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Waste Heat Recovery and Energy Efficiency for Small and Medium Power Users

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In the Philippines, achieving energy sufficiency has always been a challenge, especially during the dry and hot season, because of the increased power demand for cooling and drought-related reduced water supply.

In addressing the problem of unstable and inadequate supply of energy, the country has pursued various measures. On the supply side, increasing electric power generation means increasing the capacity and number of power plants. The government is also aggressively promoting the use of renewable energy to meet growing demand and reduce greenhouse gas emissions. On the demand side, solutions include the promotion of energy conservation and energy efficiency.

This paper focuses on technologies that would help lessen energy consumption and thus promote energy efficiency. In particular, it studies the recovery and conversion of waste heat into electricity and refrigeration/cooling. *Waste heat* refers to the unused thermal energy that is released to the environment by industrial processes or equipment, like the exhaust of combustion chambers in furnaces and engines. Left alone, the heat simply goes to waste and becomes part of an inefficiency, which represents lost opportunity. Financially, waste heat recovery (WHR) technologies would also allow operators or owners to save on power costs; environmentally, recycling waste heat for power means less emissions that contribute to global warming.

The present paper explores the use of low-temperature waste heat for power and refrigeration/cooling needs. Already done in the Philippines is the conversion of medium-temperature waste heat (i.e., 230–650°C) by steam power plants in the cement and metals industries. Nevertheless, technologies for medium-temperature conversion cannot be automatically used for low-temperature sources. By studying technologies for low-temperature waste heat (i.e., lower than 230°C), the paper hopes to broaden the access of small and medium enterprises to this relatively energy- and cost-saving technology.

This paper aims to contribute to the discussion on emerging technologies that may be used to improve energy efficiency in the country. The next sections provide a brief overview of waste heat sources and conversion technologies in the Philippines, and then explore those that may be used for low-temperature WHR. The paper ends by discussing the need for incentives, especially those under Republic Act No. 11285 or the Energy Efficiency and Conservation Act of 2019, to fully pursue this option.

Overview

One way to increase energy efficiency is to utilize waste heat, which comes as byproducts or energy from different industrial and commercial processes. Waste heat can be used in many ways through different

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technologies. Instead of letting waste heat simply escape into the environment, existing technologies convert heat into electricity for refrigeration, space cooling, and production processes.

The Philippines has embarked on waste heat utilization since 2007. Sources of waste heat of installed power plants in the country are currently limited to metal and cement industries (Cahiles-Magkilat 2021; UNFCC n.d.-a, n.d.-b). The first power plant installation that uses waste heat from a metal sintering plant became operational in 2007 (UNFCC, n.d.a). More recently, the Board of Investments approved the operator registration of a 4.5-MW power-generating unit that will utilize waste heat (Cahiles-Magkilat 2021). The few installations in the country that have adopted the technology use medium-temperature heat (230 to 650°C) as sources (Kishore and Priya 2018) to generate electricity.

It is notable that low-temperature WHR for power generation has yet to be tapped in the country despite its accessibility to small power users. Low-temperature waste heat may be sourced from activities such as cooking in stoves and baking in ovens, as well as from refrigeration and airconditioning systems that expel heat to the surroundings through condensers. Auxiliary devices like pumps, blowers, and fans can be used in any process to transfer heat that will be used for energy conversion.

Even newer models of boilers and furnaces, which commonly use heat-recovery devices to reduce waste heat and are thus more efficient and meet regulatory exhaust parameters, still produce exhaust gases that may be tapped to either generate electricity or produce refrigeration/cooling.

Systems for low-temperature energy may take off from existing systems for medium-temperature power generation. For conversion to electricity, heat engines like organic Rankine cycles (ORCs), ORCs with ejectors, and thermoelectric generators (TEGs), are commercially available. For utilization in refrigeration or airconditioning systems, absorption, adsorption, duplex Rankine cycle, and heat-driven ejector cooling systems can use waste heat for refrigeration/cooling. The physical limitations of devices that convert medium-temperature waste heat into energy or refrigeration/cooling are also addressed in a low-temperature setting either by using organic working fluids such as refrigerants in running thermo-fluid equipment like ORC and absorption/adsorption refrigerator/cooler, or using a semiconductor-based technology like a TEG. The principle is to make the temperature of the effluent as close as possible to that of the surroundings while carrying out the conversion.

BOX 1

Industries and equipment that might be tapped for waste heat recovery

1) Metal smelting and recycling plants—effluent heat from furnaces and flue gases
2) Food and beverages manufacturers—waste heat from general processing of food products
3) Thermal power generation plants—waste heat released in condensers or other cooling component
4) Boilers—waste heat in the flue gases emitted at stacks
5) Engines—waste heat in coolants, air-cooled cylinders, and
6) Data centers—heat generated by running servers, electrical and electronic components, and batteries.

Source: Kishore and Priya (2018)

Nevertheless, while almost all medium-temperature conversion technologies can be used for lower temperature sources, there is a usual penalty of reduced efficiency. For example, components of systems using steam are not efficient and difficult to control when running at lower temperatures. For one, because steam at low temperature easily condenses, there is a risk of using a steam power plant for low-temperature WHR since condensates can damage its components. Finally, common technologies for medium-temperature conversion are also usually bulky. Therefore, despite the availability of technology for the utilization of medium-temperature waste heat, there is still a need to explore the technology for the utilization of low-temperature waste heat.

BOX 2

Sources that may produce low-temperature waste heat for self-use

- Exhausts of heat-recovery devices and furnaces
- Condensate of processed steam
- Cooling water of furnace doors, annealing furnaces, air compressors, diesel/bunker/gasoline engines
- Refrigeration and airconditioning condensers
- Drying, baking, and curing ovens
- Hot processed liquids/solids

Source: Kishore and Priya (2018)

The next section presents technologies that may be used to convert waste heat at low temperature (< 230°C) (Kishore and Priya 2018) into either electricity or refrigeration/cooling by using appropriate conversion technologies as ways to enhance the overall energy efficiency of small and medium power users.

Recommended Systems for Low-Temperature Waste Heat Recovery

This study focuses on low-temperature waste heat conversion into electricity or refrigeration/cooling because it is among the most utilized by small and medium enterprises, which need it the most. Temperatures of the conversion systems can be optimally matched to those of the resources that are commonly lower than 230°C using available technologies.

Systems for conversion to electricity

- Organic Rankine Cycle (ORC)—An ORC power plant is a thermal plant that uses heat at a lower temperature than the one used in steam power plants to vaporize an organic working fluid like refrigerants and then let the vaporized fluid run a turbine to generate power. The fluid is used in a closed cycle so it does not escape to the surroundings. The ORC is one of the most mature technologies in converting small to moderate amounts of heat. It offers higher reliability and efficiency than steam power plants when running at low temperatures because it can withstand the condensate that forms in the flow of its working fluid. One notable utilization is WHR in cement plants that are already available in other countries but also have high potential in the Philippines, where existing WHR installations are steam power plants (Cahiles-Magkilat 2021; UNFCC n.d.-b). Also, this application is being used in geothermal plants in the country that have higher temperatures than low-temperature waste heat.
- Organic Rankine Cycle with Ejector—Modifying the ORC by adding an ejector is one of the emerging techniques in improving the efficiency of the ORC, which, when used in WHR, can be expected to improve the industry's energy efficiency as well.
- **Thermoelectric Generator (TEG)—It is a semiconductor-based device that can directly convert heat from a higher temperature into electricity. The waste heat from the source is transferred to the hot side of the device, and cooling on the other side is provided.**

Systems for conversion to refrigeration/cooling

- Absorption Refrigeration System—Refrigeration/cooling is carried out using a pair of fluids and heat, rather than electricity, which is used in the more common vapor compression cycle. This system uses the principle that one substance can be absorbed by another. The commonly used fluids are lithium bromide water solution (for air conditioning and above-freezing applications) and ammonia-water solution (for freezing applications).
- Adsorption Refrigeration System—It also takes advantage of using a pair of substances and heat to attain cooling. On the other hand, it uses the principle that one substance can stick to the surface of another. It is basically useful when heat is intermittently available.
- Duplex Rankine Cycle—Here, the turbine in the ORC plant is directly driving the compressor of the refrigeration system, making the set-up more efficient since the loss in converting into electricity is being avoided.

- Heat-Driven Ejector Refrigeration System—It is a direct combination of power and cooling cycles. Heat is converted into mechanical energy by the power cycle, and that energy, in turn, drives the cooling cycle. Efficiency rises because intermediate energy conversion losses are reduced.

Scale of conversion

Given the limitations of having low temperature and that the amount of waste heat can vary among sources, power generation can range from watt to megawatt capacities. As adopted from a classification according to capacity for hydropower (Hanania et al. 2021), the scale can be categorized into the following: pico power (<5 kW), micro (5 kW–<100 kW), mini (100 kW–<1 MW), small (1 MW–<15 MW), and medium (15 MW–<100 MW). For households, pico to micro levels can be expected, while for industries with furnaces like cement or metal smelting plants, small to medium levels may be attained.

Cooling applications can vary from airconditioning in a small room or cooling in a small box (kilowatt capacities) to airconditioning a whole building or running a cold-storage facility (megawatt capacities).

Savings projection

For every kilowatt-hour (kW·h) from waste heat that is used for electricity consumption, around 67 percent of savings could be attained based on electricity cost of ₱12/kW·h and own production cost of ₱4/kW·h. The same amount can also be saved when waste heat is used to provide refrigeration/cooling. From the usual coefficient of performance (COP) of 3 for commercial refrigeration/cooling systems, 3 kW·h of cooling from waste heat will only use about one-third of the equivalent electric consumption of 1 kW·h for the compressor system.

Enabling Policy Environment

Support and incentives for increasing energy efficiency are embodied in Republic Act No. 11285 or the Energy Efficiency and Conservation Act (Republic of the Philippines, 2019) that was promulgated on 12 April 2019 and its Implementing Rules and Regulations or IRR (Department of Energy 2019). The strategy is within the mandate of the Energy Efficiency and Conservation Division of the Energy Utilization and Management Bureau in the Department of Energy (DOE). The associated incentives, operational savings, and benefits to the environment can be expected to translate into energy sustainability and good portfolio, where the investment made in the strategy presents a highly effective rate of return.

Several provisions of Republic Act No. 11285 apply to any system that releases low-temperature heat. One particular requirement of the Act that the system must meet is compliance with the Minimum Energy Performance (MEP). As Section 4(w) of Republic Act No. 11285 stipulates,

> Minimum Energy Performance (MEP) refers to a performance standard which prescribes a minimum level of energy performance for the commercial, industrial, and transport sectors, and energy-consuming products including appliances, lighting, electrical equipment, machinery, and transport vehicles that must be met or exceeded before they can be offered for sale or used for residential, commercial, transport, and industrial purposes.

The energy performance metric of the system using WHR can be increased to meet the MEP through the increase in energy efficiency.

Other government programs through the DOE that are associated with Republic Act No. 11285 are “An Energy Efficiency Roadmap for the Philippines 2014–30” (The Switch-Asia Programme of The European Commission 2013) and the “Philippines Energy Efficiency and Conservation Action Plan 2016-2020” (The Switch-Asia Programme of The European Commission 2015). Based on the medium-term (2016–20) plan in the roadmap, and as monitored in the action plan, models in industry and retrofits in commercial buildings, relating to energy efficiency and introduced by energy service companies (ESCOs), became available.

Based on Republic Act No. 11285 and Executive Order No. 226, or the Omnibus Investments Code of 1987, tax benefits or holidays and duty-free importation may be enjoyed as fiscal incentives upon certification of the DOE that a particular project on WHR is an energy efficiency project. Nonfiscal incentives can include "technical assistance from government agencies in the development and promotion" of the project, as well as the "provision of awards and recognition for innovations in energy efficiency" and best practices in conservation (Republic Act No. 11285, Section 26).

For using technologies in converting waste heat to electricity or cooling, pioneer status may also be given to an industry by the Board of Investments, as some of the mentioned technologies like the ejector power plant cycle and the heat-driven ejector refrigeration cycle are new ones (Investment Code 1987, Article 17).

In the long-term (2021–30) plan in the roadmap (The Switch-Asia Programme of The European Commission 2013), low-temperature WHR can be considered for incorporation in the inclusion of residential measures in the Building Code of the Philippines and mandatory disclosure of commercial building performance.

With Republic Act No. 11285, its Implementing Rules and Regulations (IRR), and the aforementioned roadmap and action plan, technologies for the low-temperature WHR may be explored, developed, and commercialized for the country's small and medium enterprises, which comprise about 99 percent of our country's formal economy. These can also become an element in new industries or service offerings that can be brought under energy efficiency like consulting, audits, software, equipment and components, training, and insurance (Republic Act No. 11285 2019; Department of Energy 2019; The Switch-Asia Programme of The European Commission2013, 2015).

Environmental Sustainability

Waste heat is basically clean. It is expected to be of acceptable levels or free of ozone-depleting gases, greenhouse gases, and other pollutants because the processes where they come from are regulated as environmentally safe. Furthermore, the reduction in fuel consumption from the increase in energy efficiency can also help in reducing the carbon footprint in the power-generation sector.

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