# Potentials of Gas Emission Reduction (GHG) by the Glass Sheet Industry through Energy Conservation

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**Abstract.** Sheet Glass Industry is one industry that uses 75 % natural gas energy and 25 % electricity. Using the Intergovernmental Panel on Climate Change, IPCC-2006 emission calculation method, the average greenhouses gas (GHG) emissions obtained from the calcination process obtained 112 211 t $CO_2$ $yr^{-1}$ per plant and an average emission factor (EFkl) of 0.18 $CO_2$ $t^{-1}$ $yr^{-1}$ of pull. With the technology of converting heat into electrical energy, residual combustion as flue gases has the potential to be used to produce electrical energy. Referring to the analysis and calculation; one of factories has potential to generate 0.8 MW to 3 MW electric energy. It's efficiency of 10 % to 40 % so that it can be calculated as a component of GHG emission reductions whose value is 4.6 t $CO_2$ $yr^{-1}$ to 18.7 t $CO_2$ $yr^{-1}$ per plant. With this reduction, each of the GHG emission and emission factors per plant dropped to 93 442 t $CO_2$ $yr^{-1}$ and 0.16 $CO_2$ t-$pull^{-1}$

**Keywords:** Emission factor, energy efficiency, flue gas, greenhouse gas, global

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## Introduction

Global warming is a term used to describe the gradual increase in the average temperature of the earth's atmosphere and oceans, the value of 0.74 °C ± 0.18 °C (1.33 °F ± 0.32 °F) over the last 100 yr. Increasing the amount of carbon dioxide and other greenhouse gases released by burning fossil fuels, land clearing, agriculture, and other human activities, is believed to be the main source of global warming that has occurred over the past 50 yr. The Intergovernmental Panel on Climate Change (IPCC) concluded that, most of the increase in global average temperatures since the mid-20th century was most likely due to increased concentrations of greenhouse gases (GHGs) due to human activities [1].

The industrial sector provides energy consumption which varies by region, according to differences in industrial output, energy intensity (measured as energy consumed per unit of gross output), and industry composition [2]. Companies can reduce energy consumption in all ways, including improving industrial sector processes to optimize energy use and minimize energy losses, increase the use of cogeneration, and recycle materials and types of fuel to reduce costs and increase efficiency

Energy consumption in our country Indonesia until 2016 is 1 018 MBoe. In contrast to the distribution of global consumption by sector, of the total consumption of the industry is ranked second energy users, namely 30.88 %. The biggest energy consumption is the transportation sector by 43.89 % followed by residential / household 16.62 %, commercial 5.8 % and others. Based on the type of energy used, petroleum is still the largest portion of 43.7 % followed by electricity 19.9 %, natural gas 15.3 %, coal 9.6 %, LPG 8.5 % and biofuels 2.97 % [3].

Concerns from the world community on GHG emissions led to the birth of the Kyoto Protocol in December 1998, followed by the birth of the Paris Agreement at the 21st COP in Paris, 30 November to 12 December 2015. which contained agreements from member countries, which in essence agreed on the temperature threshold globally is below 2 °C, overcoming the maximum temperature change of 1.5 °C from pre-industrial times

Indonesia signed the Paris Agreement on 22 April 2016 and was later ratified through Law Number 16 Year 2016. Indonesia's commitment at COP-21 in Paris to reduce GHG emissions by 29 % in 2030 by its own efforts (CM1) or by 41 % with international assistance (CM2) as outlined in the Nationally Determined Contribution (NDC) document [4]. This momentum is the basis for changing the target for GHG emission reductions in Indonesia by 26 % in 2020. From the 29 % figure, the energy sector received a portion of emission reduction of 314 × $10^6$ t of $CO_2$ on its own efforts and 398 × $10^6$ t of $CO_2$ with international support [4].

This paper is intended to analyze and calculate the electrical energy potential of sheet glass flue gas conversion and its contribution to the GHG emission of the industrial sector in Indonesia

## 2 Literature review

Until 2016, GHG emissions in Indonesia were 1 515 × $10^6$ t $CO_2$ and this figure is down 39 % compared to 2015, and the biggest contribution was from the peat/forest fire sector 88 %, energy by 5 %, land use and forestry sector (Land use, land-use change, and forestry /LULUCF by 27 % while the Industrial sector (Industrial Processes and Production Use/ IPPU) increased by 2 % [4].

Calculation of GHG emissions using the Intergovernmental Panel on Climate Change Guidelines in the 2006 IPCC Guidelines [5, 6] and the application of this methodology has been stipulated in Minister of LHK Regulation Number P.73 / MenLHK / Setjen / Kum.

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1/12/2017 dated 29 December 2017 concerning Guidelines for the Implementation and Reporting of Greenhouse Gas Inventories [7].

The sheet glass production process begins with the preparation of raw materials for silica sand, dolomite, cullet and other supporting raw materials which are mixed into one raw material (mixed batch), then put into stages in a furnace with a capacity of 500 t $yr^{-1}$ to 700 t $yr^{-1}$ with a temperature of 1 500 °C , and operates for 24 h, 365 d, 15 yr continuously. In the production process, the biggest use of energy is natural gas (NG) in the smelting of raw materials and electrical energy in the process of forming, cooling and cutting. Figure 1 shows a diagram of the process of producing sheet glass, the use of energy and the resulting flue gas [8].

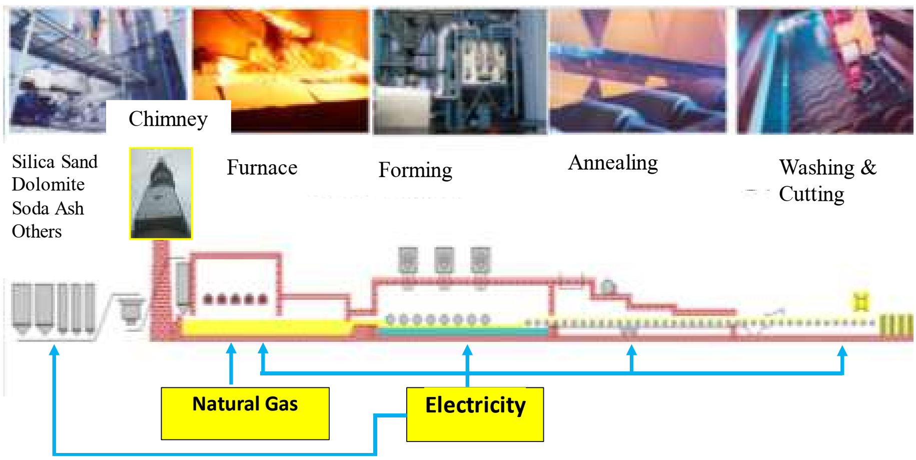


**Fig. 1.** Glass sheet manufacturing flow process

Raw material that has been melted (molten glass) is flowed on top of tin at a temperature of 600 °C to 800 °C for the formation of thickness and dimensions and is gradually cooled (annealing) with a blower.

The final process is washing, cutting (washing & cutting). In the production process, GHG emissions will occur during the melting process as direct emissions and the use of electricity in the process of forming, cooling and cutting as indirect emissions.

The Equation (1) shows the heat energy from the furnace flue gas.

$$Qhr = m \times Cp \times \Delta T \tag{1}$$

$Qhr$ = Heat (J), $m$ = mass (kg), $Cp$ = Heat Specific (J $kg^{-1}$ . K), dan $\Delta T$ = delta Temperatur In/Out (K or C)

Flue gas specific heat with NG fuel as in Table 1.

**Table 1.** Specific heat from the flue gas with NG fuel [9, 10]

| Subtance | Formula | $C_p = a + bt + bt^2 + br^3$ (t in K, $C_p$ in kJ $kmol^{-1}$, K) | | | | RANGE | %ERROR | |
|---|---|---|---|---|---|---|---|---|
| | | a | B | c | d | (K) | Max | Min |
| Nitrogen | $N_2$ | 28.9 | -1.57E-03 | 8.08E-06 | -2.87E-09 | 273 to 1 800 | 0.59 | 0.34 |
| Oxigen | $O_2$ | 25.48 | 1.52E-02 | -7.16E-06 | 1.31E-09 | 273 to 1 800 | 1.19 | 0.28 |

Table 1. Continue to the next page

| Subtance | Formula | $C_p = a + bt + bt^2 + br^3$ (t in K, $C_p$ in kJ $kmol^{-1}$, K) | | | | RANGE | %ERROR | |
|---|---|---|---|---|---|---|---|---|
| | | a | B | c | d | (K) | Max | Min |
| Carbon Dioxide | $CO_2$ | 22.26 | 5.98E-02 | -3.50E-05 | 7.47E-09 | 273 to 1 800 | 0.67 | 0.22 |
| Water Vapor | $H_2O$ | 32.24 | 1.92E-03 | 1.06E-05 | -3.60E-09 | 273 to 1 800 | 0.53 | 0.24 |
| Sulfur Dioxide | $SO_2$ | 25.78 | 5.80E-02 | -3.81E-05 | 8.61E-09 | 273 to 1 800 | 0.45 | 0.24 |

For some types of glass industry, the % of fuel that becomes heat losses in flue gas is 29 %, 30 %, 57 %, 53 %, and 56 % for sheet glass, container, press, insulation fiber, and textile fiber, as in Table 2.

**Table 2.** The capacity of furnaces and flue gases of several types of glass industry [9, 10]

| Glass industry segment | Furnace capacity range | Typical furnace capacity | Natural gas consumption | Waste heat | % natural gas input lost to heat |
|---|---|---|---|---|---|
| | (t) | (t) | (Tbtu $y^{-1}$) | (Tbtu $y^{-1}$) | (%) |
| Flat glass | 300 to 1 000 | 550+ | 41.10 | 11.82 | 29 |
| Container glass | 50 to 330 | 250 | 45.49 | 13.65 | 30 |
| Pressed/brown glass | 1 to 300 | 75 | 16.82 | 9.63 | 57 |
| Insulation fiber glass | 20 to 300 | 100 | 3.24 | 1.73 | 53 |
| Textile fiber glass | 100 to 150 | 100 to 150 | 11.05 | 6.14 | 56 |

The combustion reaction of a fuel into flue gases is describe [11] in Equation (2):

$$CH_4 + (1+EA/100) \times [2O_2 + 7.52N_2] \rightarrow \\ CO_2 + 2H_2O + (1+EA/100) \times 7.52N_2 + (9.52 \times EA/100 \times 21/100)O_2 \quad (2)$$

The percentage of each flue gas as the result of the reaction in Equation 2 with natural gas fuels can be calculated in a number of excess air as shown in Table 3.

**Table 3.** Composition of combustion flue gases with some % excess air

| Flue Gas (%) | Excess Air (EA) in % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| $CO_2$ | 8.72 | 8.05 | 7.48 | 6.98 | 6.54 | 6.16 | 5.82 | 5.51 | 5.24 | 4.99 |
| $H_2O$ | 17.43 | 16.1 | 14.95 | 13.96 | 13.09 | 12.32 | 11.64 | 11.03 | 10.48 | 9.98 |
| $N_2$ | 72.11 | 72.63 | 73.09 | 73.48 | 73.82 | 74.13 | 74.40 | 74.64 | 74.86 | 75.05 |
| $O_2$ | 1.74 | 3.22 | 4.48 | 5.58 | 6.54 | 7.39 | 8.14 | 8.82 | 9.43 | 9.98 |

GHG emission equation from energy use ($GHG_{ENG}$) [12] is describe in Equation (3).

$$GHG_{ENG} = EC \times EF \quad (3)$$

*EC* = Energy Consumption, *EF* = Emission Factor (56.2 $CO_2$ $TJ^{-1}$ for Natural Gas, 77.4 $CO_2$ $TJ^{-1}$ for Residual Oil).
GHG emission from process ($GHG_{IPPU}$) [6] is describe in Equation (4).

$$GHG_{IPPU} = Mg \times EF \times (1-CR) \quad (4)$$

Mg = pull (ton), *EF* = 0.21 kg $CO_2$ $kg^{-1}$ glass at cullet ratio 10 % to 25 %, *CR* = cullet ratio.

Assessment of several industrial sector flue gases, conversion technology and investment costs per kW electricity, potential ORC applications for the conversion of flue gas heat to electricity from four industrial intensive sectors in several countries in the EU 27 and GHG emission reduction using electricity converted from gas The flue is shown in Table 4 and Table 5.

**Table 4.** Conversion of flue gas into electricity in several industrial sectors [13].

| Industry | Temperature (°C) | Process | Technology | Efficiency (%) |
|---|---|---|---|---|
| Glass | 230 to 480 | Melting | SRC | 20 to 43 |
| | | | ORC | 8 to 12 |
| | | | TEG | 5 |
| | | | KC | 15 |
| Aluminium | 790 to 1 080 | 2nd Melting | SRC | 20 to 30 |
| Steel | 580 to 680 | Roll Mill | SRC-CO2-PC | 13 to 17 |
| Paper | 82 to 140 | Dryer | ORC | 8 to 12 |
| Food | 150 to 350 | Boiler | ORC | 8 to 12 |
| Chemical | 150 to 260 | Preheater | ORC | 8 to 12 |
| SRC (Steam Rankine Cycle), ORC (Organic Rankine Cycle), KC (Kalina Cycle).<br>SC-CO2-C (Super Critical CO2 Cycle), TEG (Thermo Electric Generator). | | | | |

**Table 5**. ORC application in four sectors in several EU27 countries [14].

| Item | Industry | Glass | Cement | Steel | Oil & gas |
|---|---|---|---|---|---|
| | Process | Melting | Clinker | Eaf+roll mill | Gcs & gsf |
| Numbers | | 58 | 241 | 399 | |
| Capacity (Mt $yr^{-1}$) | | 12 | 247 | 217 | |
| ORC Power (MW) | | 79 | 574 | 748 | |
| E Recovery (GWh $yr^{-1}$) | 5 000 h | 383 | 2 870 | 3 740 | 6 520 |
| | 8 000 h | 628 | 4 592 | 5 984 | 10 432 |
| Emission (k t $CO_2$ $yr^{-1}$ | 5 000 h | 140 | 1 212 | 1 351 | 2 328 |
| | 8 000 h | 225 | 1 940 | 2 162 | 3 724 |
| Cost Saving (ey $y^{-1}$) | 5 000 h | 35 | 260 | 344 | 583 |
| | 8 000 h | 56 | 416 | 550 | 933 |
| Power Specific ($r_p$) | | 2.7 (kW $t^{-1}$) $d^{-1}$ | 1.01 (kW $t^{-1}$) $d^{-1}$ | 6.87 (kW $t^{-1}$) $d^{-1}$ | |

## 3 Methodology

The research methodology uses qualitative and quantitative methods. Quantitative using data for 2014 to 2018 from five different factories both for data on energy consumption, raw materials, and production volume. The data for the 5 yr are averaged, then GHG emissions are calculated using the 2006 IPPC method for the energy sector and IPPU as Figure 2.

GHG uses a combination of quantitative and qualitative, while the physical data of flue gas for 60 d from one of the factories is used as a reference to determine the physical quality of flue gas heat. In the analysis, in addition to using physical / technical research data will also use qualitative methods, namely the chemical stoichiometry calculation to obtain the percentage of oxygen in the flue gas as a basis for the calculation of the resulting flue gas mass. Quantitative data was also carried out with literature studies of several previous studies on the technology of converting hot gas to electrical energy, but not in detail explained electricity from gas conversion is used in the production process and is calculated as a reduction of GHG emissions

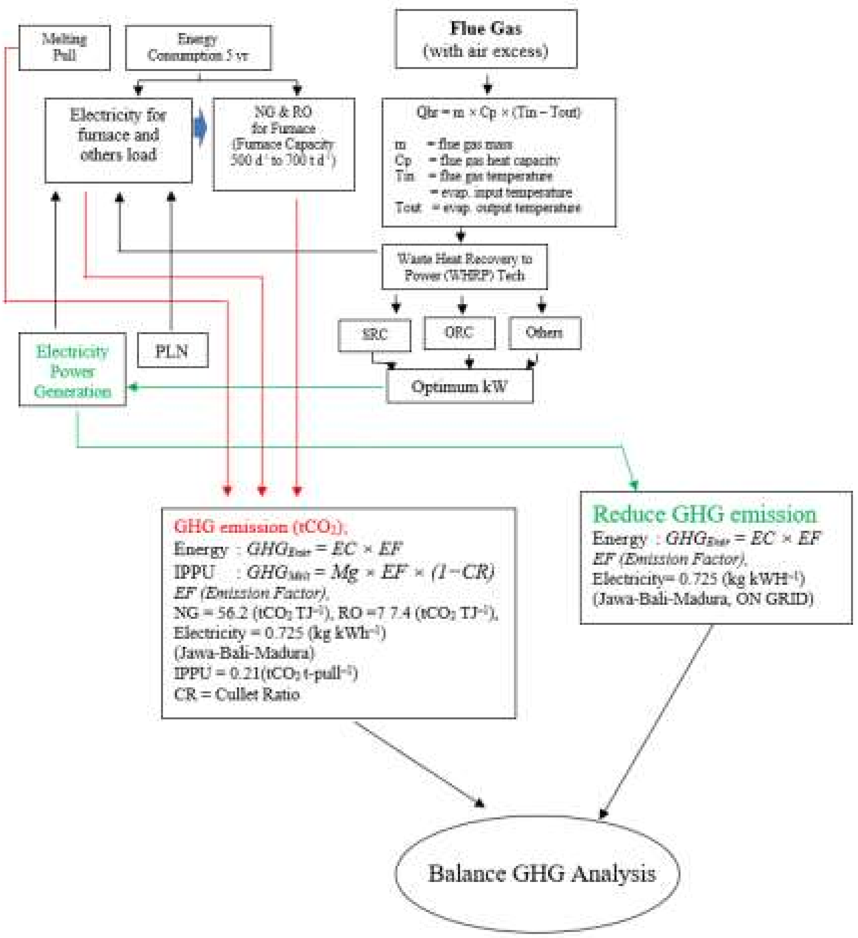


**Fig. 2.** Research flow

### 3.1 Data collection

Secondary data sources obtained from average data in 2014 to 2018, both for natural gas (NG) consumption data, residual oil, electricity and total glass volume produced (= pull) from five different factories as Table 6.

**Table 6.** Energy consumption & glass pull

| Description | Unit | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|
| Electricity (PLN) | MWh | 22 224 | 21 188 | 20 632 | 23 565 | 24 142 |
| Natural Gas | TJ | 1 217 | 1 211 | 1 126 | 1 118 | 1 175 |
| Residual Oil | TJ | - | 8 | 114 | 55 | 2 |
| Pull | t | 153 020 | 152 543 | 146 259 | 173 388 | 171 476 |
| Cullet Ratio | % | 35 | 36 | 40 | 35 | 36 |

Flue gas temperature data using a source from the Distributed Control System (DCS) in 60 d and PI for one fuel cycle (20 min) such as Figure 3 and Figure 4.

**Fig. 3.** Flue Gas Temperature within 60 d

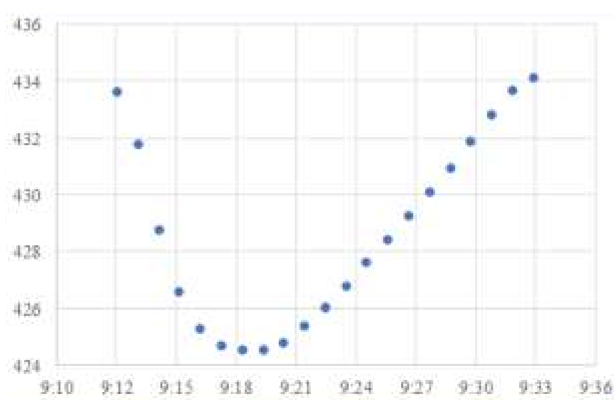


**Fig. 4.** Flue Gas Temperature within one firing cycle

From the DCS and PI data the maximum temperature is 434 °C, minimum 398 °C and an average of 416 °C.

### 3.2 Flue gas heat to electricity energy

If the density of NG = 0.74016, 1 NM3 NG = 1.0989 M3, air excess EA% from Table 3, stoichiometry A/F = 9.52, the obtained mass of 1 NM3 NG is 0.8134 kG so that the mass can be calculated each flue gas molecule such as $CO_2$, $H_2O$, $N_2$, $O_2$ and others with Equations 2 to Equation 9. With this data and the rate of natural gas consumption of 3 880 $NM^3\ h^{-1}$ (one furnace), the calculation of the molecular mass of the flue gas is shown in Table 7.

**Table 7.** The molecular mass of the flue gas in 1 $NM^3$ natural gas

| Composition | Mass (kg) | % | Cp (kcal $kg^{-1}$) | Unit |
|---|---|---|---|---|
| $CO_2$ | 2.219 | 10.8 | 0.200 7 | kcal $kg^{-1}$ |
| $H_2O$ | 1.762 | 8.57 | 0.480 0 | kcal $kg^{-1}$ |
| $N_2$ | 15 | 72.99 | 0.248 2 | kcal $kg^{-1}$ |
| $O_2$ | 1.399 | 6.81 | 0.219 7 | kcal $kg^{-1}$ |
| Others | 0.169 | 0.82 | 0.230 0 | kcal $kg^{-1}$ |
| **Total** | **20.55** | **100** | **0.261 9** | **kcal $kg^{-1}$** |

With a molecular mass of 20.55 kg, a specific heat of 0.2619 from Table 6, natural gas consumption of 3 880 $NM^3$ $h^{-1}$ , input temperature of 434 °C, output of 120 °C and putting them into equation 2-1, a flue gas heat energy of is obtained 6.732 kcal $h^{-1}$ and equivalent with 7 830 kW $h^{-1}$.

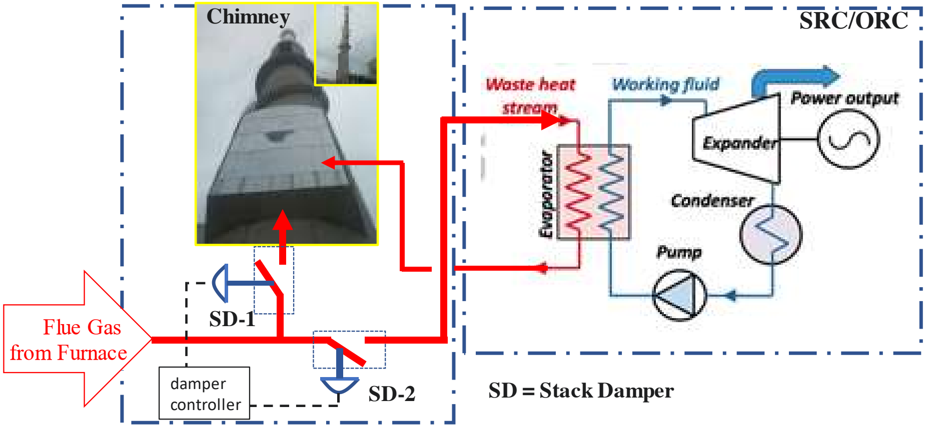


**Fig. 5.** Flue gas heat flow mechanism into the SRC/ORC

Through the process of converting heat into mechanical energy, electrical energy can be produced at 7 830 kW × the efficiency of converters such as SRC/ORC. Figure 5 shows a simple schematic mechanism of the flue gas heat flow into the SRC/ORC. The flue gas heat that is fed into the SRC evaporator is taken from the furnace output before being discharged into the chimney, through a flow regulating mechanism called a Stack Damper

## 4 Result and discussion

Using secondary data, a theoretical description of the calculation of GHG emissions and the potential heat of flue gases into electrical energy in the previous discussion, the results are presented in the following graphs.

Average emissions in 2014 to 2018 from five factories were 112 211 t $CO_2$, and were the biggest contributors to emissions from natural gas energy and 60 % residual oil, followed by the smelting process of raw materials 26 % and electrical energy by 14 %, as in Figure 6. When compared to emissions from electricity with natural gas and oil residuals to total emissions from energy, the percentage is 20 %:80 %. The amount of GHG emissions calculated is only half of the previous research data in Table 5 which is 225 Kt CO2 $yr^{-1}$

because the table is based on all processes including transportation of raw materials, yields and others within the plant but for this study only uses data in the smelting process

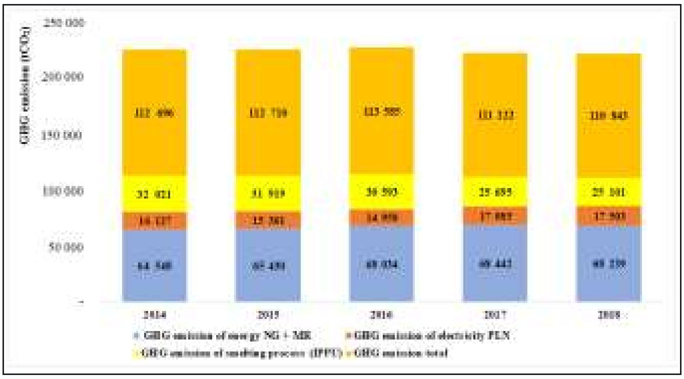


**Fig. 6**. GHG emission energy & smelting process

Emissions to ton pull, hereinafter referred to as FEkl (FEkl = Sheet Glass Emission Factor) are obtained by dividing the total GHG emissions in Figure 6 against pull in Table 6, as shown in Figure 7. The highest FEkl occurred in 2016 because because one of the factories only operates until July 2017 and used 500 TJ residual oil, almost the same as natural gas of 518 TJ while residual oil emission factors were 32 % higher than natural gas. FEkl decreased from 0.19 to 0.16 starting in 2017 and 2018 because one other new factory starts production in early 2017 has a new furnace and a greater capacity, means that the efficiency of burning a new furnace is better.

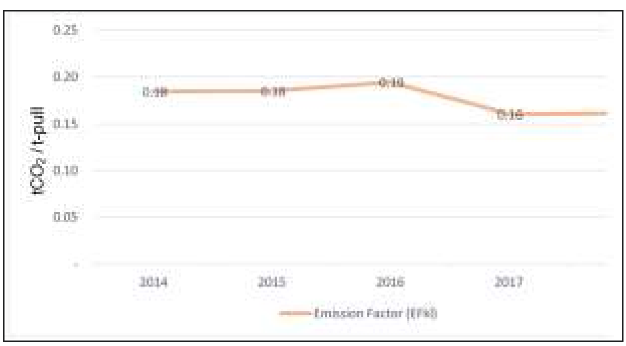


**Fig. 7.** GHG emissions ($tCO_2$) / t-pull.

The potential of electricity per year per furnace is 6 472 MWH up to 26 889 MWH from the flue gas heat of 7 830 kWh with an efficiency of SRC / ORC 10 % to 40 % as Figure 8. The higher the efficiency, the greater the electrical energy produced.

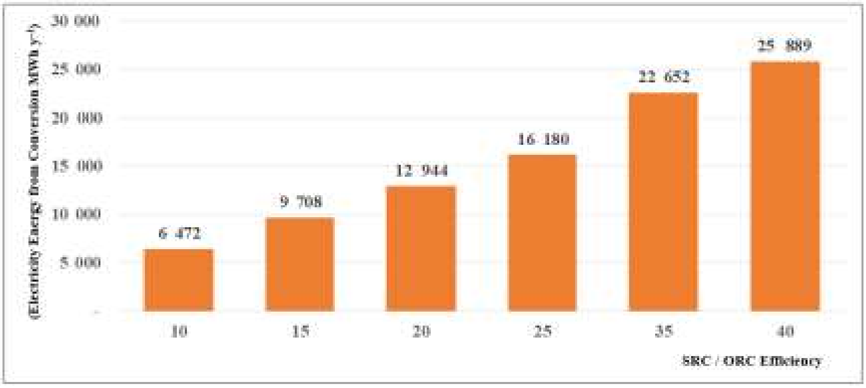


**Fig. 8.** Potential Electricity Energy (1 yr) from Flue Gas Conversion 7 830 kW-h per $NM^3 h^{-1}$ Natural Gas at SRC / ORC efficiency of 10 % to 40 %.

Calculation of the potential for reducing GHG emissions from the use of converted electricity, using the equation and the emission factor of the power plant from a PLN source of 0.725 t $CO_2$ $MWh^{-1}$ (grid Ja-Ma-Li) as shown in Figure 9.

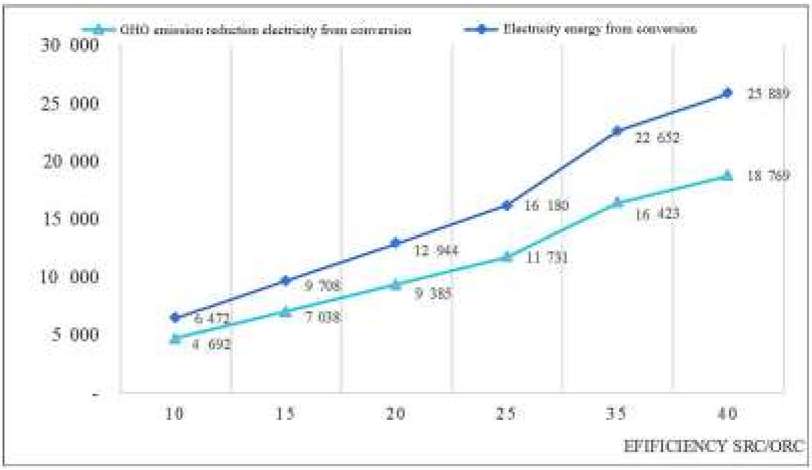


**Fig. 9.** Potential annual GHG Emission reductions from converting electricity

The converted electricity used in Figure 9 is a reduction in emissions, and will indirectly reduce the average emission factor from 0.18 t $CO_2$/ t pull on Figure 7 to 0.17 t $CO_2$ to 0.15 t $CO_2$ / t-pull, it means that the average FEkl is down by 11 %, shown in Figure 10.

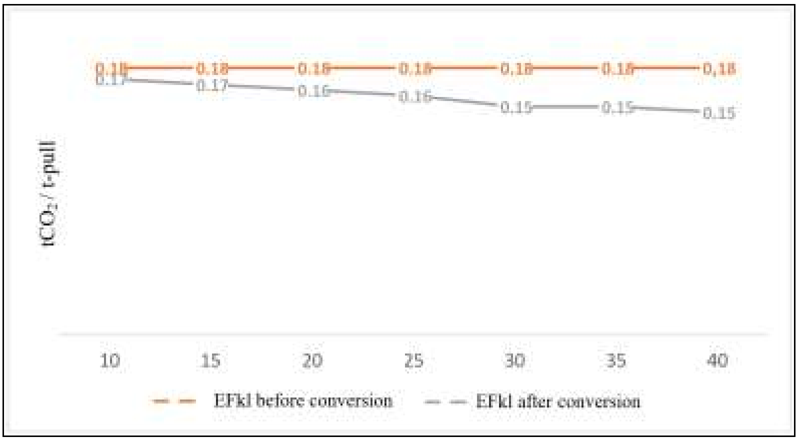


**Fig. 10.** GHG emissions per ton-pull (FEkl) before and after the use of converted electricity

## 5 Conclusion

Utilization of flue gas that is converted into electrical energy in the sheet glass industry with a pull capacity of 500 t to 700 t has the potential to generate electricity from 6 472 MWH $yr^{-1}$ to 25 889 MWH $yr^{-1}$, depending on the efficiency of the SRC/ORC used. The converted electricity will indirectly reduce GHG emissions by a factor of 0.18 t $CO_2$/ t pull to 0.17 t $CO_2$ to 0.15 t $CO_2$/ t pull, or an average reduction of 11 %, meaning that every single furnace in the glass industry can contribute to reducing emissions 11 % of emissions by utilizing flue gas into electrical energy that is used alone, and in emission total per year will reduce 112 211 t $CO_2$ $yr^{-1}$ to 93 442 t $CO_2$ $yr^{-1}$ per plant.

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