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Feasibility of developing heat exchange network between incineration facilities and industries in cities: Case of Tokyo Metropolitan Area

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ABSTRACT

Energy conservation is critical for promoting urban low-carbon and sustainable development. Because a large amount of heat energy is wasted during energy conversion and transportation, the recovery of waste heat and its cascading use would substantially save resources and reduce CO_2 emissions. As a typical case of the Tokyo Metropolitan Area, direct extracting steam from incinerators for industrial use is considered more efficient than power generation, but hard to be popularized because of long distance heat transport. On the basis of the heat atlas, this study develops an integrated model to assess the feasibility of developing heat exchange network between incineration facilities and industries in city scale, and evaluates the impacts from land use on economic and environmental indices. The result reveals that maximum 45.2% of the incineration waste heat can be utilized to cover 13.8% of the heat consumption in industries, where annual net benefit and CO_2 emission reduction could achieve 63 billion JPY (≈ 0.6 billion USD) and 2200 kt CO_2/year, respectively. However, current geographic separation between incineration facilities and industries brings a dilemma between economic and environmental benefits which will obstruct the popularization of waste heat exchange. Given this result, a cluster map to classify involved incineration facilities is provided which helps in establishing a renewal strategy considering positive land use adjustment. These results are also referable in urban planning integrated with distributed energy system as well as provide a case for promoting Urban Symbiosis.

1. Introduction

Climate change has become one of the most serious global environment problems and has attracted worldwide attention. Excessive anthropogenic greenhouse gas (GHG) emissions are the most likely cause of global warming. Because of the Paris Agreement, which was adopted by consensus at the 21st Conference of the Parties (COP21) within the framework of the United Nations Framework Convention on Climate Change (UNFCCC) on 12 December 2015, the overall target is to enhance the implementation to suppress the increase of the global average temperature to less than 2 °C compared to pre-industrial levels (2 °C target) UNFCCC (2015). To achieve this target, the adoption of not only mitigation strategies but also adaptation strategies at all administrative levels is emphasized. In 2010, the GHG emissions from electricity and heat production and from the industrial sector were estimated to be 25% and 21% of the total annual GHG emissions, respectively, which reveals that low-carbon technologies and systemic design for the energy and industrial sectors are critical (IPCC, 2014). Realizing a low-carbon urban energy system requires a decrease in unnecessary energy consumption, increased sharing of low-carbon resources, and comprehensive efficiency of energy conversion, transport, and utilization. The utilization of unused energy, including local renewables and waste heat, is a particular area of focus.

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Japan, as a developed country with substantial GHG emissions, submitted its Intended Nationally Determined Contribution (INDC) in 2015, in which the GHG emission reduction target is set at 26.0% by fiscal year 2030 compared to fiscal year 2013 (INDC, 2015). In 2014, Japan emitted 1.36 billion ton of GHGs (CO_2 equivalent), of which industry and the energy conversion sector represent 67% in direct emissions (MOEJ, 2016). By contrast, overall only approximately 40% of the primary energy input has been finally used, which reveals a large waste in energy conversion and consumption (IEA, 2012). According to a survey in 2011, the potential of unused heat in Japan, including the waste heat from incineration, industrial processes, thermal power generation, and unused heat from sewage systems, oceans, and rivers, is estimated at approximately 6000 PJ annually, which has surpassed the total energy consumption for civilian space heating and hot-water generation (approximately 5000 PJ) (JES, 2011). From a geographical perspective, Tokyo Metropolitan Area, Aichi Prefecture, and Fukushima Prefecture are consuming the highest proportion of energy, and recovering and utilizing the unused heat in these areas would substantially contribute in reducing GHG emissions (Dou et al., 2016). Promoting heat recovery in such regions could represent a large step toward achieving local and national GHG emission reduction targets.

Among the many sources of unused heat, incinerators are a priority for waste heat recovery. Generally, an incinerator can supply different qualities of heat to satisfy different requirements on the user side, such as high-pressure, high-temperature steam (300–400 °C) directly from an incinerator, low-pressure, low-temperature steam (150–170 °C) extracted from a turbine, or hot water (~60 °C) by heat exchange from condensers and exhaust gases, as shown in Fig. 1 (Ohnishi et al., 2016b; WSP, 2013). Because biomass and general waste can be combusted together in a boiler, an incinerator is able to adjust its work schedule and stably support heat to match the user's requirement, especially combined with Internet of things technologies (e.g., smart control of heat production by adjusting waste input in an incinerator) (METI, 2016). Although thermal power plants generate greater amounts of waste heat than incinerators, extracting steam during power generation would decrease the power output; meanwhile, the hot water obtained by heat exchange with a condenser has a comparatively low temperature (~40 °C) (Holmgren, 2006; Togawa et al., 2014). In addition, industrial process can sometimes supply high-temperature steam and hot water; however, the difficulty of satisfying the supply schedule of users becomes a difficult obstacle

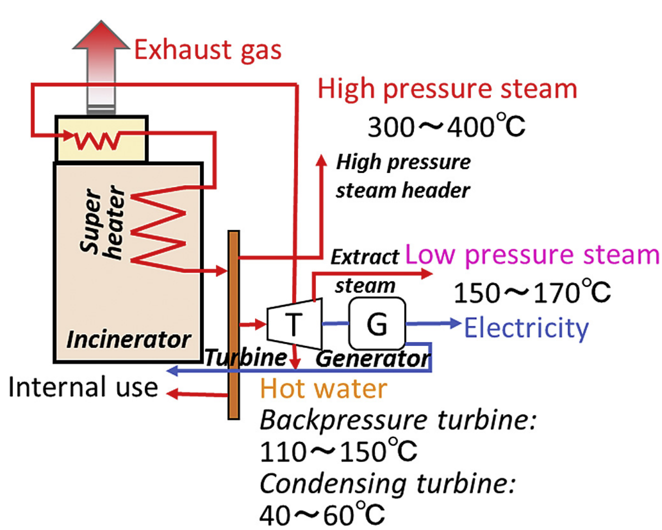

Fig. 1. Heat supply from incinerators.

for matching negotiation and implementation (Andrews and Pearce, 2011; Morandin et al., 2014).

Consequently, heat recovery from incinerators has become a common method for fuel saving and GHG emission reductions in many cases. Except for power generation, directly extracting steam from an incinerator to surrounding factories and a district heating network is also popular in global eco-industrial parks (EIPs) and eco-cities (Fujii et al., 2016; Geng et al., 2016; Ohnishi et al., 2016a). Well-known examples include steam support to factories in the Ulsan EIP of Korea (Park et al., 2016; Park and Park, 2014), hot-water-to-district heating in Kalundborg, Denmark (Jacobsen, 2006), especially the trend of heat recovery in conjunction with the popularization of 4th Generation District Heating (4GDH) and planning strategies such as Heat Roadmap Europe (Lund et al., 2014; Persson et al., 2014). Learning from these practices, policymakers have marked heat exchange with incinerators as a realistic way to significantly reduce GHG emissions in a short pay-back period (Pan et al., 2015; Persson and Munster, 2016).

By contrast, from the perspective of the supply side, although 83% of municipal waste is incinerated, the heat recovery rate in Japan is much lower than those in European countries (JESC and JWRF, 2016). In 2013, the proportion of CO_2 emissions from waste treatment reached 2.6%, of which 39% was directly emitted from incineration without any heat recovery (MOEJ, 2014). Several barriers and concerns related to the supply side have been identified in a comprehensive survey on incineration waste heat recovery (JESC and JWRF, 2016). As summarized in Table 1, the most important reasons are the unexpected long distances for heat to be transported to the potential users and the unaffordable initial investment required for heat distribution. Even though an incineration facility would share benefits such as low-cost electricity and a warm pool, it is still recognized as a NIMBY (not in my backyard) facility and would be located separately from residential and even industrial districts. Historically, incineration facilities have indeed tended to negatively affect nearby land prices (Hashimoto et al., 2015). Furthermore, concerns about the physical and economic feasibility, such as the effects of aging on facilities, scale limitations of facilities, and inefficient budget and financial support are critical considerations in final decision making. Other barriers to business such as negotiation difficulty and adjustments of operating schedules also inhibit the popularization of waste heat recovery and exchange (Tabata and Tsai, 2016). Consequently, the optimal location, facility capacity, technology and system integration, and market mechanism for maximizing the efficiency of heat recovery from incinerators should be reconsidered during the coming retrofitting period.

Recently, the Japanese government has implemented several policies aimed at or involving the promotion of utilizing unused heat and renewables in the heat supply. National laws and regulations, including the 3rd Fundamental Plan for Establishing a Sound Material-Cycle Society and the Plan for Improvement of Waste Management Facilities passed in 2013 and the Act on Rational Use of Energy revised in 2014, propose to popularize power generation from waste combustion through a feed-in-tariff (FiT) system as well as to enlarge the facility capacity and enhance technology integration in heat exchange and methane fermentation to increase their usage based on the heat requirements of the local society. Accordingly, specific subsidies are also being expanded to cover the costs of feasibility studies and part (one-third to one-half) of equipment purchases and infrastructure investment. In particular, the coming specific FiT system for a heat supply market and publication system for large facilities to annually report the quantity of waste heat would dramatically improve the feasibility of implementing heat exchange.

However, heat exchange is no more than one energy-saving