecological and economical features of utilizing alternative fuels made from waste in the Lafarge Cement, Poland [10]. Prisciandaro et al. were analyzed the experimental results of the emission of alternative fuels replaced with conventional fuel in two different cement plants in Italy [11]. Results indicated that if less than 20% of regular fuel is replaced with tire, stack emissions (NO\textsubscript{x}, SO\textsubscript{2} and CO mainly) were slightly increased. In France, Gartner has studied the feasibility of replacing Portland cement with alternative hydraulic cement that could result in lower total CO\textsubscript{2} emissions [12].

These innovation efforts, as described above, have turned the cement industry in Europe into the most active research. Data of the existing cement industry in Europe in this work is obtained mostly from the report of Boston Consulting Group [13], sustainability report of Lafarge Holcim [14] and also from CEMBUREAU or European Cement Association (the representative organization for the cement industry in Europe).

III. METHODOLOGY

A comprehensive report and research about green technology in cement industry were reviewed based on the methodology in Fig. 1. This study is initiates based on the fact that innovation in green technology in cement industry that minimizes or eliminates CO\textsubscript{2} emissions is essential. Various environmentally technologies in cement industry have been developed, especially in Europe. PT Semen Indonesia stated that a new cement plant in Rembang will adopt the latest developments in eco-friendly technologies [15]. How far this technology will be applied in new Rembang plant and its effect on CO\textsubscript{2} emissions are the main problem statement in this study. The latest developments of green technology in this study will focus on three areas: (1) green energy (use of renewable energy sources or alternative fuel), (2) green products (use of an industrial waste as raw material become a new product), and (3) green processes in operations (reducing waste generation, reducing emissions and conserving water). The recent conditions of green technology that will be compared are the existing technology in the European cement industry, the existing plant of PT Semen Indonesia and new installations that will be operated in Rembang plant. The assessments of this comparative study are based on the quality and quantity of the green technology applied, CO\textsubscript{2} emissions reduction, energy efficiency, etc. The advantage of the cement factory operation to the development of local communities is invaluable and it will support the analysis and conclusions in this paper.

Figure 1. Flowchart of the research methodology used in this study.

VIII. IV. RESULTS AND DISCUSSION

To study the comparison of the green technology in cement industry, we must understand the process flow of cement production and the main sources of emissions that will be discussed in section IV.A. Then, every development in the process production will be described and compared in section IV.B. The assessment of the green technology in new Rembang plant and direct impact to the local community will be discussed in section IV.C and IV.D, respectively.
A. Process Flow of Cement Production and Sources of Emissions

The process flow of cement production together with the alternative input and sources of particulate and gas emissions is shown in Fig. 2. A conservative estimate for every 1 kg of cement produced gives a by-product of 0.9 kg of carbon dioxide, this equates to 3.24 billion tons of CO₂ per year [2]. The production of Portland cement begins with the quarrying of raw materials (limestone). Most cement factories are located near a limestone quarry to reduce transportation costs. Quarrying limestone involves drilling, blasting, excavating as well as crushing, screening and storing. Limestone is mixed together with clay, iron sand and silica sand to achieve the appropriate compositions and start the first stage of grinding with crusher into the form of powder. The alternative raw materials from third-party industrial waste are also used and mixed together as the development of green processes. Only the operation of machinery is responsible for CO₂ emissions when quarrying for raw materials (about 7% of total emissions) [2].

The raw mill then heated in the preheater and the heating is continued inside the rotary kiln to a temperature 1450 °C with pulverized coal and additional alternative fuels. Rotary kiln is a long cylindrical rotary furnace that turns around once or twice every minute. Temperatures are generally around 1400-1600 °C, and energy demand varies depending on the calcination process. Through a chemical reaction known as calcination, the raw materials are turned into cement clinker granules. Calcination is the decomposition of calcium carbonate (limestone) to calcium oxide (lime) in order to produce basic cement usually referred to “calcine”, and in the cement business, it is called clinker. Clinker crystal is cooled in clinker cooling and the heat output is recirculated to the preheater to save energy. The theoretical heat requirement for clinker-making is calculated to be about 1.75 MJ per kg. The calcination process is the main sources of emissions (contribute to 50% of total emissions) [2]. The CO₂ emissions result from fuel consumption in the kiln and the de-carbonation of limestone to produce CaO (CaCO₃ + Heat → CaO + CO₂). Using clinker substitutes may reduce calcination CO₂ emissions but will generally require more heat energy.

Clinker is ground again with gypsum as well as additives to produce fine cement powder. Then, the fine clinker is stored in cement storage (silos). From this silo, cement is packed and distributed in packaging bags. The CO₂ emission in 2012 is 3.24 billion tons of CO₂ per year [2]. The projected CO₂ emissions in 2050 from the cement industry if no changes are made to current production methods is increased by almost 5 times the value in 1990. This would be very bad news indeed and so must clearly never be allowed to happen. Cement industry must reduce CO₂ emissions by promoting the best available efficiency technologies for new and existing production plants, increasing awareness of alternative fuels and encouraging clinker substitution.

The energy efficiency of cement production varies significantly depending on the cement production process and the rotary kiln technology. Over the past decades, the cement industry in Europe has heavily invested in rotary kiln technology with now more than 90 percent of the kilns being highly efficient dry kilns, and less than 10 percent semi-wet and wet kilns [2,13]. These developments have improved thermal and heat efficiency reduced the amount of water that needs to be evaporated in the kiln, and, overall, improved energy efficiency in the clinker production process. In addition to installing cleaner technologies, the cement industry also focuses strongly on the operational efficiency of a plant. Equipment must be operated efficiently and maintained correctly to ensure that the maximum potential savings are achieved.
B. Comparison of the Green Technology in Cement Industry

The European cement industry has made tremendous efforts to reduce its greenhouse gas emissions. As a result, the cement industry in Europe has a low CO$_2$ emission rate per ton of product (0.65 million tons of gross CO$_2$ emissions) [13]. A consistent focus on research and innovation has resulted in new, more environmentally-friendly production technologies, innovative products and increased resource efficiency. These innovation efforts have turned the cement industry in Europe into the second most active in terms of patent filing in 2011, after Asia-Pacific (excluding China), accounting for more than 800 patents. Also, Europe is the main global equipment supplier to the cement industry, accounting for over 60 percent of the global market (excluding China) [13]. Technologies developed in Europe are often then transferred to other parts of the world. The main initiatives or development to control emissions in line with the efforts to save energy and environments are divided into; (1) reclamation and biodiversity after quarrying, (2) alternative raw material, (3) alternative fuel, (4) Waste Heat Recovery Power Generation (WHRPG), (5) green product and (6) other development. The comparison and assessment of the green technology between existing PT Semen Indonesia (including a new plant in Rembang) and existing European cement industry are summarized in Table 1.
Reclamation and Biodiversity After Quarrying

Cement industry is dependent on access to raw materials for the production of clinker. As a result, nature conservation, biodiversity and ecosystems management play an important role in its long-term resource and reserve strategy. Quarrying and biodiversity are compatible through correct resource management before, during and after extraction. For example, correct quarry rehabilitation can help minimize the impact of invasive species through the introduction of native species, as seen in Portugal [13]. In France (Altkirch), almost half of the exploited area has been completely rehabilitated and has resulted in significant biodiversity enrichment. The Lafarge Holcim quarry in Yepes, Spain, covers 1,000 hectares in the center of the semi-arid Iberian Peninsula [14]. They have progressively restored the quarry over a number of years. They also have avoided monoculture pine re-planting. Instead, they provided heterogeneous with slopes, holes, and ponds, creating habitats for fauna that was already colonizing these areas.

Quarry rehabilitation can also contribute to the development of biological corridors (referred as green corridors) or green infrastructure. In the UK, a site has built an artificial bat cave, which is intended to provide an alternative long-term safe haven for bats [13]. Some companies focus on the rehabilitation of ecosystem services, which can include flood resilience, pollination, leisure facilities, as well as support for the local heritage, and in many instances, these actions address the needs of the local community. In Spain, one site has rehabilitated its quarry to provide not only habits of particular species but also leisure facilities (such as cross-country cycling,

<table>
<thead>
<tr>
<th>No</th>
<th>Development / Technology</th>
<th>Existing European cement industry</th>
<th>Existing PT Semen Indonesia (new plant in Rembang)</th>
<th>Assessment</th>
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<tr>
<td></td>
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<td>Description</td>
<td>Description</td>
<td>Qualitative</td>
</tr>
<tr>
<td>1</td>
<td>Reclamation and biodiversity after quarrying</td>
<td>Biological corridors/ green infrastructure, artificial bat cave, Total rehabilitated area: 15.96 hectares (Lafarge Holcim, France)</td>
<td>Freshwater fish farming, development of mangrove forests, conservation of Javan deer Total rehabilitated area: 80.42 hectares (Tuban plant)</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>Alternative raw material</td>
<td>Recovering waste materials, industrial by-products Alternative raw material substitution rate: 10.5% (Lafarge Holcim, France).</td>
<td>Blended cement program (hazardous and toxic waste) Alternative raw material substitution rate: 6.27% (Tuban plant).</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Alternative fuel</td>
<td>Waste tires, sewage sludge, plastics, waste oils and biomass Reduce CO₂ emissions: 100,000 tons/yr (Lafarge Holcim, France).</td>
<td>RDF (Refuse Derived Fuel) and Biomass Reduce CO₂ emissions: 10,000 tons/yr from RDF, 150,000 tons/yr from biomass.</td>
<td>✓</td>
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<td>4</td>
<td>WHRPG</td>
<td>ORC (Organic Rankine Cycle) plant Capacity: 7 MW. Reduce CO₂ emissions: 30,000 tons/yr (Rohrdorf, Germany).</td>
<td>Waste Heat Recovery Power Generation (WHRPG) joint with Nedo, Japan Capacity: 8.5 MW (Indarung Padang plant), 30.6 MW (Tuban plant) Reduce CO₂ emissions: 122,000 tons/years</td>
<td>✓</td>
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<td>5</td>
<td>Green product</td>
<td>Zero-emission concrete, pervious concrete, photo-catalytic concrete, insulated concrete Recycling rate of ~46 percent Porous concrete, flash concrete, blended or mix cement</td>
<td>Not available</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>Other development</td>
<td>zero &quot;process-water discharge&quot;NOₓ, SOₓ and dust emissions reduction Dust emissions: 55 gr/ton cement, NOₓ emissions: 982 gr/ton cement, SOₓ emissions: 196 gr/ton cement (Lafarge Holcim)</td>
<td>Zero Run Off, main bag house filter, long belt conveyor, Wortgen and Vermeer equipment (Rembang plant) Dust emissions: below 30 mg/Nm³ (Rembang plant) NOₓ emissions: 80 mg/m³, SOₓ emissions: 4 mg/m³ (Tuban plant)</td>
<td>✓</td>
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1) Reclamation and Biodiversity After Quarrying

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picnic areas and botanic paths) for the enjoyment of the local communities.

Existing PT Semen Indonesia conducts quarrying process of raw materials with consideration to biodiversities like conservation of flora and fauna, post-quarrying activities and reforestation. Then, no quarries in all work areas are located within and adjacent to the protected area and conservation area. The quarrying operations adopted the tiered system, which is completing one tier/plot and then moving to another plot. Thus, significant negative impact on biodiversity can be minimized. Until the end of 2015, PT Semen Indonesia has planted 57,362 trees for reforestation, covering an area of 80.42 hectares in Tuban plant [15].

In addition, PT Semen Indonesia has the initiative to optimize the clay post-quarrying area in Tuban as the freshwater fish farming with floating cages to maintain the sustainability of coastal area environment named Green Socorejo program. The area has been designated by the regional government as a strategic area for fishing zone, fish pond culture, maritime industry, agro-industry, wetland agriculture, forests, tourism, and development of mangrove forests to mitigate disasters. Through this program, Semen Indonesia has contributed by planting 60,000 trees. The planting was conducted along the coastal border area of Socorejo village that stretches approximately along 1.7 km with an area of approximately 6 hectares. The trees planted in the area are “Casuarina equisetifolia” and Mangrove (“Rhizophora mucronata”). Conservation of “Rusa Timorensis” or better known as Javan deer is also conducted to maintain populations of endangered fauna in their natural habitat [15].

2) Development of Alternative Raw Material

Over the last 20 years, the cement industry in Europe has played an increasingly relevant role in waste management by effectively recovering waste materials. The recovery of waste in the cement industry referred to ‘co-processing’, is the optimum way of recovering energy and material from waste. For example, use of alternative raw materials to replace the traditional raw materials, such as clay, shale and limestone. Examples of these alternative materials include contaminated soil, waste from road cleaning and other iron-, aluminum-, and silica-containing waste. Industrial by-products such as blast-furnace slag (a by-product of the iron manufacturing process) and fly ash (residues generated from coal combustion) can be used to partially substitute clinker in cement. In Europe, an additional 8.3 million tons of clinker were substituted with by-products in 2010 compared to 1990. Lower-clinker cement have become a widely-used hydraulic binder in the production of concrete for specific applications, such as infrastructure in chemically aggressive environments [13].

Co-processing offers a win-win-win solution for society, as it is beneficial to the environment, is cost competitive, and reduces the consumption of natural resources. In addition, the industry contributes to the reduction of landfills (it should be noted that landfills emissions consist of about 60 percent methane, a gas with a global warming potential which is 21 times higher than CO2) and reduces the need for solid waste incineration in Europe. The increased use of industrial by-products represented a reduction of around 7.2 million gross tons of CO2 in 2010 compared to 1990 levels (9.8%). Since 1990 Lafarge Holcim has reduced the amount of clinker in products by 14 percent with alternative mineral components. In 2016, the alternative raw material substitution rate is 10.5% [14].

Existing PT Semen Indonesia has been developing “Blended Cement program” to reduce the use of clinker by utilizing external waste from other industries for alternative raw material. They have utilized the B3 (hazardous and toxic materials) waste from other industries, such as fly ash and bottom ash from the coal-fired power plant, purified/crude gypsum from the petrochemical industry and copper slag from copper industry. Waste producer industries benefit from the practice because it reduces landfill and B3 waste management activities, which often cause environmental problems. Instead, cement plant is treating the waste with high standards to be used for combustion in the production process. External hazardous and toxic waste is treated through co-processing with combustion at high temperatures (1400 °C). The combustion process is able to decompose content of heavy metal waste into oxides. This process can improve the quality of cement produced and will not harm the environment. The blended cement that has been produced by Semen Indonesia included PPC (Pozzolana Portland Cement), SBC (Special Blended Cement) and PPC (Portland Composite Cement). Waste utilization consumed an average of 8% per year. In addition to reducing the consumption of clinker, utilization of alternative raw materials could reduce CO2 emissions and energy efficiency. In 2015, the cement mix project is able to reduce emissions of 79,758 tons of CO2, higher than the previous year 44,261 tons of CO2. Results of emission measurement at Tuban Plant since 2009 until the end of 2015 showed a decrease in CO2 emissions to 11.2% [15].

3) Development of Alternative Fuel

Use of fuel energy sources in the cement industry reached 15-20% of total production costs. The sources of energy are from fuel, coal and power, which are non-renewable energy. Around 40% of emissions related to
the clinker production are linked to the fuel combustion. Efforts to reduce CO₂ emissions in this part of the process have resulted in an increase of the usage of alternative fuels (such as waste tires, sewage sludge, plastics, waste oils and biomass) or an optimization of the energy efficiency of the kiln. A major advantage of the energy recovery from waste is that the non-combustible ash fraction is recovered as a raw material. Another reason why using waste as an alternative fuel when producing cement is good for the environment is that it preserves non-renewable fossil fuels, such as coal or oil, and it also lowers the region’s dependence on such fuels. Every year the cement industry in the Europe saves the equivalent of about 7 Mt of coal. The cement industry in Europe has significantly increased its use of alternative fuels resulting in a reduction of 15.6 million tons of CO₂ emissions. Having increased from 3 percent in 1990 to 31 percent in 2010, resulting in a total usage of 9.2 tons of waste, the cement industry in Europe uses by far the highest amount of alternative fuels in the world, followed by North America with a 13 percent substitution rate [13].

The largest Lafarge Holcim cement plant in France developed a new line with 80 percent of the fuel used in the cement plant comes from alternative sources. This equates to savings of 100,000 tons of CO₂ emissions annually and reduces the amount of waste going to landfill by 60,000 tons per year. In 2016, 15 percent of Lafarge Holcim’s thermal energy demand for clinker production was covered by alternative fuels, reducing CO₂ emissions by 8 million tons [14].

As the development of alternative fuel, PT Semen Indonesia develops utilization of RDF (Refuse Derived Fuel) and biomass for production process while reducing CO₂ emissions. PT Semen Indonesia has built municipal solid waste treatment facilities at Ngipik landfill, Gresik regency. They process municipal solid waste into the alternative fuel of RDF in the production process while reducing CO₂ emissions by 8 million tons [14].

The WHR PG project has been implemented at Indarung Padang plant and Tuban plant, PT Semen Indonesia with a capacity of 8.5 MW and 30.6 MW, respectively. This program can reduce the cost of power from PLN and reduce CO₂ emissions. The estimated efficiency of WHRPG implementation in Tuban can save power costs up to Rp. 120 billion per year and reduce consumption of power from PLN by 152 million kWh per year, and also will reduce emissions of CO₂ by 122,000 tons per year as compared to the use of conventional energy [15].

4) Waste Heat Recovery Power Generation (WHRPG)

Waste Heat Recovery Power Generation (WHRPG) program is the utilization of exhaust gases from the combustion process to generate power or electricity (Fig. 2). WHRPG is a proven technology, but until now WHRPG uptake has been limited except in China. China has become the market leader in WHRPG installations. Regulatory measures and lower capital costs have been key factors behind China’s success in mainstreaming WHRPG technology [16]. The Organic Rankine Cycle (ORC) systems have been widely used to generate power from biomass systems in Europe. The Rankine cycle is a thermodynamic cycle that converts heat into work. In Europe there are more than 250 cement plants and the theoretical ORC potential has been estimated in more than 500 MW [17]. With the festive commissioning of the waste heat power plant, the Rohrdorf cement company (Germany) can claim that it runs the most environmentally friendly and, at the same time, the most energy efficient cement plant in the world. Based on a new process, fresh superheated steam is produced by means of the heat energy of the waste gases. This steam drives the turbine that produces the electric current via the generator. At least one-third of the power requirement of the entire plant is met by the electricity produced there. The waste heat power plant is to produce a total of about seven megawatts of electric power. 12,000 tons of fossil fuels will be saved and, consequently, the emission of CO₂ will be reduced by 30,000 tons/year [13]. Development of WHRPG in China leaped forward in step with rapid cement industry development. By the end of 2012, 739 waste heat power systems were operating, with a total installed capacity of 6,575 MW [16].

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5) Development of Green Product

Innovation to create new products that are environmentally friendly with attention to the health and safety of customers are necessary. Although PT Semen Indonesia is also used hazardous waste from other
industries, it can still produce environmentally friendly cement products in good quality. The opportunity of reducing emissions is not limited solely to the cement production process but also lies in the whole life cycle of downstream products, namely concrete. Porous concrete is one of the “green products” of Semen Indonesia that is able to absorb the surface water and channeled it into the ground. Paving blocks with high porosity are suitable to be used for the road surface, the home yard, and parking area. The advantage in applying this porous concrete is increasing the deposit of groundwater and prevents the risk of flooding. Another green product is flash concrete that dried quicker than ordinary cement then making the roadwork faster [15].

Concrete can contribute significantly to reduce CO₂ emissions as concrete construction offers a higher energy saving potential compared to other construction materials. This is due to the high level of insulation offered by concrete which means that the indoor temperature remains stable even when there are fluctuations in the temperature outside. The saving potential provided by concrete buildings resulting from the production of cement. By combining all of the above, the thermal mass potential of concrete can be maximized and allow for the construction of low energy concrete buildings that reduce energy usage from an average of 200-150 kWh/m² to 50 kWh/m², or even to zero emission. In relation to civil engineering, concrete is able to withstand moisture and varying weather conditions, as well as mechanical wear and high temperatures. It is commonly used in flood-prone areas due to its resilience to flooding, in tunnels due to the benefits it offers in terms of fire safety, in power plants due to the provision of safe and secure storage of potentially dangerous fuels and in water treatment, run-off catchment and water distribution systems which provide fresh water. Concrete pavements can reduce the fuel consumption of heavy trucks by up to 6 percent, by reducing the rolling resistance between the road and the truck as concrete pavements offer a smoother surface with fewer undulations than asphalt pavements. Furthermore, the total life cycle costs of concrete are lower than those of asphalt. The other new concrete applications have also been developed, including; photo-catalytic concrete, (can reduce air pollution by 25-60%), pervious concrete (for better soil conservation by capturing rainwater), and insulated concrete formwork (for a more cost-efficient, quicker to build and energy-efficient structure). The innovation of cement and concrete industry to material recovery and recycling has led to a reduction in construction and demolition waste, and resulted in a recycling rate of ~46 percent, implying a reduction of ~250 million tons of all the waste landfilled in Europe. As a result, in Europe (excluding the UK) on average 8 percent of aggregates are recycled and recovered aggregates [13].

6) Other Development

All development that has been applied in existing PT Semen Indonesia plant will be adopted in a new plant at Rembang with some innovations. For example the innovation of dust emission and noise reduction to minimize the impact of cement operation and to create a balance of the natural and social environment by replacing Electrostatic Precipitator (ESP) device with main bag house filter. ESP device has the weakness in the safety interlock that will shut off the system when the rotary kiln generates gas, then resulted in high CO₂ gas. The dust that is not captured by the ESP will look like thick smoke over the stack. All the equipment installed at Rembang Plant reduced dust emissions to below 30 mg/Nm³, even when the rotary kiln operation is being offset. Development of long belt conveyor from quarries to processing plant will reduce dust emissions significantly. In addition to dust control, new Rembang plant will operate Wirgten and Vermeer equipment to minimize the impact of noise during quarrying activities. In contrast to the blasting method, the supporting equipment for limestone quarrying process does not cause noise. Quarrying methods will be used a Zero Run Off concepts, in which the ground water is carefully managed to prevent the discharge from the mine area, then the amount of ground water is increased. Rembang plant is equipped with the Variable Frequency Drive (VFD) technology on the application of large motors, which is claimed to be able to save electricity consumption up to 60 percent. The decline in electricity consumption also indirectly reduces greenhouse gas (GHG) emissions. To manage water use, Rembang Plant is equipped with technology and mechanism of surface water utilization from the reprocessing of gray water. The processing is carried out at the water treatment plant (WTP) through the process of dissolved air flotation (DAF) and ultrafiltration (UF), which is more efficient in chemicals and electricity consumption [15].

In Europe, notable improvements have been achieved in other areas such as NOₓ, SOₓ and dust emissions reduction. From 1995 to 2010, the European cement industry reduced NOₓ emissions by a total of 20 percent, which represents the emissions of 870,000 cars in one year, and SOₓ emissions by 34 percent [13]. In France, to reducing freshwater withdrawal in its cement segment, Lafarge Holcim operates on a zero “process-water discharge” and uses recycled water in its batching operations over freshwater, wherever possible. In 2016, they withdrew 356 liters of freshwater per ton of cement. In its quarrying operations, they harvest and stores rainwater in large onsite catchment areas for production.
use. The system is designed to allow excess rainwater to bypass the catchment area and leave the site as uncontaminated stormwater run-off. Projects include a storm water project at Beenleigh aggregate quarry resulting in increased rainwater holding capacity and real-time remote access water use monitoring [14].

C. Assessment of the Green Technology in Cement Industry

Based on the comparison that has been discussed in section IV.B and summarized in Table 1, green technology that has been applied in existing plant of PT Semen Indonesia and new installations that will be operated in Rembang plant have equal quality with the existing technology in European cement industry. All new developments in European cement industry are also developed by PT Semen Indonesia qualitatively. Quantitatively (based on some parameter for example total rehabilitated area, CO₂ emissions, etc.), green technologies in PT Semen Indonesia are better than selected cement plant in Europe (for example Lafarge Holcim) in case of reclamation and biodiversity after quarrying, use of alternative fuel and Waste Heat Recovery Power Generation (WHRPG). Meanwhile, in case of alternative raw material substitution rate and development of green product, technologies in PT Semen Indonesia are still left behind with Europe.

Total direct green-house gas (GHG) in 2015 at Tuban plant is 656 kg CO₂ per ton cement product [15]. This value is equal to average gross CO₂ per ton cement product of China and lower than the rest of Asia and North America (Fig. 3) [13]. Meanwhile, the world average value is 657 kg CO₂ per ton cement product. Brazil’s cement industry is among the most advanced in the world. It had average CO₂ emissions as low as 592 kg CO₂ per ton of cement, ahead of Europe, China, Japan, Australia and New Zealand. Fig. 4 shows the comparison of gross CO₂ emissions between Lafarge Holcim and PT Semen Indonesia at Tuban plant. Lafarge Holcim is one of the most carbon-efficient cement companies in the world. In 2016, their cement contained an average of 72 percent clinker, and gross CO₂ emissions per ton of cement were 603 kg/ton, a reduction of 24 percent against the 1990 benchmark [14]. The new plant of PT Semen Indonesia in Rembang is expected to reach these values.

Even though the comparison of green technology between PT Semen Indonesia and European cement industry in this work is not a straightforward assessment due to the various factor influences and limited data available. But, from the results, as discussed above, we can conclude that cement factory that will be operated in Rembang by PT Semen Indonesia is applying a modern environmentally friendly plant with the latest technology and lower CO₂ emissions than some cement factory in Asia (more efficient use of water, chemicals, fuel, and electricity). Then, these technologies will become a pioneer and a standard for the construction of a new cement industry in Indonesia. The operations of the Rembang plant will cause positive and negative impacts on the environment and surrounding communities. To minimize the negative impacts and enhance positive impacts, a study on environmental and social impact has been conducted.

D. Direct Impact to Local Community

The advantage of the cement factory operation to the development of local communities is invaluable as it also develops local wisdom. The positive impact of plant development began to be enjoyed by communities, including job opportunities, serves as the backbone for local economies by promoting a local industrial base, education and socio-economic programs. The presence of PT Semen Indonesia operation and local suppliers managed to employ the surrounding community who
support operational activities. Construction of the new plant in Rembang is also expected to give a socio-economic contribution to the communities around the area of operation. Until the end of 2015, total local suppliers of PT Semen Indonesia reached 313 companies. Total plant employees reached 3,282 people, who originated from Rembang was 1,009 people (approximately 30%) [15].

PT Semen Indonesia managed to change the post-quarrying land with an area of 8 hectares of clay into a "source of life" for communities around Tuban Plant. They built retention basin (reservoirs of surface water) that has been utilized by 40 farmers in fish farming with floating cage system. In addition, the retention basin has been used by residents around the plant to irrigate of rice fields during the dry season. To produce alternative fuels, PT Semen Indonesia has built partner with local biomass suppliers. They use agricultural product waste such as rice husk, cocopeat, tobacco waste and sawdust in order to reduce the use of fossil fuels. This pattern has had a positive impact; it develops 11 local suppliers in the area around the plant operations and each local supplier has been able to employ 15-20 workers, then providing extra income for farmers, owners of rice husk mill and sawmills [15].

As for the community around the operational areas of PT Semen Indonesia who have a strong will in entrepreneurship, the company has provided support through corporate social responsibility (CSR) programs. This program focuses on; improving competence through education programs (include scholarships, training and skills of the community, as well as providing learning facilities), environmental programs (include the development of Green Secorejo and limestone post-quarrying reclamation in Tuban Plant), socio-economic programs (include assistance for education, sports, arts, health, public facilities and infrastructure, as well as assistance for natural disasters), coaching and mentoring the partners. The partner business sectors include trade, culinary, agribusiness, creative industries, to the various other small industrial sectors.

In Europe, the production of cement provides an estimated 61,000 direct skilled jobs, and up to 3-5 times as many indirect jobs, translating into a total of ~245,000 to ~365,000 jobs related to cement production. In addition, over 305,000 people are employed in concrete production. The European cement industry also contributes to the prosperity of local communities. In France, over 50 percent of French cement plants are located in municipalities with less than 5000 inhabitants. In addition, the hiring of local people contributes towards maintaining positive contact with communities. Many companies work with communities at regional and local level offering educational programs. Companies also develop community collaboration plans to foster activities such as school visits, create foundations to support local community projects or partner with local NGOs to support the underprivileged [13, 14].

IX. V. CONCLUSION

The latest developments of green technologies in European cement industry and the existing plant of PT Semen Indonesia including new installations in Rembang plant were described and compared. Qualitatively, all new developments in European cement industry are also developed by PT Semen Indonesia. Quantitatively, green technologies in PT Semen Indonesia are better than selected cement plant in Europe in case of reclamation and biodiversity after quarrying, use of alternative fuel and Waste Heat Recovery Power Generation (WHRPG). Meanwhile, in case of alternative raw material substitution rate and development of green product, technologies in PT Semen Indonesia are still left behind with Europe. Total gross CO2 per ton cement product of existing plant PT Semen Indonesia is lower than the rest of Asia and North America.

Cement factory that will be operated in Rembang by PT Semen Indonesia is applying a modern environmentally friendly plant with the latest technology and a higher efficiency than another cement factory in Asia (more efficient use of water, chemicals, fuel and electricity). Then, these technologies will become a pioneer and a standard for the construction of a new cement industry in Indonesia. The advantage of the cement factory operation to the development of local communities is invaluable as it also develops local wisdom.

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