Primary Energy®

Illinois Power Agency
105 W. Madison Street, Suite 1401
Chicago, IL 60602
Attn: Mr. Anthony Star, Director

February 28, 2022

Re: Request for comment - 2022 Long Term Renewable Resource Procurement Plan

Mr. Star:

I write in response to your January 13, 2022, correspondence wherein the Illinois Power Agency requested comment on the Agency's 2022 Long Term Renewable Resources Procurement Plan. I appreciate the opportunity to provide input into this process.

I am the Chief Executive Officer for Primary Energy Recycling. Primary Energy assists its North American steel and manufacturing clients to become more efficient (and thus, more competitive) in their manufacturing processes by matching those industries with state-of-the-art thermal recycling technologies. Primary creates value for its customers by capturing waste heat incidental to the manufacturing process, and using that heat to generate electricity. This electricity, in turn, is used by the manufacturer to replace electricity that it would have otherwise obtained from other sources.

In 2021, Primary Energy and Kanin Energy, another waste heat to power entity, commissioned ICF, a global advisory and digital service provider, to prepare a white paper which compares the carbon reduction potential for waste heat to power applications as compared to various other "renewable" technologies (solar, wind, and gas-fired combined heat to power). That study is provided herewith, as Exhibit A, as support for the positions taken by Primary Energy, and for the Agency's consideration as it moves forward in finalizing the draft 2022 Long Term Plan. *See*, Exhibit A, ICF (2021). *Assessment of Carbon Reduction Potential for Waste Heat to Power Applications* [White paper].

One hundred percent of the thermal energy produced in the subject manufacturing processes is lost to the surrounding environment *unless* that heat can be harnessed for a beneficial use. Waste Heat technologies capture this waste heat and convert it to electricity. Importantly, the "waste heat to power" technology involves no supplemental energy beyond what would have been used in the underlying manufacturing process. As such, waste heat electricity is considered a zero-emission energy source. *ICF, p. 2.* By capturing this waste heat, the technology reduces heat dissipation into the surrounding environment, and also reduces the manufacturer's demand for purchased grid electricity that would otherwise come from other (perhaps carbon-based) sources. It is estimated that the use of waste heat electricity avoids over 1,000 pounds of carbon for every megawatt hour produced. *ICF, p. 13.*

Prior to 2016, Illinois properly recognized waste heat technologies as a "renewable energy resource" which qualified for the generation of renewable energy credits for addressing Illinois Renewable Portfolio Standard. Pre-2016, as a "renewable energy resource," waste heat resources in adjacent states were able to provide renewable energy credits into Illinois, to assist in carbon reduction goals. Primary Energy commends the Illinois General Assembly for its vision in returning that status to this important technology.

Primary Energy currently partners with five Indiana manufacturers and is considering additional projects in all states that have compatible manufacturing industries, including Illinois. As primary looks forward to once again being able to participate in Illinois' carbon reduction goals, the company seeks clarification/guidance relating to the draft Long-Term Plan.

First, it appears that, subsequent to 2016, the IPA adopted certain public interest criteria for wind and solar facilities located in adjacent states to participate in the Illinois REC market. Those 5 criteria are outlined on page 92 of the Draft Plan with associated formulae for 4 of the 5 categories discussed in subsequent pages. Primary looks to understand that, if a waste heat renewable energy resource located in an adjacent state, applies for approval and meets the minimum score outlined in the Draft Plan it will, without further qualification, be able to produce REC's for compliance with the Illinois RPS.

Secondly, in the Draft Plan, at footnote 201 (p. 103), the Agency references the 2018 adjacent state application form. Moving forward, does the Agency contemplate making any changes to the referenced application form?

Finally, given the fact that the Illinois General Assembly has once again recognized that waste heat is indeed a renewable energy resource, will the Agency concur with the position that waste heat electricity is indeed a zero incremental emission technology?

Thank you again for allowing these comments. We look forward to the Agency's response to the questions set forth herein.

Mo Klefeker

Mo Klefeker, CEO
Primary Energy Recycling

EXHIBIT A

PRIMARY ENERGY

Assessment of Carbon Reduction Potential for Waste Heat to Power Applications

Prepared for
Kanin Energy
Primary Energy

IMPORTANT NOTICE: This is a Kanin Energy commissioned study prepared for Kanin Energy and Primary Energy by ICF. This report and information and statements herein are based in whole or in part on information obtained from various sources. The study is based on public data on equipment performance for solar photovoltaic, wind turbine, combined heat and power (CHP) and waste heat to power (WHP) systems, combined with marginal emission factors from the Environmental Protection Agency to determine emissions impacts. The study used 2019 AVERT emission rates Neither ICF nor Kanin Energy make any assurances as to the accuracy of any such information or any conclusions based thereon. Neither ICF nor Kanin Energy are responsible for typographical, pictorial, or other editorial errors. The report is provided AS IS. No warranty, whether express or implied, including the implied warranties of merchantability and fitness for a particular purpose is given or made by ICF or by Kanin Energy in connection with this report. You use this report and the results contained within at your own risk. Neither ICF nor Kanin Energy are liable for any damages of any kind attributable to your use of this report.

Table of Contents

Assessment of Carbon Reduction Potential for Waste Heat to Power Applications

Executive Summary

Waste Heat to Power (WHP) systems are proven technologies that produce electricity from existing sources of waste heat with zero incremental carbon emissions. WHP systems primarily use either the Steam Rankine Cycle (SRC) or the Organic Rankine Cycle (ORC) to transfer energy from waste heat to a working fluid.[1] The evaporated working fluid is pushed through a turbine or expander to produce the rotational energy needed to generate electricity.

WHP systems function similarly to geothermal power plants, but with a different heat source. In both applications, a consistent source of heat is used to evaporate water (SRC) or an organic fluid (ORC) and run it through a turbine to generate power. No incremental emissions are created in either case, as both WHP systems and geothermal power plants produce electricity with existing heat energy.

Figure ES-1 diagrams a simple WHP system using an Organic Rankine Cycle.

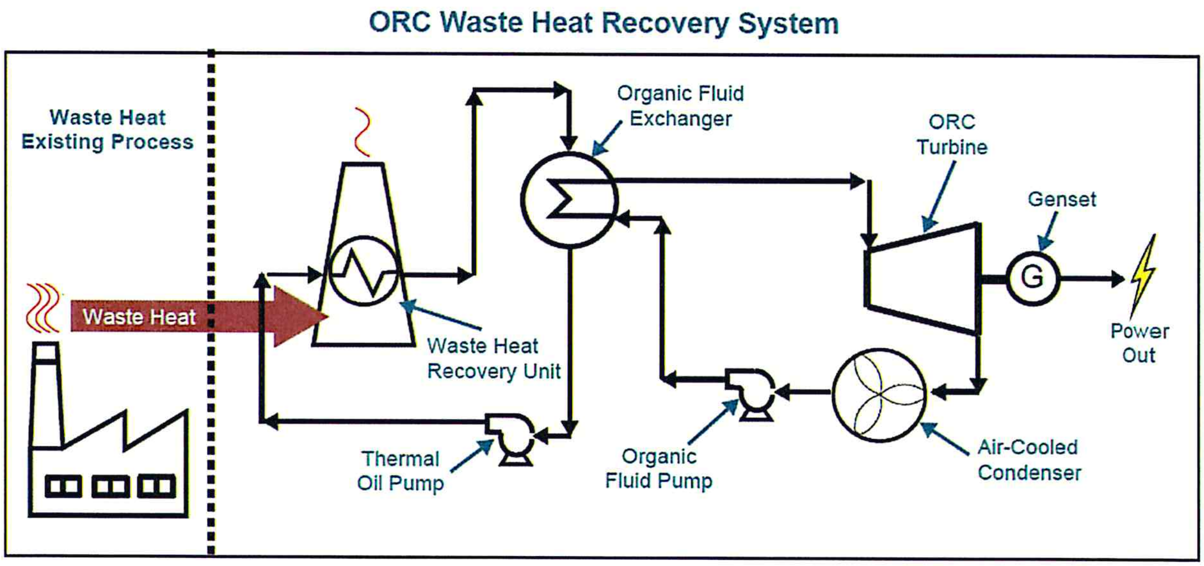

Figure ES-1. Waste Heat to Power System Diagram (ORC system)

Zero-emission WHP systems can contribute towards decarbonization efforts and provide additional sources of electricity for the electrification of end-uses. The additional electricity production from WHP makes use of energy from high-temperature thermal processes that are difficult to electrify, which can help relieve grid congestion and enable the electrification of other processes.

State and local policies incentivizing WHP installations have lagged behind other comparable renewable and energy-efficient technologies. Out of 37 states with Renewable Portfolio or Energy

[1] In SRC systems, water is the working fluid, while in ORC systems, the working fluid is an organic compound (typically pentane) with a lower boiling temperature.

Efficiency Resource Standards (RPS or EERS), only 11 explicitly recognize WHP technologies, while all 37 include solar photovoltaics (PV) and wind.[2]

In order to assess the emissions benefits of WHP compared to other technologies, ICF analyzed the emissions reduction potential of WHP, PV, wind, and gas-fired combined heat and power (CHP) systems in three U.S. locations.

- Los Angeles, California
- Columbus, Ohio
- Baton Rouge, Louisiana

ICF determined the average carbon emissions impact of WHP systems *per MWh* of generation and reached the following conclusions:

- WHP, PV, and wind all produce ***zero on-site carbon emissions***.
- WHP and solar PV systems have similar avoided grid emission rates *per MWh* of generation.
- WHP systems offer higher avoided grid emissions compared to wind systems across all three analysis locations.

Figure ES-2 shows the carbon emissions impact per MWh of energy generation by technology in all three analysis locations. In the chart, the negative Y-axis shows avoided grid emissions while the positive Y-axis shows on-site emissions.

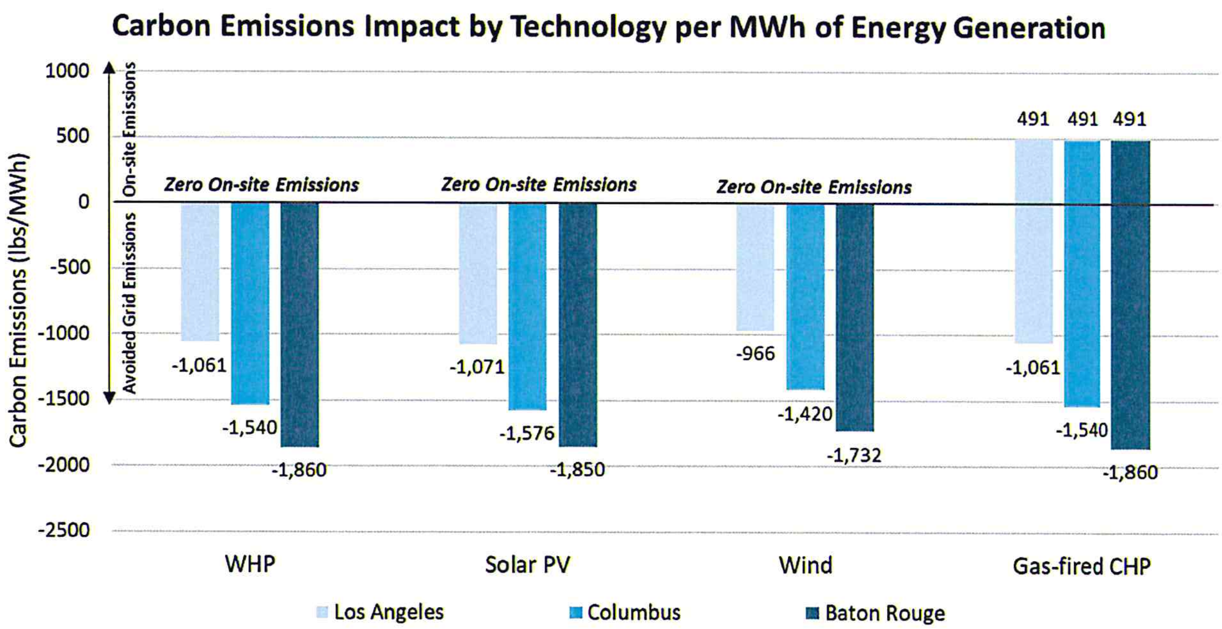

Figure ES-2: Carbon Emissions Impact by Technology – Equivalent Energy Production Basis

[2] NC Clean Energy Technology Center, *Database of State Incentives for Renewables & Efficiency*, www.dsireusa.org, Accessed September 2021.

ICF also analyzed the *annual* carbon emissions impact of 1 MW of WHP compared to solar PV, wind, and CHP systems of equivalent generation capacity. The key takeaways of this analysis include:

- WHP systems have the **highest** avoided grid emissions on a tons/MW-year basis. This is due to the high annual capacity factor of WHP systems.
- For an equivalent capacity, WHP systems displace substantially higher amounts of grid electricity and associated grid emissions compared to other generation technologies.

Figure ES-3 shows the *annual* carbon emissions impact (in tons/MW-year) of 1 MW of generation capacity by technology in all three analysis locations.

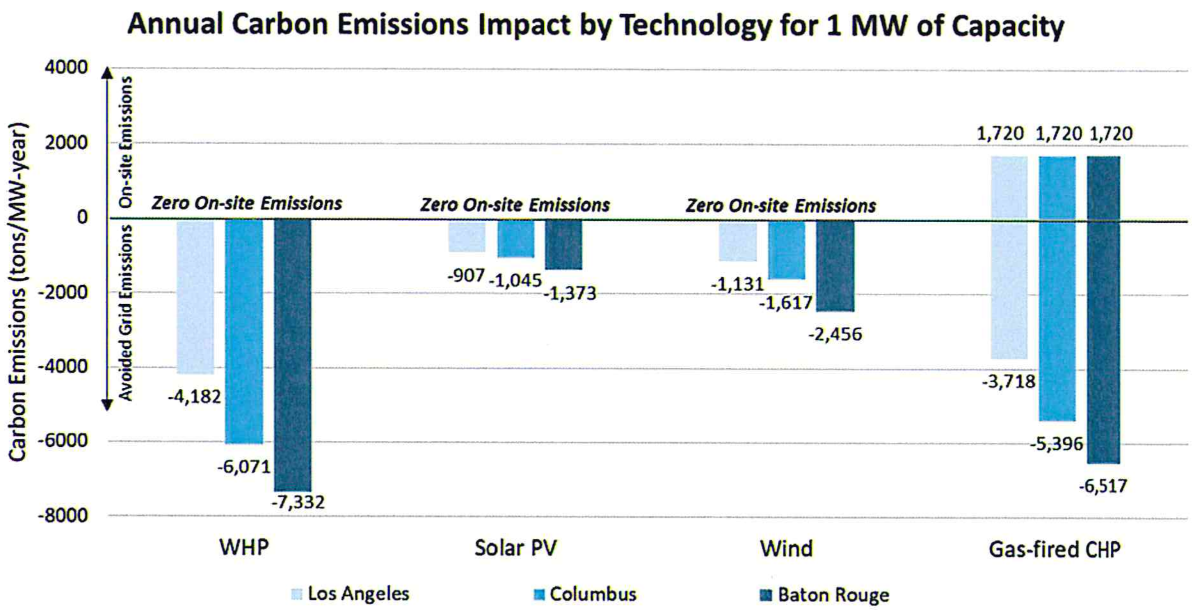

Figure ES-3: Annual Carbon Emissions Impact by Technology – Equivalent Generation Capacity Basis

ICF's analysis demonstrates that the carbon emissions reduction potential for WHP is comparable to distributed PV and wind power systems. All three technologies produce electricity with zero emissions. On a capacity-basis, WHP systems offer significantly more emissions reductions due to higher operational capacity factors.

WHP systems provide superior benefits compared to intermittent renewables such as solar and wind, and other energy efficient technologies, but WHP does not currently receive the same level of policy support. WHP installations can have high capital cost barriers depending on waste heat sources and system design. For the decarbonization and grid benefits of WHP to be realized, more supportive policies and incentives will likely be needed, particularly at the state and local level. Additionally, wider recognition of WHP as a clean energy resource by corporate renewable energy buyers will expand the market for WHP.

Introduction: Waste Heat to Power

At commercial buildings and industrial facilities across the United States, processes that produce and consume energy also generate large quantities of heat. The vast majority of this heat is wasted into the atmosphere, while it could be captured and converted into useful electric or mechanical energy. Waste heat to power systems that generate electricity on-site with zero incremental emissions have been successfully deployed both in the United States and overseas. Research published by the Oak Ridge National Laboratory in 2015 also shows that there is approximately 15 GW of untapped WHP potential in the U.S. that can contribute towards efforts to decarbonize the energy sector.[3]

WHP systems function like geothermal power plants, but with a different source of heat. WHP systems capture heat from existing thermal processes while geothermal power plants capture heat from the Earth. In both applications, a consistent source of heat is used to create vapor to drive a turbine, generating electricity.

In high temperature applications (+1000F), water is converted into steam in a heat recovery steam generator (HRSG) and the steam is used to drive a Steam Rankine Cycle (SRC) turbine. In lower temperature applications (+250F), thermal oil is heated in a waste heat recovery unit (WHRU) which is then used to vaporize an organic fluid (e.g., pentane) to drive an Organic Rankine Cycle (ORC) turbine.

WHP systems are agnostic to the heat source and do not produce any new emissions. WHP systems simply make use of existing heat energy to produce electricity, resulting in zero on-site emissions and significant carbon emission *reductions* compared to the utility grid. Figure 1 shows how a Steam WHP system is configured, and Figure 2 shows an ORC WHP system configuration.

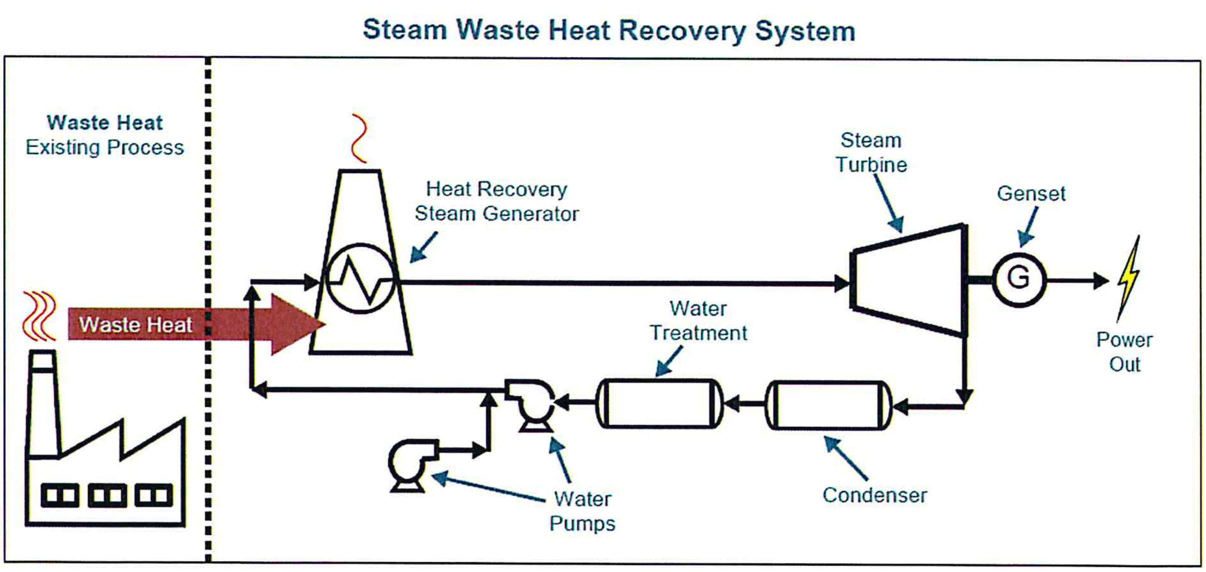

Figure 1. Typical Steam Waste Heat Recovery Configuration

[3] Oak Ridge National Laboratory and ICF. *Waste Heat to Power Market Assessment, March 2015,* https://info.ornl.gov/sites/publications/files/Pub52953.pdf

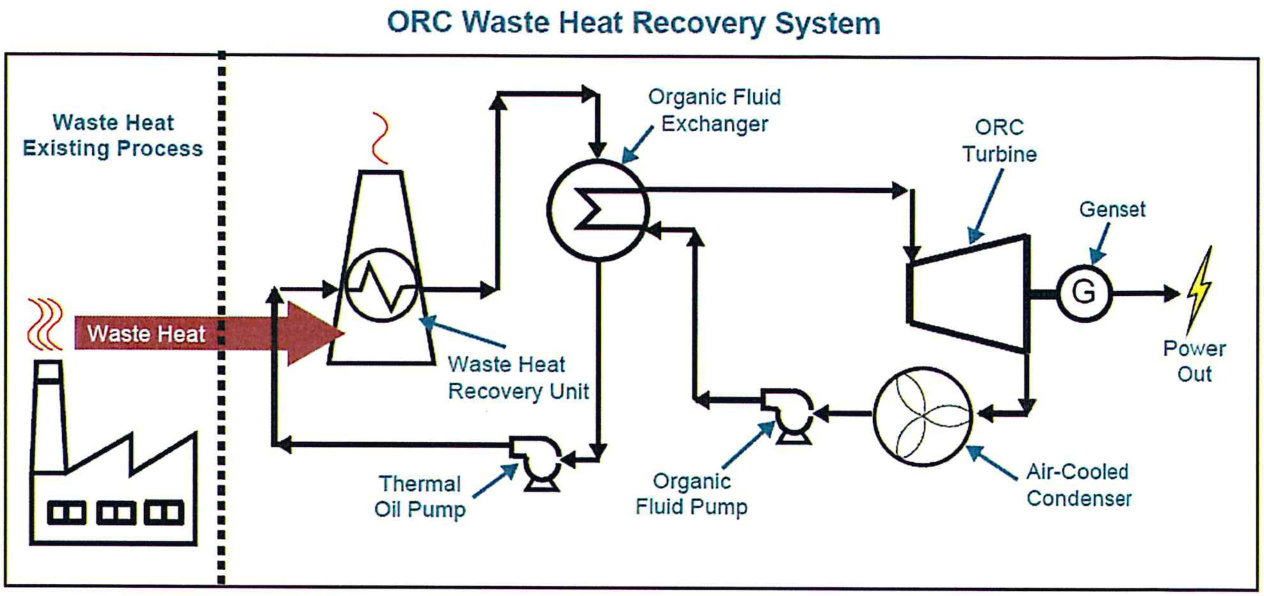

Figure 2. Typical ORC Waste Heat Recovery Configuration

The facility providing waste heat on the left of both Figures 1 and 2 could be replaced with any source of heat. A geothermal heat source would effectively turn the WHP system into a geothermal power plant. However, geothermal resources sufficient for power production tend to be located far from energy requirements, so transmission lines must be built to transport the electricity. With WHP, the source of heat is co-located with facilities that can make use of the electricity and replace the need for grid electricity which is often produced from fossil fuels.

Zero-emission WHP systems can contribute towards decarbonization efforts and provide additional sources of electricity for the electrification of end-uses. The additional electricity production from WHP makes use of energy from high-temperature thermal processes that are difficult to electrify, which can help to relieve grid congestion and enable the electrification of other processes.

Federal and state governments have enacted policies to encourage more WHP installations. In 2020 the Federal Investment Tax Credit (ITC) was amended to provide WHP systems with the same incentives as renewable energy technologies such as solar photovoltaic (PV) and wind power projects, recognizing the strong potential for carbon emission reductions.

Historically, and at the state/local level, WHP policies have not experienced the same level of parity with PV, wind, and other renewable and energy-efficient technologies. Out of 37 states with Renewable Portfolio or Energy Efficiency Resource Standards (RPS or EERS), only 11 explicitly recognize WHP technologies, while all 37 include PV and wind.[4] WHP can sometimes be included in policies and incentives for combined heat and power (CHP) installations, as WHP can be considered a form of CHP. However, WHP systems often require additional considerations due to differences

[4] NC Clean Energy Technology Center, *Database of State Incentives for Renewables & Efficiency*, www.dsireusa.org, Accessed September 2021.

with traditional CHP installations, including efficiency measurements, zero-emission status, and variations in the accessibility and content of available waste heat streams.

In this paper, ICF provides an overview of waste heat sources, applications, and potential, followed by an analysis that compares the carbon emission reduction potential of WHP systems compared to PV, wind, and CHP applications at three U.S. locations (Los Angeles, Columbus, and Baton Rouge). At the conclusion, ICF offers key findings and takeaways from the analysis.

Overview of WHP Applications

Waste heat that can be used for power generation can come from a number of different sources. Thermal processes such as boilers, furnaces, ovens, incinerators, and kilns release heat that can be captured and converted into electricity.

Industrial manufacturing facilities often make use of continuous processes that release heat in large quantities. Exothermic chemical reactions used in fertilizer manufacturing are a prime example. The Mosaic Company incorporates over 90 MW of WHP steam turbines at their fertilizer manufacturing facilities in Bartow, Florida, consistently producing zero-emission power throughout the year.[5] Industrial processes such as steel production generate large amounts of waste and byproduct heat, making them highly suited for integration with WHP system. Most industrial processes generate high temperature exhaust heat streams (> 450 degrees F) and are

Cleveland Cliffs Steel Mill: East Chicago, Indiana

System Size	90 MW
Prime Mover	Steam Rankine Cycle
Fuel Type	Waste Heat
Installation Year	1996
Energy Savings	Serves >20% of facility electricity requirements

Cleveland Cliffs Steel deployed a 90 MW steam-driven WHP system in their East Chicago, Indiana steel plant in 1996 to utilize high temperature waste heat and waste byproduct fuel (which would otherwise be flared) to generate emission-free electricity. The WHP system generates sufficient electricity to meet over 20 percent of the facility electricity requirements and was recognized by the U.S. EPA in 2007 for its environmental performance and efficiency.

Photo courtesy of Primary Energy
Learn more about this project at https://www.heatispower.org/port-arthur-steam-energy-lp-pase/1

[5] United States DOE CHP Installation Database, https://doe.icfwebservices.com/chp, accessed October 2021.

typically paired with steam WHP systems. In 1996, Cleveland Cliffs Steel installed a 90 MW ABB steam turbine at their East Chicago, Indiana steel plant to convert exhaust heat and waste byproduct fuel from the No. 7 steel blast furnace into emission-free electricity.

There are also opportunities for WHP systems using ORC technologies to recover lower-temperature waste heat from commercial, institutional, and industrial facilities. For example, the Utah Associated Municipal Power Systems installed a 7.8 MW ORMAT ORC unit attached to the Kern River Gas Compressor station to supply carbon-free electricity to the local electric grid. adjacent to the Kern River.[6]

Veyo Heat Recovery Project: Veyo, Utah

System Size	7.8 MW
Prime Mover	Organic Rankine Cycle
Fuel Type	Waste Heat
Installation Year	2016
Emission Reduction	Carbon-free Electricity

Utah Associated Municipal Power Systems and Kern River Gas Transmission deployed the Veyo Heat Recovery Project in May 2016 to capture waste heat from the adjacent gas compressor station and generate electricity with zero incremental carbon emissions. The WHP system is rated at 7.8 MW of power and can generate electricity sufficient to power approximately 800 homes. The WHP system is interconnected with the local distribution grid operated by Rocky Mountain Power.

Learn more about this project at https://chptap.lbl.gov/profile/262/Veyo-Project_Profile.pdf

WHP systems are currently providing benefits to facilities in all sectors across the country. To date there are 140 WHP installations at 123 locations across the United States, providing over 1 GW of electric capacity without additional fuel consumption.[7]

Waste heat to power also has a large amount of technical potential. To characterize WHP potential, it is necessary to define the waste stream's composition, availability, temperature, and flow rate, as well as the presence of contaminants in the flow stream. According to recent estimates, there is over 8.8 GW of technical potential for WHP systems with heat sources above 450 degrees Fahrenheit. This potential is seen across 2,946 sites within the United States, primarily in industrial

[6] Upper-West CHP Technical Assistance Partnership, *Project Profile: Veyo Heat Recovery Project*, 2016, https://chptap.lbl.gov/profile/262/Veyo-Project_Profile.pdf
[7] United States DOE CHP Installation Database, https://doe.icfwebservices.com/chp, accessed September 2021.

facilities.[8] There is more potential for waste heat recovery from heat sources under 450 degrees from a wider range of facility types, but this untapped potential has not been quantified. Table 1 below highlights the industries which have the highest WHP potential for >450 F applications.[9]

Table 1. Technical Potential of WHP with High Temperature Heat Sources

Sector	Primary Waste Heat Source	Technical Potential (MW)
Petroleum and Coal Products	Petroleum coke calciners	3,593
Primary Metals	Blast furnaces, coke ovens, furnaces	2,186
Non-Metallic Minerals	Melting furnaces, lime/cement kilns	1,173
Pipeline Transportation	Natural gas compressor stations	1,102
Oil and Gas Extraction	Flared Gas	538
Waste Management	Incinerators	113
Chemical	Petrochemicals, exothermic processes	92
Other Industrial Sources	Combustion for heating/drying	43

Waste management is one sector that can benefit from WHP. A good example is found at the Albany County Water Purification District in New York, where waste heat generated from sewage-sludge processing is utilized through a Turboden ORC system to produce 925 kW of on-site electricity.

Albany County Water Purification District North Plant: Albany, NY

System Size	925 kW
Prime Mover	Organic Rankine Cycle
Fuel Type	Waste Heat
Installation Year	2012
Emissions Reductions	1,445 tons/yr

The Albany County Sewage District's North Plant disposes of its remaining post treatment sewage and sludge through a thermal process. The facility harnesses heat energy from process that would otherwise be wasted and uses it to fuel an Organic Rankine cycle (ORC) waste heat to power system to produce electricity. By generating power from on-site waste heat, the facility avoids using natural gas for additional electricity needs.

Photo courtesy of the County of Albany
Learn more about this project at https://www.heatispower.org/steel-mill-waste-heat-to-electricity/

[8] United States Department of Energy, *Combined Heat and Power (CHP) Technical Potential in the United States*, March 2016.
[9] Ibid.

The large technical potential for WHP presents an opportunity for facilities to reduce emissions by using existing heat sources to produce on-site electricity instead of purchasing from the electricity grid, where marginal generation tends to be provided by baseload energy systems powered by fossil fuels.

WHP Emissions Analysis

ICF performed a carbon emissions analysis comparing on-site and avoided grid emissions of WHP with that of solar PV, wind, and gas-fired CHP systems. ICF performed the emissions analysis for three locations in the United States – Los Angeles, CA; Columbus, OH; and Baton Rouge, LA. These three locations were selected for the analysis to assess the emissions performance of WHP systems against a range of incumbent electric grid emission rates with Los Angeles, Columbus, and Baton Rouge respectively representing low, average, and high grid emission rates relative to the U.S. average. Capacity factors of PV and wind systems which are reliant on location-specific resource availability were also taken into consideration.

Detailed assumptions and results for each analysis location are provided in the Appendix.

Assumptions and Methodology

To assess the carbon emissions impact of WHP systems relative to solar PV, wind, and CHP, ICF made some key assumptions regarding the carbon emission rates and generator capacity factors to be used in the analysis.

Carbon Emission Rates

On-site Emissions

ICF applied *zero* on-site emission rates for WHP, solar PV and wind systems and an on-site emission rate of 491 lbs/MWh for CHP. As demonstrated previously in Figure 1, WHP uses existing waste heat streams and produces zero incremental carbon emissions, similar to renewable resources like PV and wind. ICF estimated the on-site emissions for CHP by modeling a 1 MW natural gas-fired reciprocating engine with full thermal utilization. Data on on-site emissions of CHP was drawn from the Department of Energy (DOE) Technology Factsheet for Reciprocating Engines.[10]

Avoided Grid Emissions

ICF utilized data from the Environmental Protection Agency's (EPA) AVERT database to characterize the avoided grid emission rates for each technology and location combination in this analysis. The AVERT database provides estimates of average avoided marginal grid emission rates (in lbs of CO_2 per MWh) of distributed PV systems, onshore wind, and uniform energy efficiency, which represents a constant reduction in grid requirements similar to the effect of baseload WHP and CHP systems.[11]

[10] U.S. Department of Energy. *Combined Heat and Power Technology Fact Sheet Series*. Available at: https://www.energy.gov/sites/default/files/2016/09/f33/CHP-Recip%20Engines.pdf

[11] U.S. Environmental Protection Agency, *AVoided Emissions and geneRation Tool (AVERT)*, https://www.epa.gov/avert

EPA AVERT Emissions Database

The Avoided Emissions and generation Tool or AVERT is a resource provided by EPA to assess the grid emission abatement benefits of energy efficiency programs and renewable energy systems. AVERT separates the contiguous United States into 14 distinct electricity regions and incorporates assumptions regarding the resources that make up the electric grid at an hourly granularity level in each of these regions. AVERT also incorporates assumptions regarding the generation profiles of renewable resources such as solar PV and wind at hourly granularity for each of the 14 regions.

Using the underlying data from AVERT, EPA reports the average avoided marginal grid emission rates (in lbs/MWh) for distributed solar PV, onshore wind, and uniform energy efficiency (representing baseload resources) for each of the 14 AVERT regions. ICF applied these technology and location-specific emission rates in this analysis to characterize the emissions benefits of WHP relative to solar PV, wind, and CHP systems in Los Angeles, Columbus, and Baton Rouge.

Table provides a summary of the assumptions regarding on-site and avoided grid emission rates applied in this analysis.

Table 2: On-site and avoided grid emission rate applied in the analysis categorized by technology and location

Technology	Net On-Site Emissions (lbs/ MWh of CO2)	AVERT Avoided Grid Emission Rate (lbs/MWh of CO2)		
	All Locations	**Los Angeles, CA**	**Columbus, OH**	**Baton Rouge, LA**
WHP	0	1,061	1,540	1,860
Solar PV	0	1,071	1,576	1,850
Wind	0	966	1,420	1,732
CHP	491	1,061	1,540	1,860

Capacity Factors

ICF applied standard capacity factor assumptions of 90% for WHP and 80% for CHP systems across all three analysis locations, representing typical 24/7 industrial or institutional applications that are ideal for WHP and CHP. These assumptions reflect ICF's subject matter expertise on the operating characteristics of CHP systems, and Kanin Energy's experience owning and operating WHP systems across various applications. For solar PV and wind systems, ICF applied location-specific capacity factor assumptions based on data obtained from the National Renewable Energy Lab's PVWatts calculator,[12] and the DOE WINDExchange program.[13]

Table provides a summary of capacity factor assumptions applied in the analysis.

[12] National Renewable Energy Laboratory. *PVWatts Calculator*. Available at: https://pvwatts.nrel.gov/

[13] U.S. Department of Energy. *Wind Energy Capacity Factors*. Available at: https://windexchange.energy.gov/maps-data/332

Table 3: Capacity factors applied in the analysis categorized by technology and location

Technology	Equipment Capacity Factor Assumptions		
	Los Angeles, CA	Columbus, OH	Baton Rouge, LA
WHP	90%	90%	90%
Solar PV	19%	15%	17%
Wind	27%	26%	32%
CHP	80%	80%	80%

ICF carried out the emissions analysis for the three chosen study locations using two bases of comparison – Equivalent Energy Production and Equivalent Generation Capacity.

Equivalent Energy Production Basis

In this scenario, ICF estimated the carbon emission reduction potential *per MWh* of energy generated by a WHP system compared to solar PV, wind, and CHP. For each analysis location, ICF applied technology-specific on-site emissions and AVERT grid emission rates (as shown in Table 1) to compare the emissions impacts (in lbs/MWh) of WHP systems with solar PV, wind, and CHP systems. This comparison is intended to demonstrate how the emission impacts of WHP compare with other generation technologies in each of the three analysis locations owing to differences in on-site and avoided grid emission rates.

Equivalent Generation Capacity Basis

In this scenario, ICF estimated the carbon emission reduction potential of 1 MW of WHP *over the course of one year* compared to solar PV, wind, and CHP systems of equivalent capacity. For each analysis location, ICF applied technology-specific on-site emissions and AVERT grid emission rates (as shown in Table 1) and technology capacity factors (as shown in Table 2) to compare the *annual* emissions impacts (in tons/MW-year) of WHP systems with solar PV, wind, and CHP systems. This comparison is intended to demonstrate the differences in annual emission reduction potential of each technology owing to differences in avoided grid emission rates across the analysis locations and technology-specific capacity factors.

ICF applied the assumptions and analysis methodology described above to estimate the carbon emission impacts of WHP systems compared to solar PV, wind and CHP systems in Los Angeles, Columbus, and Baton Rouge. The results of this analysis are described in the Summary of Findings section below.

Summary of Findings

This section presents the results of the WHP emissions analysis categorized by the two bases of comparison - Equivalent Energy Production and Equivalent Generation Capacity.

Equivalent Energy Production Basis

ICF analyzed the average carbon emissions impact of WHP systems *per MWh* of generation compared to solar PV, wind, and CHP systems. The following are the key takeaways of this analysis:

- WHP systems generate **zero** on-site emissions similar to solar PV and wind systems while gas-fired CHP reciprocating engines across all three locations have an estimated on-site emissions rate of 491 lbs/MWh.
- WHP and solar PV systems have similar avoided grid emission rates *per MWh* of generation. In Los Angeles and Columbus, the avoided grid emission rate per MWh of solar PV is slightly higher than WHP systems while in Baton Rouge, WHP systems avoid slightly higher grid emissions. ICF's assessment is that on average, the avoided grid emission rate per MWh of WHP is on par with solar PV.
- WHP systems offer higher avoided grid emissions compared to wind systems across all three analysis locations. This is likely due to the fact that wind energy systems mostly displace grid electricity during late evening and night hours when the grid is supplied predominantly by baseload resources. In comparison, the steady generation of WHP systems allows for the displacement of less efficient marginal resources during peak demand hours in addition to displacing baseload electricity outside of peak demand hours.

Figure 3 shows the carbon emissions impact per MWh of energy generation by technology in all three analysis locations. In the chart, the negative Y-axis shows avoided grid emissions while the positive Y-axis shows on-site emissions.

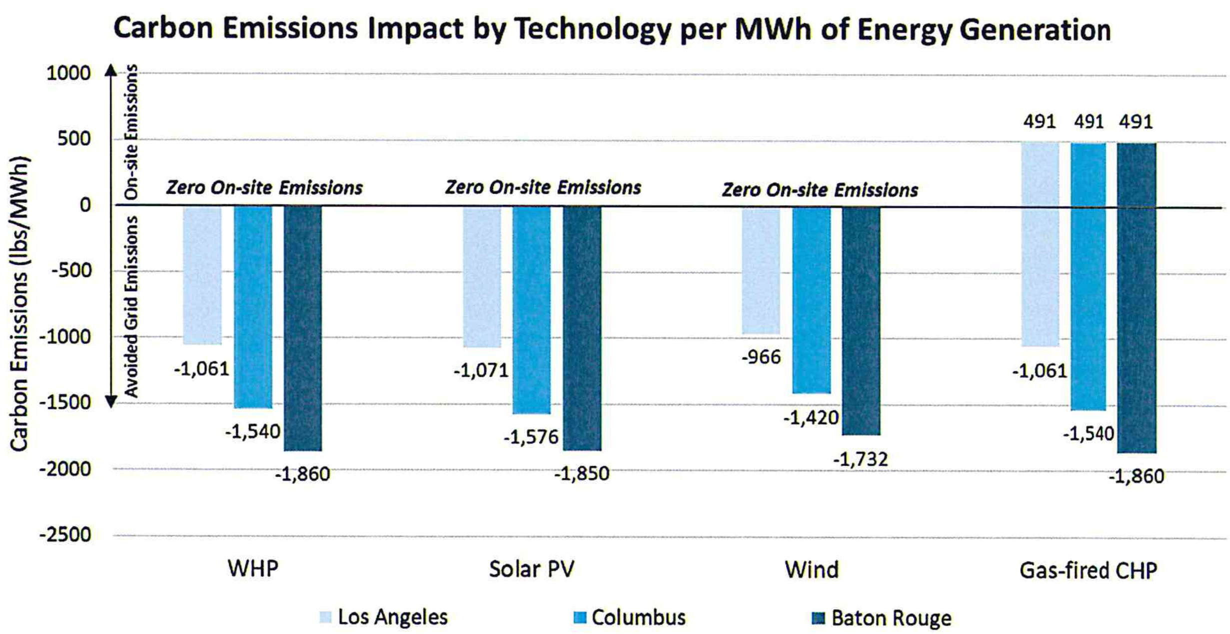

Figure 3. Carbon Emissions Impact by Technology – Equivalent Energy Production Basis

Equivalent Generation Capacity Basis

ICF analyzed the *annual* carbon emissions impact of 1 MW of WHP compared to solar PV, wind, and CHP systems of equivalent generation capacity. The following are the key takeaways of this analysis:

- WHP generate **zero** *annual* on-site emissions similar to solar PV and wind systems while gas-fired CHP reciprocating engines across all three locations have estimated annual on-site emissions of 1,720 tons/MW-year.
- WHP systems have the **highest** avoided grid emissions on a tons/MW-year basis. This is due to the high annual capacity factor of WHP systems compared to solar PV, wind, and CHP systems. A 1 MW WHP system can, therefore, displace substantially higher amounts of grid electricity and associated grid emissions over the course of a day or year compared to other generation technologies included in this analysis.

Figure 4 shows the *annual* carbon emissions impact (in tons/MW-year) of 1 MW of generation capacity by technology in all three analysis locations.

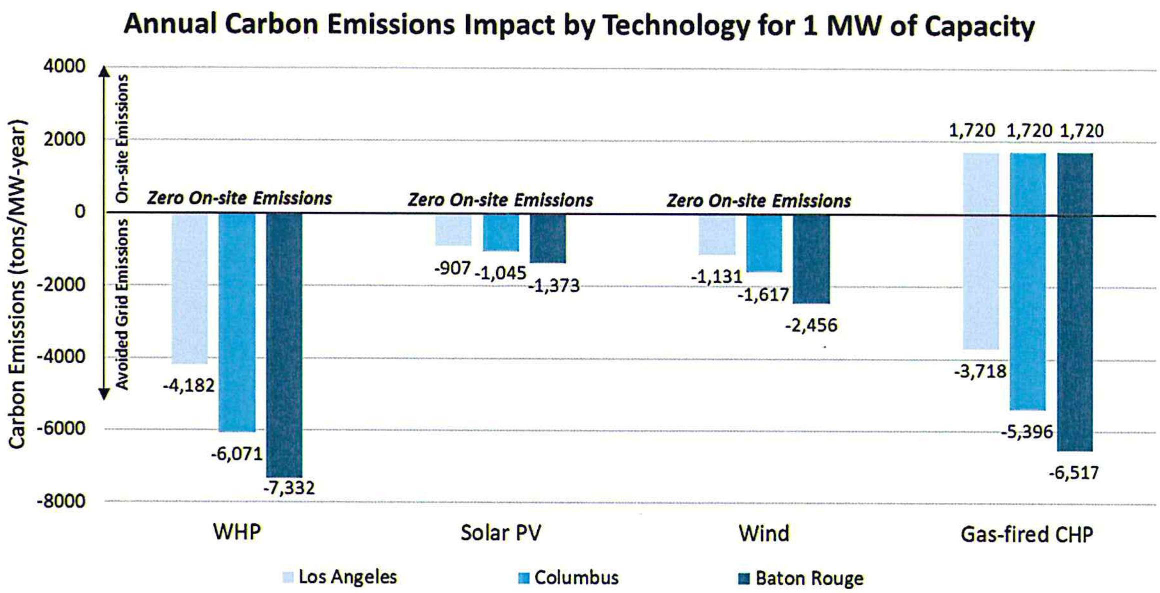

Figure 4. Annual Carbon Emissions Impact by Technology – Equivalent Generation Capacity Basis

From the above analysis, it is evident that WHP systems offer emission benefits at par with solar PV and higher than wind systems for a given volume of energy generation. WHP systems can also avoid substantially higher amounts of grid emissions compared to solar PV and wind systems of equivalent generation capacity due to its high annual capacity factor. Despite these benefits, there is not widespread policy support for WHP systems in the United States today. Policy makers can encourage the increased deployment of WHP by extending policies that currently support solar PV and wind systems such as recognition in RPS standards, tax credits and rebates, and exemption from standby rates to WHP installations.

Conclusions

Waste heat to power systems produce electricity with no incremental increase in carbon emissions. Additionally, electricity produced with WHP offsets emissions associated with purchased grid electricity, avoiding over 1,000 pounds of carbon for every megawatt-hour produced.

ICF's analysis demonstrated that carbon emission reduction potential for WHP is comparable to distributed PV and wind power systems. For all three technologies, electricity is produced with zero emissions, and this electricity displaces marginal grid resources, which are primarily fossil fuels. On a capacity-basis, WHP systems offer significantly more emission reductions than other technologies, due to higher operational capacity factors.

A large number of facilities produce waste heat in sufficient quantities for on-site power production with WHP. As governments and corporations seek ways to decarbonize, WHP technologies offer solutions that reduce carbon emissions while also lowering grid demand and congestion from increased electrification of energy end-uses.

WHP systems provide similar emissions and grid benefits to other renewable and energy efficient technologies, but WHP does not receive the same level of policy support as other options. WHP installations provide numerous benefits, but they can have high capital cost barriers depending on waste heat sources and system design. More supportive policies and incentives can help overcome these costs barriers and will help states, local governments, and utilities reduce emissions and reach their decarbonization goals.

Appendix: Detailed Assumptions and Results

This Appendix is intended to provide additional details about the assumptions applied by ICF to carry out the emissions analysis and presents detailed emission impact results for each analysis location.

Detailed Assumptions

This section further details the assumptions prepared by ICF regarding on-site and avoided grid emission rates, and the capacity factor of each technology option included in this analysis.

Carbon Emission Rates

On-site Emissions

ICF assumed that WHP, solar PV and wind systems would have *zero* marginal on-site emissions while CHP would have positive on-site emissions. The gas-fired CHP system used in the analysis is assumed to be a 1 MW reciprocating engine. ICF estimated the on-site emissions of this system as 491 lbs/MWh based on data from the Department of Energy (DOE) Technology Factsheet for Reciprocating Engines, if 100% of thermal energy produced by this system can be fully utilized.[14]

Avoided Grid Emissions

ICF utilized data from the Environmental Protection Agency's AVERT Database to characterize the avoided grid emission rates for each technology and location combination in this analysis. The AVERT database categorizes the contiguous 48 states into 14 electricity regions (Figure 5). Using data from AVERT, EPA reports the average avoided marginal grid emission rates (in lbs/MWh) for utility-scale and distributed solar PV, onshore and offshore wind, and baseload resources for each of the 14 AVERT regions.

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[14] U.S. Department of Energy. *Combined Heat and Power Technology Fact Sheet Series*. Available at: https://www.energy.gov/sites/default/files/2016/09/f33/CHP-Recip%20Engines.pdf

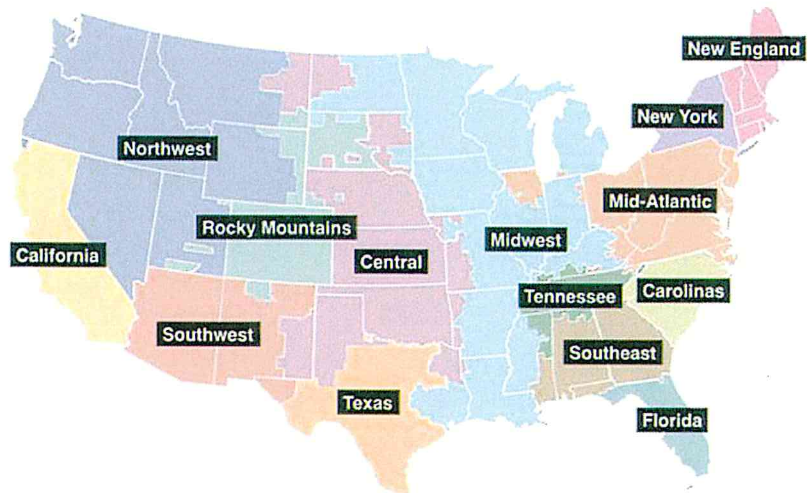

Figure 5: AVERT Electricity Regions

For each analysis location, ICF applied avoided grid emission rates corresponding to the AVERT region within which it is contained. Table 4 shows the specific AVERT region assigned to each analysis location.

Table 4: AVERT Region Assigned to each Analysis Location

Analysis Location	AVERT Region
Los Angeles, California	California
Columbus, Ohio	Mid-Atlantic
Baton Rouge, Louisiana	Midwest

For each generation technology included in the analysis, ICF assigned the AVERT emission factor that best suits its generation profile. Table 5 shows the AVERT emission factor assigned to each generation technology.

Table 5: AVERT Emission Factors Applied in the Analysis by Technology

Technology	AVERT Emission Factor
WHP	Uniform EE
Solar PV	Distributed PV
Wind	Onshore Wind
CHP	Uniform EE

Using these assumptions, ICF determined the specific emissions factors to be applied in this analysis as shown in Table 6.

Table 6: On-site and Avoided Grid Emission Rate Applied in the Analysis Categorized by Technology and Location

Technology	On-Site Emissions (lbs/ MWh of CO2)	AVERT Avoided Grid Emission Rate (lbs/MWh of CO2)		
	All Locations	Los Angeles, CA	Columbus, OH	Baton Rouge, LA
WHP	0	1,061	1,540	1,860
Solar PV	0	1,071	1,576	1,850
Wind	0	966	1,420	1,732
CHP	491	1,061	1,540	1,860

Capacity Factors

ICF applied standard capacity factor assumptions of 90% for WHP and 80% for CHP systems across all three analysis locations, in consultation with Kanin Energy. This assumption best reflects ICF's subject matter expertise on the performance characteristics of WHP and CHP systems, and Kanin Energy's demonstrated experience of owning and operating WHP systems.

To estimate the location-specific annual average capacity factor of solar PV systems, ICF modeled the performance of a 1 MW-DC solar PV system on the National Renewable Energy Laboratory's (NREL) PVWatts Calculator, [15] applying the following inputs:

- PV Array type – Fixed open rack with no tracking
- Panel tilt angle – Equivalent to the latitude of each analysis location
- Inverter efficiency – 96% consistent with industry standards
- Ground Cover Ratio (GCR) – Estimated by ICF for each analysis location based on NREL's PV panel spacing recommendations[16]

The total annual energy production of a 1 MW PV system with the above inputs was modeled in PVWatts for each of the three analysis locations and was used to estimate the annual average capacity factor. Figure 6 provides a snapshot of the PVWatts Calculator tool.

[15] National Renewable Energy Laboratory. *PVWatts Calculator*. Available at: https://pvwatts.nrel.gov/

[16] Ground Cover Ratio is defined as the ratio of the total area on the ground assigned to house PV arrays to the actual panel surface area. The higher the GCR, the higher the spacing between rows of PV panels.

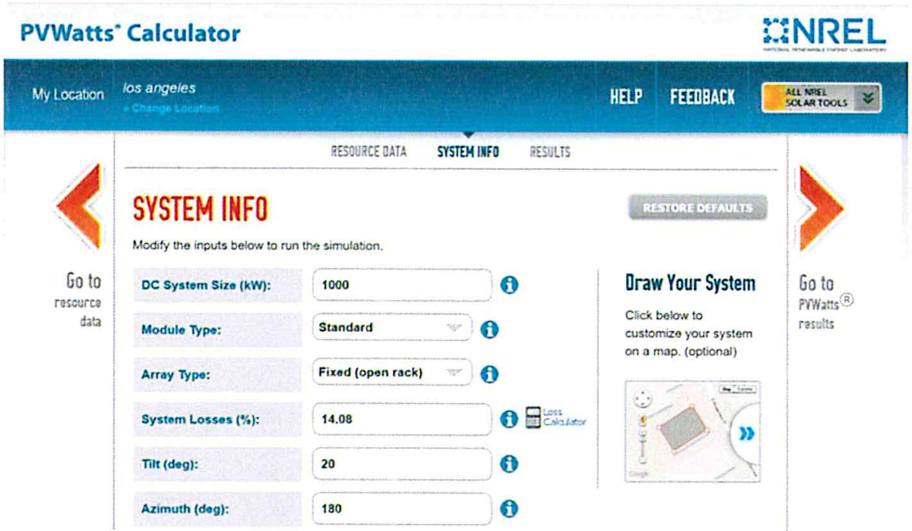

Figure 6: Snapshot of NREL's PVWatts Calculator Interface

ICF drew from DOE's WINDExchange model to estimate location-specific capacity factors for onshore wind systems. [17] The WINDExchange model reports actual capacity factors of several individual wind installations in the 48 contiguous states as shown in Figure 7.

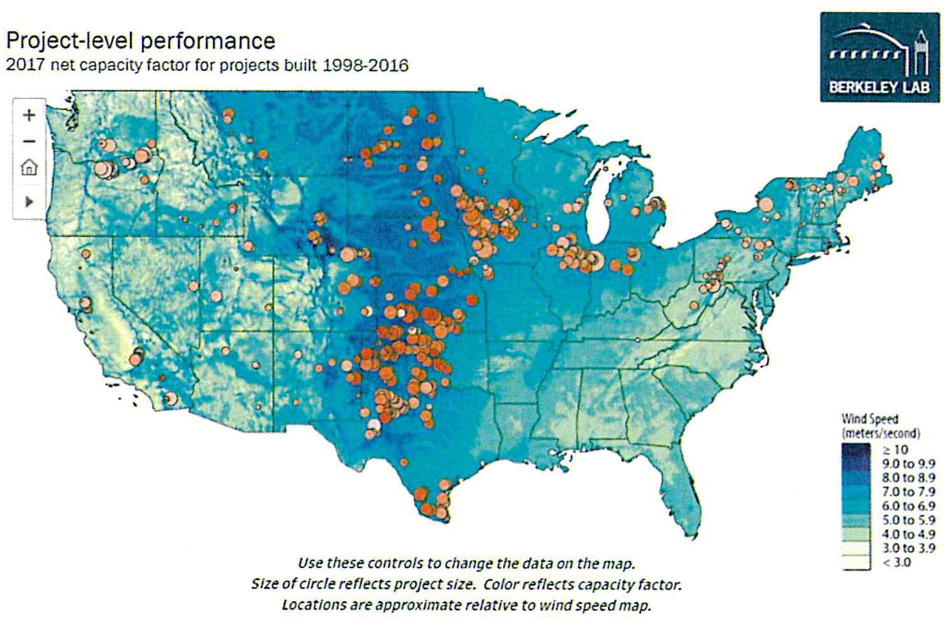

Figure 7: Project-level Performance Estimates Provided by DOE's WINDExchange Model

Using data from the WINDExchange model, ICF prepared estimates for wind capacity factors for each analysis location as follows:

[17] U.S. Department of Energy. *Wind Energy Capacity Factors*. Available at: https://windexchange.energy.gov/maps-data/332

- Los Angeles – ICF applied the average capacity factor of wind installations located in southern California
- Columbus – ICF applied the average capacity factor of three wind installations in central Ohio
- Baton Rouge – Louisiana has no wind installations to date; ICF applied the average capacity factor of wind installations in the Gulf coast of Texas given similarity in wind resource availability

Table 7 provides a summary of capacity factor assumptions applied in the analysis by location and technology.

Table 7: Capacity factors applied in the analysis categorized by technology and location

Technology	Equipment Capacity Factor Assumptions		
	Los Angeles, CA	Columbus, OH	Baton Rouge, LA
WHP	90%	90%	90%
Solar PV	19%	15%	17%
Wind	27%	26%	32%
CHP	80%	80%	80%

Detailed Results

ICF carried out an analysis to estimate the emission impacts of WHP compared to solar PV, wind, and CHP systems in three U.S. locations – Los Angeles, CA; Columbus, OH; and Baton Rouge, LA. In this analysis, ICF compared the emission impacts of WHP systems against the other generation technologies using two bases of comparison – 1) Equivalent Energy Production, and 2) Equivalent Generation Capacity. In this section, ICF presents detailed results of this analysis along with a brief discussion of the findings categorized by analysis location.

Los Angeles, California

ICF applied assumptions for on-site and avoided grid emissions, and equipment capacity factors for Los Angeles as shown in Table 8 below.

Table 8: Emissions Factor and Capacity Factor Assumptions for Los Angeles by Technology

Technology	On-site Emissions (lbs/MWh CO_2)	AVERT Avoided Grid Emission Rate (lbs/MWh CO_2)	Capacity Factor
WHP	0	1,061	90%
Solar PV	0	1,071	19%
Wind	0	966	27%
CHP	491	1,061	80%

Using the above assumptions, ICF carried out an emissions analysis to estimate the emission impacts of WHP systems compared to solar PV, wind, and CHP systems in Los Angeles. Results of this analysis are presented below.

Equivalent Energy Production Basis

ICF's analysis for Los Angeles showed that WHP generates *zero* on-site carbon emissions similar to solar PV and wind, while CHP generates on-site emissions at a rate of 491 lbs/MWh. On an equivalent energy production basis, solar PV and WHP systems in Los Angeles have similar avoided grid emission rates, with solar PV offering marginally higher avoided grid emissions compared to WHP. Net of on-site emissions, WHP offers a higher emission reduction potential *per MWh of generation* than wind and CHP systems. Figure 8 shows the emissions impacts of WHP, solar PV, wind, and CHP systems per MWh of generation in Los Angeles.

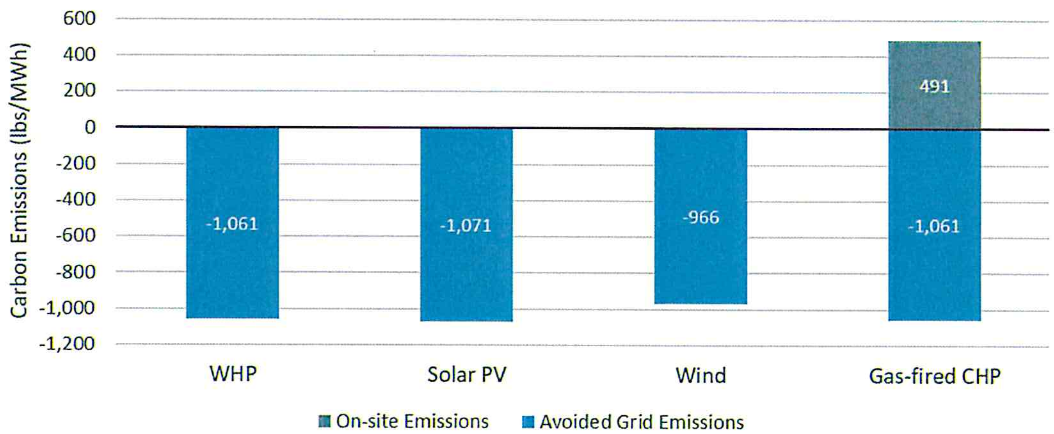

Figure 8: Carbon Emissions Impact by Technology in Los Angeles per MWh of Energy Production

Equivalent Generation Capacity Basis

ICF's analysis for Los Angeles, showed that WHP systems generate *zero* on-site carbon emissions similar to solar PV and wind, while CHP generates on-site emissions at a rate of 1,720 tons/MW-year. For 1 MW of generation capacity, a WHP system in Los Angeles offers 360%, 270% and 109% higher emission reductions *over the course of a year* compared to solar PV, wind, and CHP systems, respectively. Figure 9 shows the *annual* emission impacts of 1MW of WHP, solar PV, wind, and CHP systems in Los Angeles.

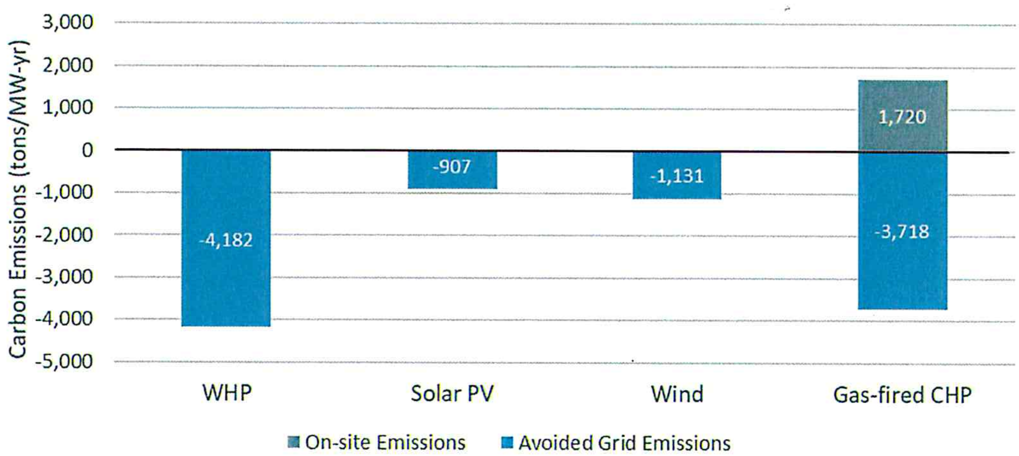

Figure 9: Carbon Emissions Impact by Technology in Los Angeles for 1 MW Generation Capacity

Columbus, Ohio

ICF applied assumptions for on-site and avoided grid emissions, and equipment capacity factors for Columbus as shown in Table 9 below.

Table 9: Emissions Factor and Capacity Factor Assumptions for Columbus by Technology

Technology	On-site Emissions (lbs/MWh CO_2)	AVERT Avoided Grid Emission Rate (lbs/MWh CO_2)	Capacity Factor
WHP	0	1,540	90%
Solar PV	0	1,576	15%
Wind	0	1,420	26%
CHP	491	1,540	80%

Using the above assumptions, ICF carried out an emissions analysis to estimate the emission impacts of WHP systems compared to solar PV, wind, and CHP systems in Columbus. Results of this analysis are presented below.

Equivalent Energy Production Basis

ICF's analysis for Columbus showed that WHP generates *zero* on-site carbon emissions similar to solar PV and wind, while CHP generates on-site emissions at a rate of 491 lbs/MWh. On an equivalent energy production basis, solar PV and WHP systems in Columbus have similar avoided grid emission rates, with solar PV offering marginally higher avoided grid emissions compared to WHP. Net of on-site emissions, WHP offers a higher emission reduction potential *per MWh of generation* than wind and CHP systems. Figure 10 shows the emissions impacts of WHP, solar PV, wind, and CHP systems per MWh of generation in Columbus.

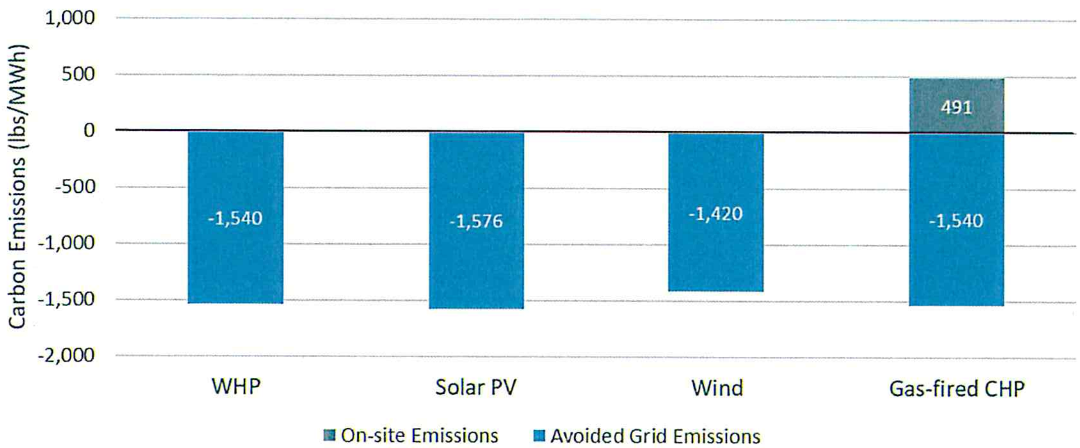

Figure 10: Carbon Emissions Impact by Technology in Columbus per MWh of Energy Production

Equivalent Generation Capacity Basis

ICF's analysis for Columbus showed that WHP systems generate *zero* on-site carbon emissions similar to solar PV and wind, while CHP generates on-site emissions at a rate of 1,720 tons/MW-year. For 1 MW of generation capacity, a WHP system in Columbus offers 480%, 275% and 109% higher emission reductions *over the course of a year* compared to solar PV, wind, and CHP systems, respectively. Figure 11 shows the *annual* emission impacts of 1MW of WHP, solar PV, wind, and CHP systems in Columbus.

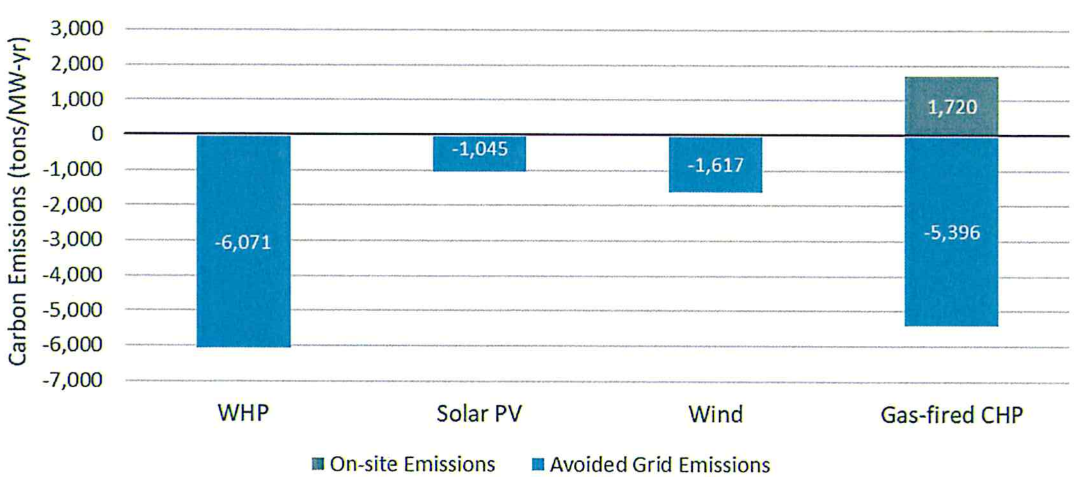

Figure 11: Carbon Emissions Impact by Technology in Columbus for 1 MW Generation Capacity

Baton Rouge, Louisiana

ICF applied assumptions for on-site and avoided grid emissions, and equipment capacity factors for Baton Rouge as shown in Table 10 below.

Table 10: Emissions Factor and Capacity Factor Assumptions for Baton Rouge by Technology

Technology	On-site Emissions (lbs/MWh CO_2)	AVERT Avoided Grid Emission Rate (lbs/MWh CO_2)	Capacity Factor
WHP	0	1,860	90%
Solar PV	0	1,850	17%
Wind	0	1,732	32%
CHP	491	1,860	80%

Using the above assumptions, ICF carried out an emissions analysis to estimate the emission impacts of WHP systems compared to solar PV, wind, and CHP systems in Baton Rouge. Results of this analysis are presented below.

Equivalent Energy Production Basis

ICF's analysis for Baton Rouge showed that WHP generates *zero* on-site carbon emissions similar to solar PV and wind, while CHP generates on-site emissions at a rate of 491 lbs/MWh. On an equivalent energy production basis, solar PV and WHP systems in Baton Rouge have almost similar avoided grid emission rates, with solar PV offering marginally higher avoided grid emissions compared to WHP. Net of on-site emissions, WHP offers a higher emission reduction potential *per MWh of generation* than wind and CHP systems. Figure 12 shows the emissions impacts of WHP, solar PV, wind, and CHP systems per MWh of generation in Baton Rouge.

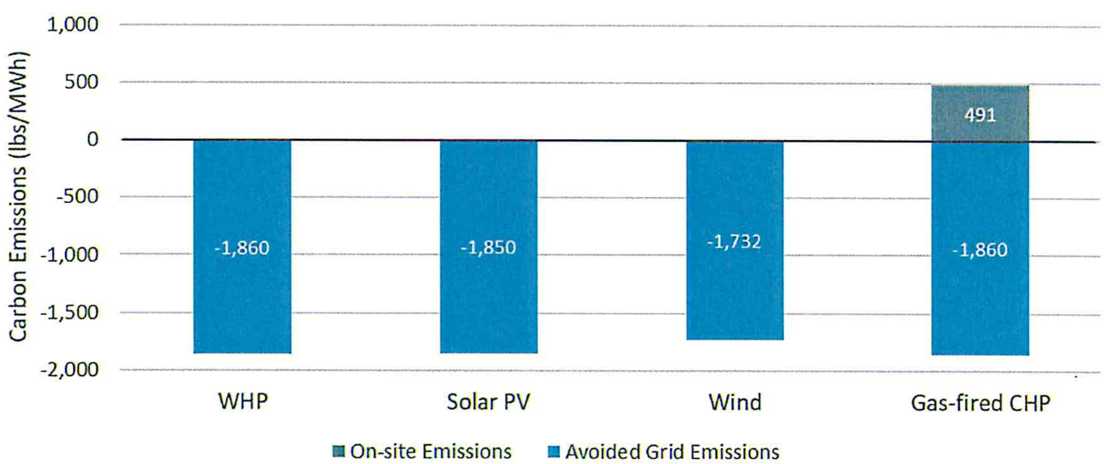

Figure 12: Carbon Emissions Impact by Technology in Baton Rouge per MWh of Energy Production

Equivalent Generation Capacity Basis

ICF's analysis for Baton Rouge, showed that WHP systems generate *zero* on-site carbon emissions similar to solar PV and wind, while CHP generates on-site emissions at a rate of 1,720 tons/MW-year. For 1 MW of generation capacity, a WHP system in Baton Rouge offers 430%, 200% and 50% higher emission reductions *over the course of a year* compared to solar PV, wind, and CHP systems, respectively. Figure 13 shows the *annual* emission impacts of 1MW of WHP, solar PV, wind, and CHP systems in Baton Rouge.

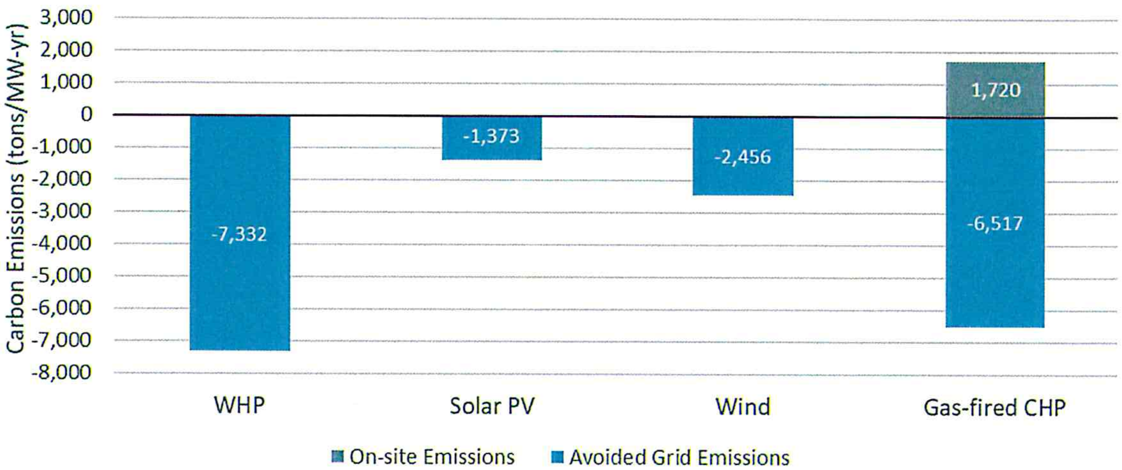

Figure 13: Carbon Emissions Impact by Technology in Baton Rouge for 1 MW Generation Capacity