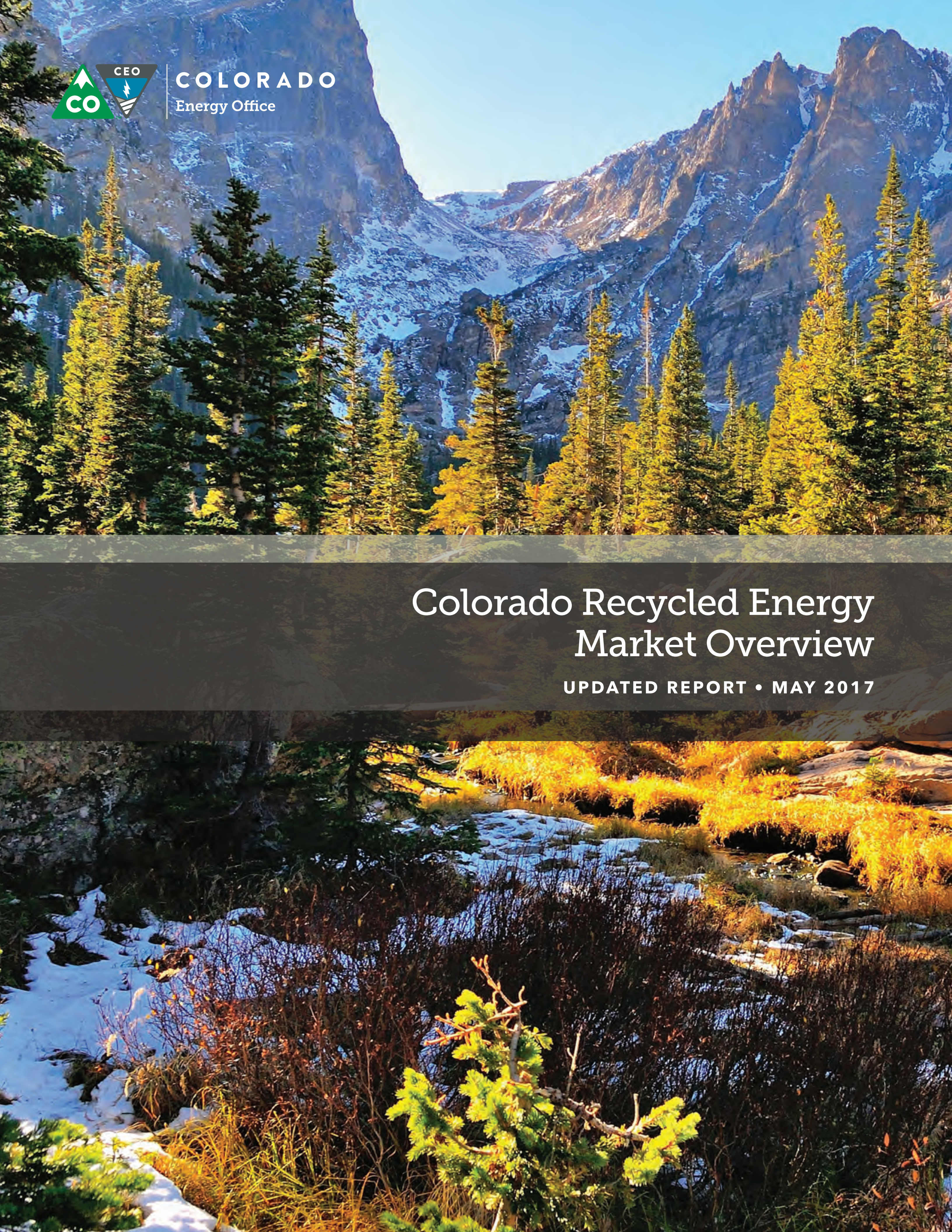

COLORADO Energy Office

Colorado Recycled Energy Market Overview

UPDATED REPORT • MAY 2017

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Executive Summary

Recycled energy, also known as waste heat to power (WHP), is the process of capturing heat discarded by an existing process and using that heat to generate electricity. In Colorado, the term recycled energy is more commonly used and qualifies under the state's Renewable Energy Standard (RES) as an eligible resource.[1] Under the Colorado RES, recycled energy systems must have a nameplate capacity of 15 megawatts (MW) or less, convert the otherwise lost energy from the heat from exhaust stacks or pipes to electricity, and not combust additional fossil fuels to be eligible. The RES definition of recycled energy does not include energy produced by systems that use waste heat from a process whose main purpose is the generation of electricity.

In the industrial sector, most recycled energy streams are generated by kilns, furnaces, ovens, turbines, engines, and other equipment. Waste streams suitable for recycled energy can also be generated at field locations, including landfills, compressor stations, wastewater treatment plants, and mining sites. While waste heat streams are also produced in the residential and commercial sectors, compared to industrial sites, these waste heat streams typically have lower temperatures and lower volumetric flow rates. The economic feasibility for recycled energy declines as the temperature and flow rate decline, and therefore, recycled energy technologies are most often applied in industrial markets where waste heat streams have higher temperatures and flow rates.

This updated report expands upon a previous report published in February 2016 that assessed the potential market for recycled energy in Colorado, discussed market and policy trends, and included recommendations on policies and programs that Colorado can adopt to support further development of recycled energy projects. While the previous report focused on waste heat streams greater than 450°F and larger projects that generate more than 250 kilowatts (kW), this update includes the technical potential, economic potential, and market penetration for projects with waste heat streams less than 450°F and projects that generate less than 250 kW, along with revised chapters on current policies and state opportunities. The types of industrial waste heat streams that are considered in this study are shown in Table 1 and are described in more detail below.

TABLE 1: TYPES OF WASTE HEAT STREAMS

Sources of Waste Heat Stream	Example (illustrations only, examples are not intended to be all inclusive).
Thermal Process	Energy recovered from a furnace, oven, or kiln.
Mechanical Drive	Energy recovered from a natural gas pipeline compressor station.
Other	Waste heat recovered from industrial or other processes that generate heat as a byproduct, such as exothermic reactions, incineration, and pressure reduction.

[1] Colorado Legislature, "Colorado Revised Statutes 2016 – Title 40: Utilities" Statute: 40-2-124, Renewable Energy Standards, https://leg.colorado.gov/sites/default/files/images/olls/crs2016-title-40.pdf.

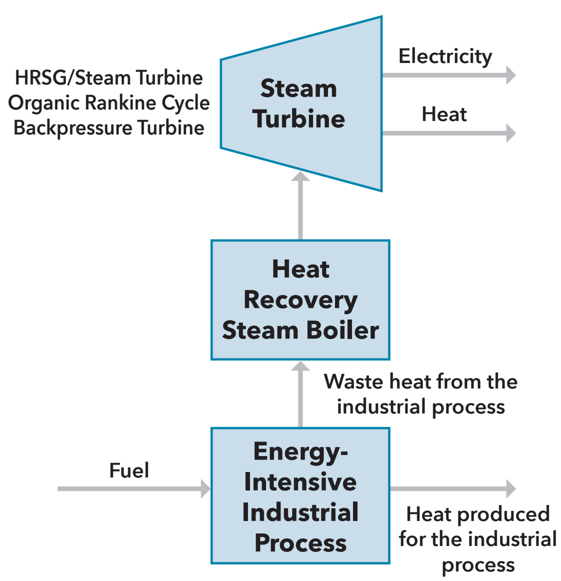
1 | Introduction to Recycled Energy in Colorado

Recycled energy, also known as WHP, is the process of capturing heat discarded by an existing process and using that heat to generate electricity. In Colorado, the term recycled energy is used in the RES, and therefore will be the term used throughout this report. Recycled energy systems are defined as eligible under Colorado's RES as "energy produced by a generation unit with a nameplate capacity of not more than 15 MW that converts the otherwise lost energy from the heat from exhaust stacks or pipes to electricity and that does not combust additional fossil fuels." This excludes energy produced by any system whose primary purpose is the generation of electricity.[2] Most recycled energy applications are at larger industrial facilities.

The waste heat sources that drive recycled energy technologies can be divided into three categories that have unique attributes, both in terms of viable technologies and legal definitions that may apply. All three categories of recycled energy discussed below can qualify under Colorado's RES.

Waste heat from a thermal process – Energy can be recovered from a furnace, oven, kiln, or other industrial processes[3] and converted to electricity using a thermodynamic process such as a Rankine cycle steam turbine.[4] This configuration for a recycled energy system is also referred to as bottoming cycle cogeneration, a type of combined heat and power (CHP) system. In a bottoming cycle, fuel is combusted to provide thermal input to industrial process equipment like a kiln or furnace, and the heat rejected from the process is captured and used for power production.

FIGURE 1: DEFINING RECYCLED ENERGY



Acronym: HRSG – heat recovery steam generator.

Waste heat from a mechanical drive – Engines and turbines can be used to drive mechanical shafts that in turn spin compressors, pumps, and electrical generators. An example is a pipeline compressor station that utilizes a gas turbine to drive a compressor that in turn moves natural gas through a pipeline. Waste heat can be recovered from the gas turbine exhaust and used to generate electricity.

Waste heat from other systems – Heat generated as a byproduct from some industrial processes—such as exothermic reactions like those used in the manufacture of fertilizer, incineration of sewage sludge, and release of heat from pressure relief valves—can be captured and used to generate electricity. These recycled energy systems differ from those listed in the first category in that they do not generate heat for a thermal purpose but as a byproduct of their operation.

Although the definition for recycled energy or WHP differs from state to state, all such systems have one thing in common: they use waste heat or leftover heat to generate electricity. In Colorado, if this heat comes from a process whose primary purpose is not the generation of electricity, then it could meet the definition of recycled energy in the state RES.

Common Technologies

From an energy-conversion perspective, a recycled energy system consists of two major components: 1) a heat engine and 2) an electrical generator (see Figure 2). In thermodynamic terms, the heat engine converts energy (heat) in the waste heat stream to mechanical energy (work).

[2] U.S. Environmental Protection Agency, Combined Heat and Power Partnership, *Portfolio Standards and the Promotion of Combined Heat and Power* (Washington, DC: U.S. Environmental Protection Agency, Combined Heat and Power Partnership, March 2016), https://www.epa.gov/sites/production/files/2015-07/documents/portfolio_standards_and_the_promotion_of_combined_heat_and_power.pdf.

[3] Processes include calciners, kilns, flares, incinerators, ovens, reciprocating engines, regenerative oxidizers, thermal oxidizers, and exhaust from petroleum refining.

[4] Other thermodynamic processes, such as organic Rankine cycles and Kalina cycles, can be used particularly for lower-temperature waste heat streams.

The mechanical energy (e.g., a rotating shaft) is then used to generate power in an electrical generator.

In a heat engine, heat flows from a hot reservoir to a cold reservoir, and the temperature difference between these reservoirs governs the efficiency of the heat engine. The maximum, or Carnot efficiency (η) is defined as the work performed by the system divided by the total heat entering the system (see Figure 3 for illustration):

$$\eta = \frac{W}{Q_H} = 1 - \frac{T_C}{T_H}$$

W – work performed

Q_H – heat input

T_C – absolute temperature of the cold reservoir

T_H – absolute temperature of the hot reservoir

For recycled energy technologies that are commercially available, the actual efficiencies are much lower than the theoretical Carnot efficiencies. In actual recycled energy systems, there are irreversible thermodynamic losses that push the efficiencies downward. In addition, energy is also lost in the electrical generation process.

The Rankine thermodynamic cycle is commonly used for recycled energy systems. Variations of this cycle include the steam Rankine cycle (SRC), organic Rankine cycle (ORC), Kalina cycle, and supercritical carbon dioxide (CO_2) cycle. These Rankine cycles are briefly described on the following pages, along with a short description of emerging recycled energy technologies.

FIGURE 2: MAJOR COMPONENTS IN A RECYCLED ENERGY SYSTEM

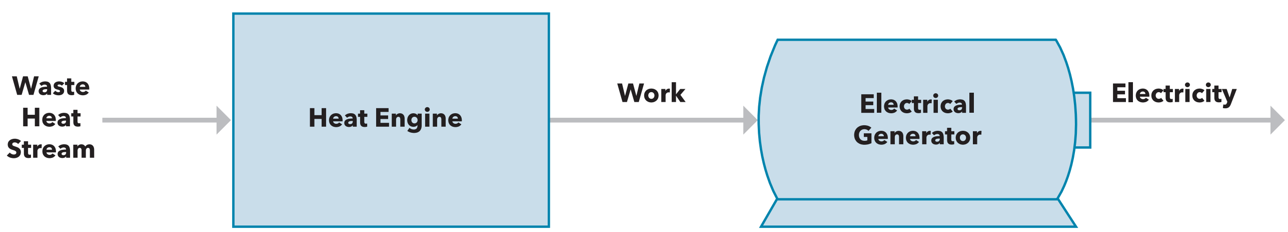


FIGURE 3: HEAT ENGINE DIAGRAM

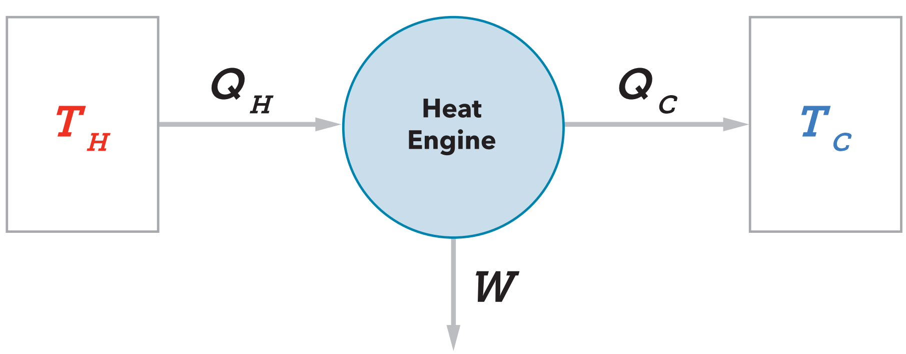
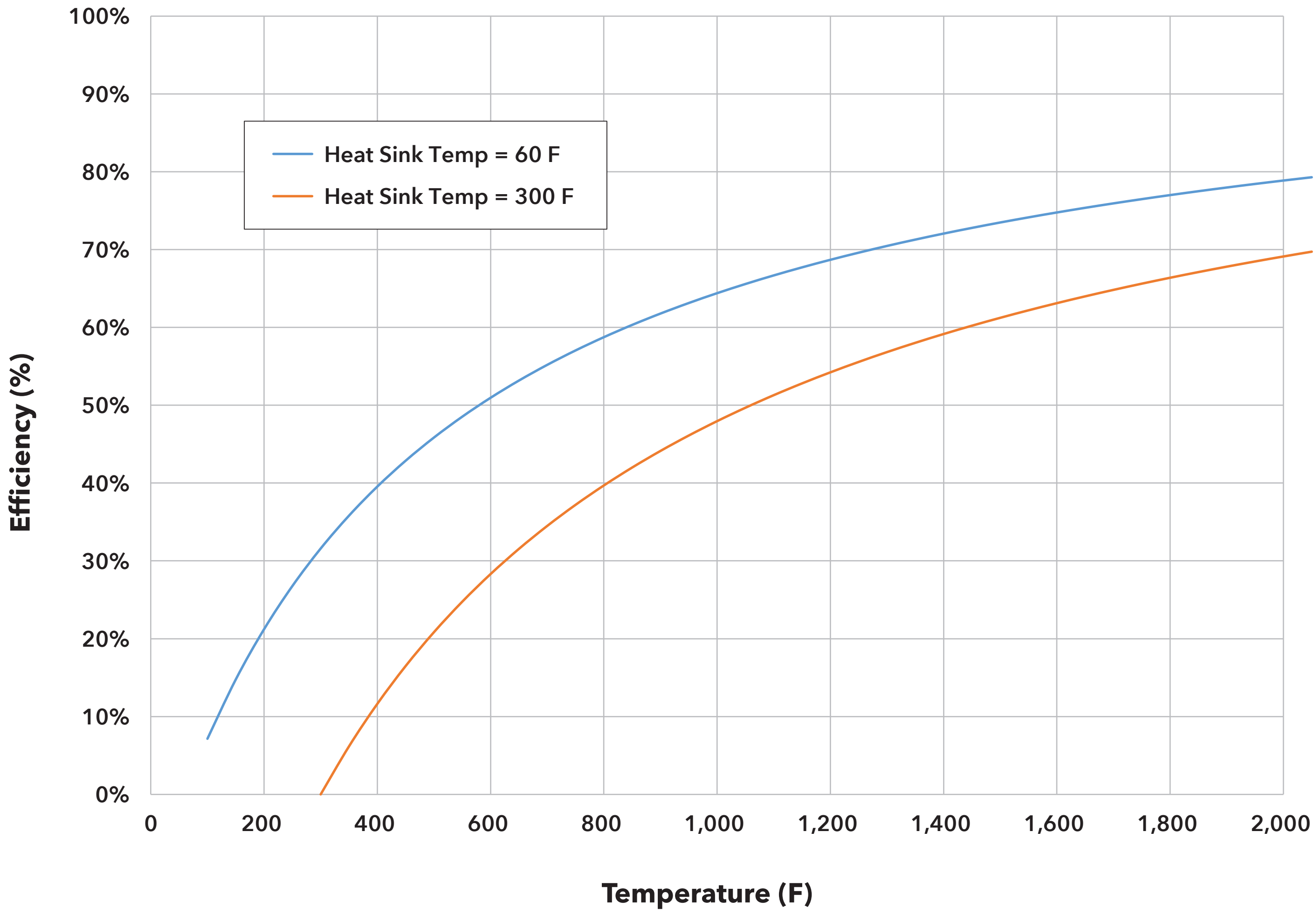


FIGURE 4: CARNOT (MAXIMUM) HEAT ENGINE EFFICIENCY



Rankine Cycle

In a Rankine cycle (either SRC or ORC), a liquid working fluid is compressed to elevated pressure (via a pump as illustrated in Figure 5) before entering an evaporator (the heat recovery steam boiler in Figure 5). The pressurized fluid is vaporized using energy captured from a waste heat stream and then expanded to lower temperature and pressure in an expander (the power turbine, Figure 5), generating mechanical power that can drive an electric generator. The low-pressure working fluid is then exhausted to a condenser where heat is removed by condensing the vapor back into a liquid. The condensate from the condenser is returned to the compressor and the cycle is repeated. For recycled energy applications, the Rankine cycle's efficiency typically ranges from 30%–50% of the Carnot theoretical efficiency. For example, if the Carnot efficiency is calculated to be 60% for a 900°F heat source, the actual efficiency achieved will likely be in the range of 18%–30%.

Most commercially available recycled energy technologies in the United States are based on either SRC or ORC systems. The Kalina cycle and supercritical CO_2 (sCO_2) cycle are variations of the Rankine cycle that have recently entered the market. For SRC systems, the working fluid is water, and for ORC systems the working fluid is a hydrocarbon, hydrofluorocarbon, or ammonia. The Kalina cycle uses a combination of water and ammonia, and the sCO_2 cycle uses carbon dioxide.

Steam Rankine Cycle

The most common example of the Rankine cycle is the steam turbine, or steam Rankine cycle. In an SRC system, the working fluid is water, and steam is created to drive a turbine. Most of the electricity produced in the United States is generated by conventional steam-turbine power plants that use coal, natural gas, or nuclear energy as a fuel source. In recycled energy applications, the capacity of steam turbines can range from 50 kW to several hundred megawatts.

Organic Rankine Cycle

ORC systems are similar to SRC systems, but instead of water, the working fluid is a hydrocarbon, hydrofluorocarbon, or ammonia. Figure 6 shows one configuration of an ORC system. This ORC design consists of an evaporator (e.g., a boiler), expander (e.g., a turbine), condenser,

FIGURE 5: RANKINE CYCLE HEAT ENGINE

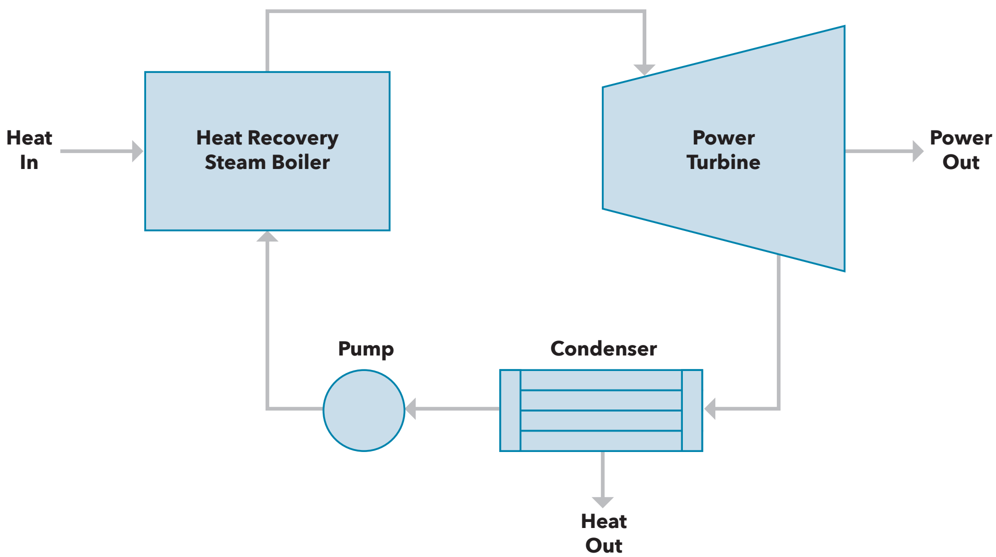
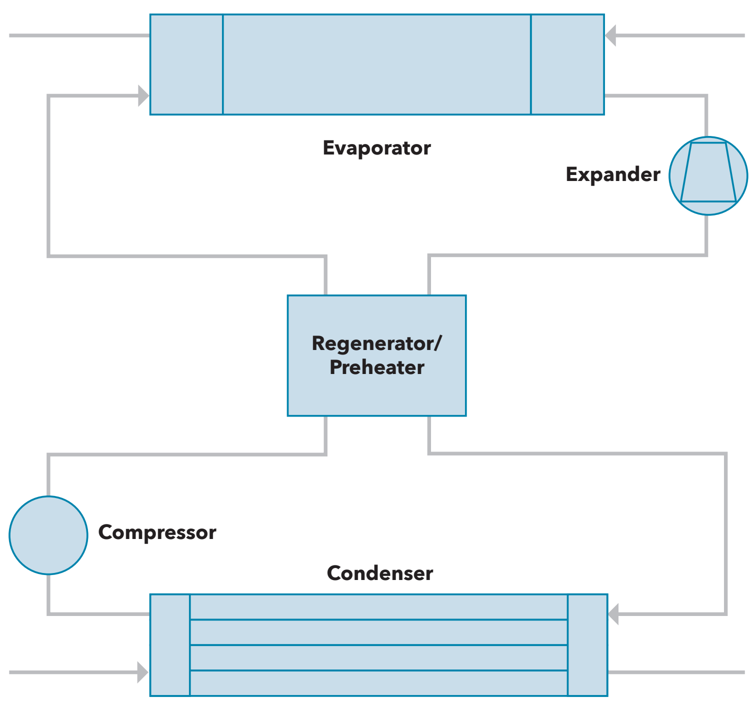


FIGURE 6: ORGANIC RANKINE CYCLE HEAT ENGINE WITH REGENERATOR



and compressor (e.g., a pump). The regenerator improves efficiency by adding a regenerator/preheater to preheat the working fluid with energy that would otherwise be rejected. The working fluid in an ORC machine typically has a lower boiling point than water, which allows ORC systems to operate with relatively low-temperature heat sources—sometimes as low as 200°F or below.[5] Working fluids that have been used in ORC systems include silicone oil, propane, isopentane, isobutane, xylene, and toluene. The working fluid is chosen based on the best thermodynamic match to the available heat source.

In comparison with water, the fluids used in ORCs have thermodynamic properties (e.g., boiling point characteristics) that enable operation with waste heat sources that have temperatures near 200°F, or even lower. Operation at such low temperatures, however, is typically only cost-effective when using a liquid waste stream, which allows the use of a

[5] ElectraTherm's Green Machine and the Ener-G-Rotors' ORCA™ systems are examples of modular ORCs that have the ability to operate with relatively low-temperature heat sources.

liquid-to-liquid heat exchanger.[6] For gaseous heat sources, such as hot exhaust from an industrial process, a temperature of at least 500°F is typically required for commercially available technologies.

While both cycles are classified as Rankine cycle heat engines, there are a few key distinctions between SRC and ORC systems:

- SRCs are generally installed in high-power applications to maximize efficiency; they are also generally more expensive and customized to the application.
- SRCs are generally operated on higher temperature heat sources than ORCs.
- ORCs' working fluid pressure (in the evaporator) is generally lower, thus allowing the system to use a less expensive, non-pressurized boiler (compared to SRCs); additionally, the evaporator is generally a once-through system—further reducing cost.
- The ORC condenser is not operated at a vacuum or at sub-atmospheric pressure, which helps to avoid introducing air into the system.

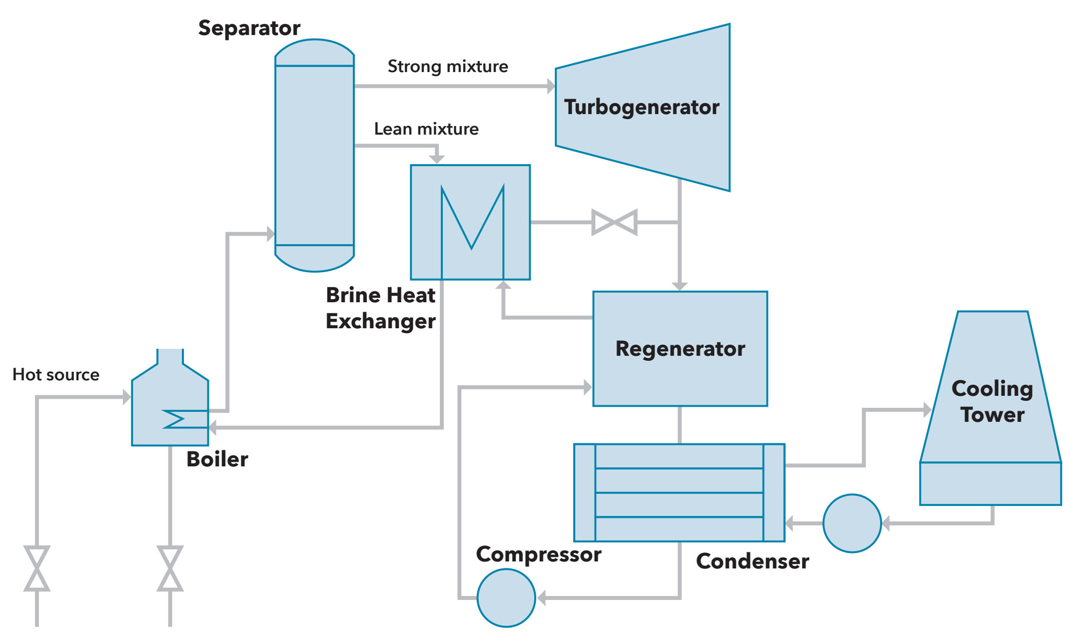
ORC systems are commonly used to generate power in geothermal power plants, and more recently, in pipeline-compressor heat recovery applications. There is a description of an ORC pipeline compressor application installed by Ormat Technologies, Inc. on the Trailblazer Pipeline in Colorado in the next section of this report. In these and other ORC applications, electric generation efficiencies range from around 8% with waste heat sources at 300°F, to around 15% with waste heat sources near 800°F. As expected, these efficiencies are lower than the maximum Carnot efficiencies. For example, the Carnot efficiency for a heat source at 300°F and a heat sink at 77°F is about 30%.

Kalina Cycle

The Kalina cycle is a variation of the Rankine cycle, using a binary fluid pair as the working fluid (typically water and ammonia). Figure 7 shows a schematic view of a Kalina-cycle power plant for waste heat. In addition to the classic four-stage Rankine cycle components (evaporator, expander, condenser, and compressor) and the regenerator, there is a distillation-condensation subsystem consisting of a series of separators, heat exchangers, and pumps.

Like SRCs/ORCs, the Kalina cycle is specifically designed for converting thermal energy to mechanical power, optimized for use with thermal sources that are at a relatively low temperature compared to the heat sink (or ambient) temperature. The primary difference between a single-fluid Rankine cycle and the Kalina cycle is the temperature profile during boiling and condensation. In the SRC and ORC cycles, the temperature remains constant during boiling. As heat is transferred to the working fluid, its temperature slowly increases to the boiling temperature, at which point the temperature remains constant until all the fluid has evaporated. In contrast, a binary mixture of water and ammonia (each of which has a different boiling point) will increase in temperature during evaporation. This process allows better thermal matching with the waste heat source, and with the cooling medium in the condenser in counter-flow heat exchangers. Consequently, these systems have

FIGURE 7: KALINA CYCLE HEAT ENGINE



[6] For equivalent levels of heat transfer, a liquid-to-liquid heat exchanger is much smaller, and less expensive, compared to a gas-to-liquid heat exchanger.

relatively good energy efficiency performance compared to other recycled energy thermodynamic cycles. Operating efficiencies for a Kalina-cycle recycled energy system are around 15% with a heat source temperature of 300°F. Because the phase change from liquid to steam is not at a constant temperature, the temperature profiles of the hot and cold fluids in a heat exchanger can be closer, thus increasing the overall efficiency. Because of these performance characteristics, the Kalina cycle is well suited for geothermal power plants,[7] where the hot fluid is often below 212°F. As the technology is further commercialized, other applications are becoming available[8] such as the following:

- Gas compressor stations
- Iron and steel industry
- Cement industry
- Chemical industry
- Incineration plants
- Diesel plants
- Low-temperature geothermal plants.

Supercritical CO_2 Cycle

Another variation of the Rankine Cycle is the sCO_2 cycle, which utilizes CO_2 in place of water and steam for a heat-driven power cycle. The sCO_2 cycle in its simplest form consists of these main components: waste heat and recuperator heat exchangers, condenser, system pump, and turbine. Ancillary components (valves and sensors) provide system monitoring and control. Heat energy is introduced through a waste heat exchanger installed into a customer's exhaust stack, boiler or turbine exhaust duct, hot process gas or liquid line, or solar thermal concentrator. The fluid, in either a liquid or dense supercritical state, is then compressed. The high-pressure fluid is preheated in the recuperator with residual heat from the expanded fluid discharged from the turbine. The preheated fluid is raised to its highest temperature by transferring heat from the process—either exhaust or other heat source(s). Next, the high-temperature, high-pressure fluid is expanded through a turbine, which drives a generator and the compressor. As the sCO_2-cycle pressure ratio is relatively low, the fluid at the turbine exit retains sufficient heat to warrant recovery in the recuperator. Finally, the fluid is cooled back to the compressor inlet temperature via the condenser and heat exchanger. Both air-cooled and water-cooled systems are applicable.

CO_2 is a low-cost working fluid that is nontoxic and non-flammable. The high fluid density of sCO_2 enables compact turbomachinery designs and permits the use of compact heat-exchanger technology to reduce system component size, cost, and footprint. Due to its high thermal stability and non-flammability, the exhaust heat exchanger can be placed in direct contact with high-temperature heat sources, typically from 400°F to 1,000°F (or higher), eliminating an intermediate heat-transfer loop.

Emerging Technologies

There are a number of advanced technologies in various stages of research, development, and demonstration that are providing or will provide expanded options for direct power generation from waste heat sources. These technologies include thermoelectric generators,[9] piezoelectric generators, thermionic devices, thermophotovoltaic generators, Stirling engines,[10] and innovative concepts utilizing steam engines.

These systems vary in terms of commercial readiness in the United States. A few have undergone prototype testing in applications such as heat recovery in automotive vehicles, and others have made initial commercial deployments for heat recovery from co-produced liquids or flare gas in oil and gas wells.[11]

Target Applications

The analysis of recycled energy potential begins with quantifying the amount of waste heat available for industrial applications in the United States. There are two reports that have provided this information. A 2004 Oak Ridge National Laboratory study presented an inventory of waste heat from manufacturing establishments (North American Industry Classification System [NAICS] 31–33).[12] A 2008 U.S. Department of Energy (DOE) study presented an inventory of waste heat for selected manufacturing sources only.[13] Figure 8 shows the waste heat potential by industry. Temperature ranges of waste heat differ substantially across the different industries. For example, the petroleum-refining sector's waste heat is mainly above 450°F, while for the chemical industry, it is mainly less than 450°F. The figure shows that the largest waste heat source for both the entire temperature range as well as the range from 450°F to 1,200°F is the petroleum refining industry. The nonmetallic minerals, chemicals, primary metals, and food-manufacturing sectors have the next-largest amounts of waste heat above 450°F.

[7] Alexander I. Kalina, "New Thermodynamic Cycles and Power Systems for Geothermal Applications," *Geothermal Resources Council Transactions* 30: (2006), http://pubs.geothermal-library.org/lib/grc/1025123.pdf.

[8] Sunil Macwan, "THE KALINA CYCLE: A Major Breakthrough in Efficient Heat to Power Generation," (presentation, National CHP 2013 and WHP 2013 Conference, October 7–9, 2013, Houston, Texas), http://www.heatispower.org/wp-content/uploads/2013/11/Recurrent-Eng-macwan_chp-whp2013.pdf.

[9] "Fuel Efficiency vs. Electrification: The Race is On," Alphabet Energy, accessed, May 19, 2017, https://www.alphabetenergy.com/media/fuel-efficiency-vs-electrification.pdf.

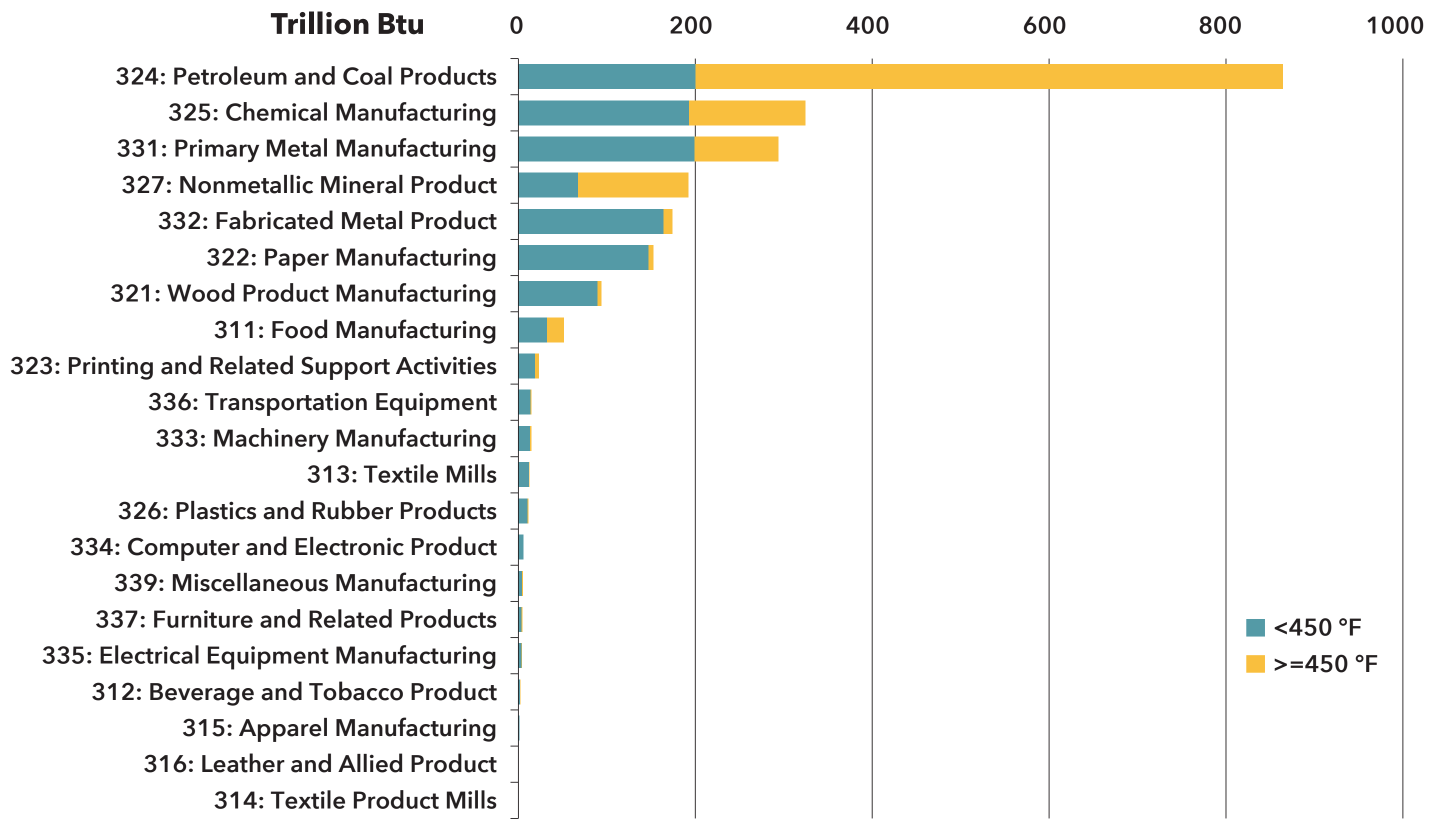
[10] "How It Works," Cool Energy Inc., accessed May 19, 2017, http://coolenergy.com/how-it-works/.

[11] "Tech company turning natural gas flares into electricity in Eagle Ford," *San Antonio Business Journal*, March 8, 2017, http://www.bizjournals.com/sanantonio/news/2017/03/08/tech-company-turning-natural-gas-into-electricity.html.

[12] Oak Ridge National Laboratory, *An Inventory of Industrial Waste Heat and Opportunities for Thermally Activated Technologies* (Prepared by United Technologies Research Center for Oak Ridge National Laboratory, 2004).

[13] U.S. Department of Energy, *Waste Heat Recovery: Technology and Opportunities in U.S. Industry* (Washington, DC: BCS, Incorporated, for the U.S. Department of Energy, Industrial Technologies Program, March 2008), https://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf.

FIGURE 8: U.S. MANUFACTURING SECTOR WASTE HEAT INVENTORY BY INDUSTRY AND TEMPERATURE RANGE (REFERENCE TEMPERATURE AT 120°F)[14]



NAICS 324/Standard Industrial Classification (SIC) 29: Petroleum and Coal Products

Petroleum and coal product manufacturing, particularly petroleum refining, represent the largest energy-consuming industrial group in the United States. This industrial group includes the production of refined end-use products, such as gasoline, kerosene, and liquefied petroleum gas, as well as the production of feedstocks used in other industries, such as chemicals, rubber, and plastics manufacturing. Basic processes used in petroleum refineries include distillation processes (fractionation), thermal cracking processes, catalytic processes, and treatment processes. Although these processes use large amounts of energy, modern refineries capture and use waste heat for other processes, resulting in integrated heat recovery systems for process use.

Some exhaust streams at refineries contain high-quality waste heat that could be recovered for power production. An example is the exhaust from petroleum coke calciners. In this process, petroleum coke is heated to 2,400°F, and energy from the hot exhaust is recovered. One example is the heat recovery boiler/steam turbine recycled energy project at a petroleum coke plant in Texas. Port Arthur Steam Energy recovers energy from the 2,000°F exhaust from three petroleum-coke calcining kilns and produces 450,000 pounds per hour of steam for process use at an adjacent refinery, plus 5 MW of power. [15]

NAICS 325/SIC 28/38: Chemical Manufacturing

The chemical industry is the second-largest consumer of energy in the industrial sector, producing 70,000 different products.[16] Many of the processes used to produce these products result in significant amounts of waste heat that has the potential to be converted to power. Major sectors in the chemical industry that have the potential for recycled energy applications include petrochemicals, industrial gases, alkalies and chlorine, cyclic crudes and intermediates (e.g., ethylene, propylene, and benzene/toluene/xylene), plastic materials, synthetic rubber, synthetic organic fibers, and agricultural chemicals (fertilizers and pesticides).

The Mosaic fertilizer plant in Bartow, Florida, for example, produces sulfuric acid as an intermediate product, which is then used with other feedstock chemicals to manufacture a variety of dry fertilizer products. The sulfuric acid plant generates superheated steam at pressures in the range of

[14] The 2004 Oak Ridge National Laboratory (ORNL) and 2008 DOE reports were used to establish a baseline for the analysis in the 2015 ORNL *Waste Heat to Power Market Assessment* and the 2015 Colorado Energy Office (CEO) Colorado Recycled Energy Market Overview. This current analysis supplements and expands the 2015 CEO report with <450°F data; for full nationwide renewable energy results for >450°F, see the 2015 ORNL *Waste Heat to Power Market Assessment*.

[15] U.S. Environmental Protection Agency, Combined Heat and Power Partnership, "Waste Heat to Power Systems" (Washington, DC: Environmental Protection Agency, Combined Heat and Power Partnership, 2012), https://www.epa.gov/sites/production/files/2015-07/documents/waste_heat_to_power_systems.pdf.

[16] Joan L. Pellegrino, *Energy and Environmental Profile of the U.S. Chemical Industry* (Washington, DC: Energetics Inc., for the U.S. Department of Energy, Office of Industrial Technologies, May 2000), https://energy.gov/sites/prod/files/2013/11/f4/profile_full.pdf.

150 to 600 per square inch gage (the sulfuric acid process is exothermic). The site has 70 MW of recycled energy capacity and exports about 40% of the electricity through the local utility grid to five nearby Mosaic plants.

NAICS 327/SIC 32: Non-Metallic Mineral Products

The non-metallic mineral products industries, which include cement manufacturing; glass and glass products manufacturing; and clay tile and brick material manufacturing, are large consumers of energy with a strong potential for use of recycled energy for power production. Similar to chemical manufacturing, there are numerous processes for which recycled energy could provide benefit. The glass industry uses high-temperature raw material melting furnaces, annealing ovens, and tempering furnaces, from which exhaust heat may be available for power generation. Clay building products are fired in high-temperature kilns. Clay firing employs tunnel kilns and periodic kilns, depending on the product being produced. Periodic kilns do not represent a good opportunity for heat recovery for power due to their intermittent operation, but tunnel kilns are steadier in output and could represent an economically feasible application.

NAICS 331/SIC 33: Primary Metals

The primary metals sector has a large number of high-temperature processes that are applicable to waste heat recovery, including coke ovens, blast furnaces, basic oxygen furnaces, and electric arc furnaces. Metal foundries, for example, have a variety of sources and applications like melting furnace exhaust, ladle preheating, core baking, pouring, shot-blasting, castings cooling, heat treating, and quenching. Additionally, the metal products are often at high temperatures after processing and need to be cooled, representing a significant opportunity for recovery.

NAICS 486/SIC 49: Pipeline Transportation: Natural Gas Compressor Stations

Compressor stations are suitable for waste heat to electricity conversion. Waste heat is available in the form of exhaust from the internal combustion engines or gas turbines that drive the compressors. In most cases, there is no thermal requirement at compressor stations; therefore, there is a strong case for converting the waste heat to electricity.[17] Currently, there are 12 ORC power generation systems installed at natural gas compressor stations in the United States, including the Trailblazer Pipeline compressor station in Colorado. The 12 U.S. systems have a total electric capacity of 64 MW using the exhaust heat from 247,000 horsepower of gas turbine-driven compressors.[18] A recycled energy system at a natural gas compressor station qualifies under Colorado's RES since the primary purpose of the facility is to compress gas, not combust gas to produce electricity.

NAICS 311/312/SIC 20: Food Products

Most of the waste heat potential in the food products sector is from low-temperature sources, generally under 500°F. Major applications include food storage (largely freezing or cooling applications) and preparation (including processing steps like drying, heating, roasting, pasteurization, grinding, and evaporating) and associated support systems like motors, compressed air systems, and space heating and cooling.

Other Market Sectors and Applications for Recycled Energy

Sectors like coal mining (NAICS 212/SIC 12), educational services (NAICS 611/SIC 82), and national security (NAICS 928/SIC 97) are potential sectors for recycled energy systems. These sectors contain large, integrated collections of buildings or facilities often with their own power production, heating, and cooling demands. Many of these systems contain significant potential for recycled energy applications, and some are isolated from utilities or other areas of energy supply and demand; thus, they could benefit from developing an onsite supply.

NAICS 562/SIC 4953: Waste Management: Landfill Gas

There are two types of opportunities for recycled energy at landfills. At facilities that use engines or turbines to produce power, there is an opportunity for additional power generation using ORC systems to generate power from the exhaust gases. Facilities that do not have energy recovery could install an ORC recycled energy system to recover the heat associated with gas flaring or use the byproduct fuel in a reciprocating engine to generate electricity. A biogas-fired electric generating unit is eligible under Colorado's RES. However, exhaust gases from a natural gas-fired engine or turbine that is used for additional power generation using ORC would not be eligible.

NAICS 324/SIC 29: Petroleum and Coal Products: Flare Gas in Oil and Gas Production

In oil and gas production, methane-containing gases are vented and flared throughout the production cycle. Flares are used for both background and upset (emergency) use. Adding an ORC system to a flare to produce electricity is an alternative to the option of removing the flare and using the previously flared fuel in an internal combustion engine or microturbine. The internal combustion engine or microturbine option would produce more power per unit of heat input and would generally be less costly. However, where fuel quality is variable and contains contaminants, the ORC recycled energy option may be technically and economically preferable. An ORC recycled energy system added to a flare would be eligible under Colorado's RES since the primary purpose is the flaring of gas, not the production of electricity.

[17] Using exhaust gases or byproduct fuels to generate power does qualify under the RES as long as the system does not combust additional fossil fuels and the system's primary purpose is not the generation of electricity, see, 40-2-124 C.R.S., accessed at http://www.lexisnexis.com/hottopics/colorado/.

[18] These are ICF International's estimates, based on personal correspondence and data from pipeline compressor companies.

2 | Evaluation of Existing Waste Heat Systems

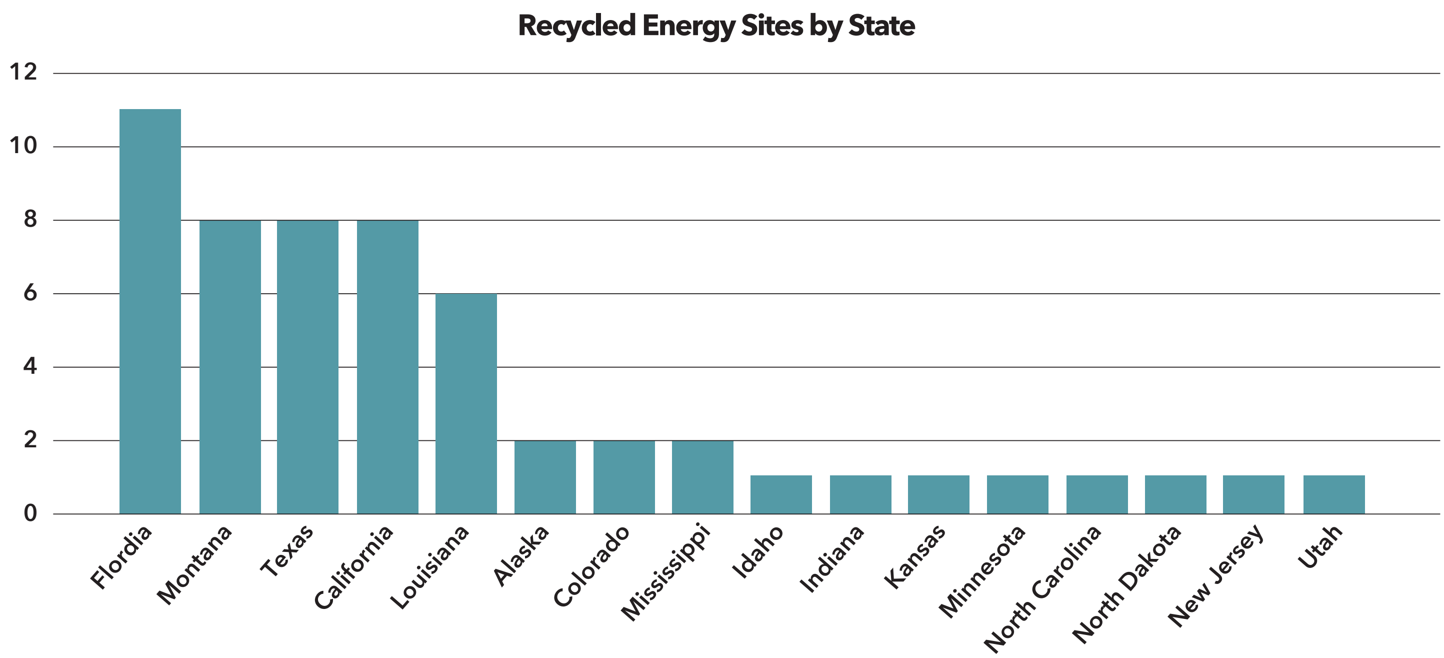
Nationwide Trends

The installed base of recycled energy in the United States was derived by first examining the annual electric generator data from the U.S. Energy Information Administration (EIA) Form EIA-860 to identify the number of recycled energy generators that leverage waste heat not directly attributed to a fuel source.[19] Form EIA-860 collects generator-level-specific information about existing and planned generators and associated environmental equipment at electric power plants with 1 MW or greater of combined nameplate capacity. Within the Form EIA-860, generators with waste heat as the energy source were identified and system-specific power factors were applied to derive actual capacity. For systems below 1 MW, DOE's CHP Installation Database[20] was leveraged to identify additional waste heat systems.

In total, there are 55 operable electric generators nationwide with waste heat as the primary energy source that have a combined nameplate capacity of 989.8 MW. Applying system-specific power factors to the identified generators results in an actual nationwide capacity of 853.7 MW. Of the existing recycled energy capacity in the United States, industrial providers account for 90% of the capacity, independent power producers account for 9%, and electric utilities and commercial non-CHP providers account for less than 1%.

Recycled energy sites are located in 16 states as shown in Figure 9, with Florida having the largest total capacity at 316 MW from 11 generators, accounting for 37% of total nationwide recycled energy capacity. Louisiana accounts for 12% of recycled energy capacity with 106 MW from six generators, and Indiana accounts for 11% with 95 MW from one generator. California, Texas, and North Carolina account for 25% of total nationwide recycled energy capacity with a combined 217 MW from 17 generators. Montana and Utah provide an additional 9% of total nationwide recycled energy capacity with 48 MW from eight generators and 27 MW from one generator, respectively. The remaining eight states, Alaska, Colorado, Idaho, Kansas, Minnesota, Mississippi, New Jersey, and North Dakota, comprise the remaining 5% of total nationwide recycled energy capacity at 44 MW from 11 generators.

FIGURE 9: RECYCLED ENERGY SITES BY STATE



[19] "Form EIA-860 detailed data," U.S. Energy Information Administration, October 6, 2016, https://www.eia.gov/electricity/data/eia860/.

[20] U.S. DOE Combined Heat and Power Installation Database, U.S. Department of Energy, Application Version 1.0.12, last modified December 31, 2015, https://doe.icfwebservices.com/chpdb/.

TABLE 2: OTHER WASTE HEAT SYSTEMS IN COLORADO

Organization Name	Facility Name	City	State	NAICS	Op Year	Capacity (MW)	Prime mover
Sterling Ethanol, LLC	Sterling Ethanol	Sterling	CO	325193	2006	1	BPST/WH
Yuma Ethanol	Yuma Ethanol	Yuma	CO	325193	2007	2	BPST/WH

Recycled Energy Systems in Colorado

Colorado has one 4.5 MW maximum-capacity recycled energy facility that is eligible under Colorado's RES, Ormat's Trailblazer Pipeline project.

Trailblazer Pipeline Compressor Station Recycled Energy Project

One of the recycled energy systems in Colorado is owned by Ormat, a leading provider of ORC systems for geothermal energy and recycled energy. In March 2009, the Ormat ORC system was constructed along a natural gas compression station (owned by Trailblazer Pipeline Company) in Peetz, CO.[21] The facility captures waste heat from the exhaust of existing gas turbines that drive the compressor and converts it into electricity. Ormat owns and operates this facility, and Highline Electric Association buys the output through a 20-year power purchase agreement. Ormat has secured the rights to use the waste heat under a Waste Heat Host Agreement with Trailblazer Pipeline Company (owned by Kinder Morgan). The Ormat ORC system is in the service territory of Highline Electric Association and is the only recycled energy project in Colorado that counts towards Colorado's RES.

Other Waste Heat Systems in Colorado

Colorado has two additional waste heat systems that are not eligible under the state's RES. The Sterling and Yuma ethanol facilities are both configured as bottoming-cycle CHP systems, meaning that there is an industrial process that utilizes the thermal energy (heat) first, and then the excess or leftover heat is used to generate electricity.

Sterling Ethanol Plant Recycled Energy Project

Sterling Ethanol LLC, has a 42-million-gallon-per-year plant in Sterling, CO, in the northeast corner of the state. The ethanol plant uses a natural gas-fired CHP system to meet its electricity and steam needs. Some of the steam enters the boilers at 130 pounds per square inch. The rest of the steam goes through a back-pressure steam (or steam letdown) turbine system, which lowers the steam to ambient pressure for use in the evaporators. As part of the process of reducing the pressure of the steam to meet plant requirements, the back-pressure steam turbine (BPST) generates additional electricity. The BPST generates about 1 MW of electricity.[22] This represents between a quarter and a third of the plant's electric demand, which runs to 3–4 MW. This project is not eligible under Colorado's RES—the generation of power and then capture of any waste heat to produce additional power is not considered an eligible activity since the primary purpose is the production of electricity. This system is functioning like a natural gas CHP system, which consists of three components—a gas turbine that burns fuel to generate electricity, a heat recovery system that captures exhaust and distributes it for use as steam, and a steam turbine that delivers additional electricity from the unused steam. Such system configurations are not eligible under the RES since their primary focus is electricity production.

Yuma Ethanol Plant Recycled Energy Project

The Yuma Ethanol Plant, located in Yuma County, Colorado, is designed to produce 40 million gallons of ethanol annually. The CHP system that provides heat and power to the plant consists of a 2-MW boiler/steam turbine that began operation in 2007. The CHP system operates in a similar fashion to the Sterling Ethanol plant; the leftover steam is used to power a turbine. Again, this project is not eligible under Colorado's RES because the system's primary purpose is electricity production.

Technologies Installed

In the United States, most of the existing recycled energy systems are SRC configurations. There are some heat recovery steam generator and steam turbine combinations, some ORC systems, and some ORC + combustion turbine combinations.

[21] "Trailblazer Pipeline: 3.5-MW Waste Heat to Power System," U.S. Department of Energy, Combined Heat and Power Technical Assistance Partnership, accessed May 4, 2017, http://www.southwestchptap.org/data/sites/1/documents/profiles/Trailblazer-Project_Profile.pdf.

[22] Jonathan Eisenthal, "Self-Powering Ethanol Production," *Ethanol Today*, accessed May 4, 2017, http://www.ethanoltoday.com/index.php?option=com_content&task=view&id=5&Itemid=6&fid=106.

3 | Technical Potential for Recycled Energy above 450°F in Colorado

This section provides an estimate of the technical market potential for recycled energy in all applicable applications throughout the state of Colorado. The technical potential is an estimation of market size constrained only by technological limits–the ability of recycled energy technologies to fit customers' energy needs. Recycled energy technical potential is calculated in terms of recycled energy electrical capacity that could be installed at existing and new industrial and commercial facilities, based on the estimated electric and available onsite waste heat streams. The technical market potential does not consider screening for economic rate of return, or other factors such as ability to retrofit, owner interest in applying recycled energy, capital availability, or variation of energy consumption within customer application/size class. The technical potential is useful in understanding the potential size and distribution of the target recycled energy market in the state. Identifying the technical market potential is a preliminary step in the assessment of actual economic market size.

Technical Potential Methodology above 450°F

To determine the economic potential, a recycled energy technical potential site database[23] was developed based on the analysis of five source databases:

- U.S. Environmental Protection Agency (EPA) Greenhouse Gas Reporting Program (EPA GHGRP) database
- *Oil & Gas Journal's* gas processing plants database
- *Oil & Gas Journal's* refinery survey
- Portland Cement Association's cement kilns database
- Association of Iron and Steel Engineer's *Directory–Iron and Steel Plants*.

The EPA GHGRP provided an essential database for information on many different manufacturing processes, enabling the creation of a methodology upon which many of the applications were modeled. The GHGRP provided information on the following:

- Facility name and zip code
- Process name and process type
- Fuel input capacity (millions of British thermal units per hour [MMBtu/hour]) and annual fuel consumption (MMBtu/year)
- Annual CO_2 emissions
- Fuel type and greenhouse gas (GHG) emissions factor (kilograms/MMBtu)

All of the databases, except for the EPA GHGRP database, cover a specific industry or application. Databases for a specific industry or application were used to identify facilities for that specific application, and for confirmation and for all other applications, the EPA GHGRP database was used. The data was cross-checked between the sources, and if a site was present in an industry-specific source, as well as the EPA GHGRP database, it was only entered into the overall recycled energy potential site database once.

Power generation from waste heat has predominantly occurred with medium- to high-temperature waste heat sources (i.e., >450°F) for commercially available technologies. There are several emerging technologies that utilize low-temperature waste heat streams that are becoming commercialized; see Section 4 for the analysis of the technical potential for sites with waste heat streams below 450°F.

Since recycled energy is powered by waste heat streams, sizing a recycled energy unit to a facility depends upon the quantity and quality of the waste heat available onsite. The waste heat temperature is a factor in selecting the prime mover technology. The recycled energy system and capacity are a function of the temperature of the waste heat and the expected efficiency of the technology.[24] The information from the aforementioned databases was used to estimate the energy content available from the waste heat at each site.[25]

For most of the sites identified, the waste heat content was derived from the stack gas temperature and CO_2 emissions as reported in the EPA GHGRP database. The volume of the reported stack gas CO_2 emissions was calculated using standard gas temperature, pressure, volume relationship using the assumed stack gas temperature for the equipment (see Table 3), and an assumed minimum recovery temperature of 250°F. Total volume of stack gas emissions was estimated based on stack gases of 3% oxygen by volume.[26] Using the density of air at the stack temperature and the average specific heat for combustion of 0.26 British thermal units per pound, the mass flow rate was then calculated for each site. Then the reported operating hours (or estimated hours[27]) were used to calculate total waste stream energy content.

[23] The technical potential from the national database created from the resources described in this section.

[24] The type of prime mover selected for the site will depend on the application.

[25] For example, for the GHGRP, stack temperatures were established for each relevant type of manufacturing equipment (kilns, incinerators, ovens, etc.).

[26] Amelia Elson, Rick Tidball, and Anne Hampson, "Appendix A," in *Waste Heat to Power Market Assessment* (Fairfax, VA: IFC International, for Oak Ridge National Laboratory, March 2015), http://info.ornl.gov/sites/publications/files/Pub52953.pdf.

[27] Some of the source databases used to build up the site list included information on plant operating hours. When specific data was not available, an estimate of 8,000 hours per year was assumed.

Finally, the total of available, technically recoverable energy was calculated using the standard Carnot efficiency—given the temperature difference between the stack temperature and the heat sink/cooling reservoir (in this case, the heat sink was assumed to be a cooling tower at 85°F)—and the relative efficiency of the site's heat recovery technology (see Table 4).

Refineries identified in the *Oil & Gas Journal's* Gas Refinery Survey and plants identified in the Portland Cement Association's Cement Kilns database often had more than one major process or kiln at each location; therefore, the technically recoverable energy for each refining process or kiln—onsite—was derived (starting with the data from the EPA GHGRP database and using the process described above), and then summed to provide the technical potential results for an entire site.

For some sites—those gas-processing facilities identified in the *Oil & Gas Journal's* Gas Processing Plants database and plants from the Association of Iron and Steel Engineers' *Directory—Iron and Steel Plants*—existing recycled energy installation characterizations were used as models. For the processing plants, the daily gas processing rate (in millions of cubic feet per day) was matched to existing recycled energy installation characteristics in order to size the systems. For the steel plants, the capacities of the major processes in each facility were taken from the directory, and the latest studies and assessments of recycled energy in the iron and steel industry were used to size the systems.

Table 3 displays the exhaust heat stack temperatures assumed for the various processes and equipment types. The theoretical electrical efficiency of the system is estimated

TABLE 3: STACK EMISSIONS TEMPERATURE BY EQUIPMENT

Equipment	Equipment Temperature (°F)
GHGRP Equipment	
Calciner, Kilns	700
Flare	1,200
Incinerator	1,400
Oven	700
Reciprocating Engine	800
Regenerative Oxidizer	1,200
Thermal Oxidizer	1,200
Gas Refining	
Coking	800
Thermal Cracking	800
Visbreaking	800
Catalytic Cracking	1,148
Catalytic Reforming	900
Hydrocracking	800
Desulfurization	968
Alkylation	800
Coke Production	1,000
Steam Methane Reforming	1,500
Cement Manufacturing (type of kiln)	
Dry	840
Dry/Precalciner	640
Dry/Preheater	640

TABLE 4: RECYCLED ENERGY PRIME MOVER TECHNOLOGY BY APPLICATION ABOVE 450°F

SIC	NAICS	NAICS Description	Recycled Energy Technology
29	324	Petroleum Refining	SRC
32	327	Non-Metallic Minerals	SRC
33	331	Primary Metals	SRC
49	486	Pipeline Transportation	ORC
49	562	Waste Management	ORC

based on the relationship of these temperatures with the selected technology. Each waste heat temperature has a Carnot theoretical electrical efficiency associated with converting the waste heat steam into electricity. In practice, however, the actual electrical efficiencies achieved by these systems are less than the Carnot efficiency.[28] The recycled energy prime mover technology chosen for each site was tailored to the application, and it is displayed in Table 4.

Table 4 displays the assumed prime mover selected by application.[29] An ORC or an SRC was selected depending on the application in which the recycled energy system is installed. Rankine cycle technologies were chosen because of their widespread commercial availability and economic feasibility compared to other types of recycled energy prime mover technologies. The selection by application will often depend on the quality of the waste heat (in terms of temperature). Commercially available ORC technologies using gaseous heat sources usually require a temperature of at least 450°F.[30]

Technical Potential Results above 450°F

Using the methodology described above, 108 MW of recycled energy technical potential was identified at 70 sites throughout the state of Colorado. Table 5 displays a more detailed breakdown of the technical potential. Roughly 53% (58 MW) of the total technical potential were found in systems with capacities greater than 5 MW. However, 65 of the 70 sites have a technical potential smaller than 5 MW. This indicates that there are fewer candidate sites for large systems than there are for low-capacity systems.

Table 6 shows the technical potential breakdown by utility. The Xcel Energy and Black Hills Energy service territories contain roughly 60% (26 MW and 38 MW, respectively) of the entire technical potential capacity. However, Xcel Energy's service territory contains almost 40% (27) of the candidate sites within the entire state, making this territory of particular importance for recycled energy potential within the state.

TABLE 5: ONSITE RECYCLED ENERGY TECHNICAL POTENTIAL ABOVE 450°F BY APPLICATION

SIC	Application	50–500 kW		500–1,000 kW		1–5 MW		5–20 MW		>20 MW		Total Sites	Total Onsite Potential (MW)
		No. of Sites	Onsite Potential (MW)	No. of Sites	Onsite Potential (MW)	No. of Sites	Onsite Potential (MW)	No. of Sites	Onsite Potential (MW)	No. of Sites	Onsite Potential (MW)		
29	Petroleum Refining	14	3.7	2	1.3	6	10.5	3	23.9	0	0	25	39.4
32	Non-Metallic Minerals	1	0.4	0	0	4	10.8	1	7.4	0	0	6	18.5
33	Primary Metals	0	0	0	0	0	0	0	0	1	26.5	1	26.5
49	Pipeline Transportation	20	4.5	9	6.4	8	12.8	0	0	0	0	37	23.7
49	Waste Management	1	0.3	0	0	0	0	0	0	0	0	1	0.3
	Total	**36**	**8.9**	**11**	**7.7**	**18**	**34.1**	**4**	**31.4**	**1**	**26.5**	**70**	**108.4**

[28] For recycled energy systems using the Rankine cycle, the electrical efficiencies are generally 30%–50% of the "theoretical" or Carnot efficiency for the technology-temperature pairing. For this study, Rankine cycle efficiencies were estimated to be 40% of the Carnot efficiency.

[29] More recycled energy applications exist. However, the applications listed in this table are those relevant for Colorado technical potential.

[30] Hot exhaust gas from industrial processes will typically satisfy this criterion.

TABLE 6: ONSITE TECHNICAL POTENTIAL ABOVE 450°F BY UTILITY

Utility	0–<500 kW		500–1,000 kW		1–5 MW		5–20 MW		>20 MW		Total Sites	Total Onsite Potential (MW)
	No. of Sites	Onsite Potential (MW)	No. of Sites	Onsite Potential (MW)	No. of Sites	Onsite Potential (MW)	No. of Sites	Onsite Potential (MW)	No. of Sites	Onsite Potential (MW)		
Black Hills Energy	1	0.2	0	0	1	3.9	1	7.4	1	26.5	4	38
Empire Electric Association	0	0	1	0.9	0	0	0	0	0	0	1	0.9
Fort Morgan Electric Light Dept.	1	0.4	0	0	0	0	0	0	0	0	1	0.4
Grand Valley Rural	0	0	1	0.7	0	0	0	0	0	0	1	0.7
Highline Electric Association	0	0	0	0	2	3.7	0	0	0	0	2	3.7
Intermountain Rural Electric Association	1	0.3	0	0	0	0	0	0	0	0	1	0.3
KC Electric Association	5	1.3	1	0.7	2	4.3	0	0	0	0	8	6.3
La Plata Electric Association	0	0	0	0	2	4.2	0	0	0	0	2	4.2
Longmont Electric Utility	0	0	0	0	1	2.2	0	0	0	0	1	2.2
Moon Lake Electric Association	2	0.6	1	0.5	0	0	0	0	0	0	3	1.1
San Isabel Electric Association	1	0.5	1	0.6	0	0	0	0	0	0	2	1.0
Southeast Colorado Electric Association	4	0.9	0	0	0	0	0	0	0	0	4	0.9
White River Electric Association	2	0.2	1	0.7	3	3.7	2	17	0	0	8	21.6
Xcel Energy	15	4.1	5	3.6	7	12.0	1	7.0	0	0	28	26.8
Yampa Valley Electric Association	2	0.4	0	0	0	0	0	0	0	0	2	0.4
Y-W Electric Association	2	0.2	0	0	0	0	0	0	0	0	2	0.2
Total	**36**	**9.0**	**11**	**7.7**	**18**	**34.0**	**4**	**31.4**	**1**	**26.5**	**70**	**108.4**

4 | Technical Potential for Recycled Energy below 450°F in Colorado

This section expands upon the estimates of technical market potential for recycled energy above 450°F from Section 3 by examining waste heat streams below 450°F. These waste streams can come from a larger variety of sources than were seen with the high-temperature waste streams, including smaller installations (e.g., natural gas compression stations), additional industry subsectors (e.g., food processing), and equipment within larger processing steps or systems (e.g., boilers). As before, the technical potential is an estimation of market size constrained only by technological limits.

Technical Potential Methodology below 450°F

Following the same methodology as described in Section 3, sites in Colorado with technical potential for recycled energy projects using waste heat below 450°F were identified. Table 7 expands on Table 3 from Section 3 adding additional process and equipment types with temperatures below 450°F and compares them to some of the other process and equipment analyzed previously. The primary types of equipment that exhaust waste heat below 450°F are boilers, combined cycle turbines, other electricity generation equipment, mine air heaters, and other combustion equipment used in gas processing.[31, 32, 33, 34, 35, 36, 37]

The Kalina cycle was chosen as the recycled energy technology to use in the calculations of technical potential because it is well suited for low-temperature applications. This suitability is due to the improved thermal match compared to single-fluid systems (as described in Section 1) and due to its commercial availability. Compared to the Rankine cycle efficiencies of 40% (relative to the Carnot efficiency) used in calculating the technical potential in Section 3, the Kalina cycle's efficiency was estimated at 60% of the Carnot efficiency.[38]

TABLE 7: STACK EMISSIONS TEMPERATURE BY GHGRP PROCESS OR EQUIPMENT TYPE

GHGRP Process/Equipment Type	Equipment Temperature (°F)
Boiler[31]	310
Combined Cycle Turbine[33]	310
Electricity Generation[31]	310
Mine Air Heaters	310
Other Combustion (gas processing)[31]	310

Technical Potential Results below 450°F

Using the methodology described above, 39.1 MW of recycled energy technical potential was identified at 75 sites with process waste heat below 450°F throughout the state of Colorado. Table 8 displays a more detailed breakdown of the technical potential. Roughly 93% (36.4 MW) of the total technical potential was found at 25% (19) of the sites, each of which could generate greater than 0.25 MW (250 kW). The remaining 56 sites, each of which has technical potential of less than 250 kW, have a combined technical potential of 2.7 MW.

[31] Nenad Sarunac "Power 101: Flue Gas Heat Recovery in Power Plants, Part I," *POWER Magazine*, April 1, 2010, http://www.powermag.com/power-101-flue-gas-heat-recovery-in-power-plants-part-i/?pagenum=3; Nenad Sarunac, *Recovery and Utilization of Heat from the Flue Gas for Improved Power Plant Performance and Availability and Reduction in CO_2 Emissions*, http://www.academia.edu/5688890/Recovery_and_Utilization_of_Heat_from_the_Flue_Gas_for_Improved_Power_Plant_Performance_and_Availability_and_Reduction_in_CO2_Emissions.

[32] Amelia Elson, Rick Tidball, and Anne Hampson, "Appendix A" in *Waste Heat to Power Market Assessment* (Farifax, VA: ICF International for Oak Ridge National Laboratory, March 2015), http://info.ornl.gov/sites/publications/files/Pub52953.pdf.

[33] D. L. Chase and P. T. Keogh, *GE Combined-Cycle Product Line and Performance* (Schenectady, NY: GE Power Systems, 2000), http://physics.oregonstate.edu/~hetheriw/energy/topics/doc/elec/natgas/cc/combined%20cycle%20product%20line%20and%20performance%20GER3574g.pdf.

[34] Bruce A. Hedman, *Waste Energy Recovery Opportunities for Interstate Natural Gas Pipelines* (Washington, D.C.: Interstate Natural Gas Association of America, February 2008), http://www.ingaa.org/File.aspx?id=6210.

[35] U.S. Environmental Protection Agency (EPA), "Section 3.2: 3.2 Natural Gas-fired Reciprocating Engines," in *AP-42: Compilation of Air Emission Factors*, Fifth Edition, Volume 1 (Washington, DC: EPA, 2000), https://www3.epa.gov/ttn/chief/ap42/ch03/final/c03s02.pdf.

[36] "Gas Turbines," World Alliance for Decentralized Energy, accessed May 3, 2017, http://www.localpower.org/deb_tech_gt.html; Clair Soares, "Gas Turbines in Simple Cycle and Combined Cycle Applications," undated, https://www.netl.doe.gov/File%20Library/Research/Coal/ energy%20systems/turbines/handbook/1-1.pdf.

[37] Kalina cycle technologies improve efficiency 20%–50% over Rankine at low temperatures, not including advancements from second-generation Kalina cycle technologies: http://www.globalgeothermal.com/Technology.aspx.

[38] Kalina cycle technologies improve efficiency 20%–50% over Rankine at low temperatures, not including advancements from second-generation Kalina cycle technologies, http://www.globalgeothermal.com/Technology.aspx.

In Colorado, 97% (37.7 MW) of technical potential for low-temperature waste heat is at pipeline compressor stations. The bulk of the potential is at 19 sites, each with the potential to generate >250 kW, with a total potential of 36.3 MW. The remainder of the potential is at another 19 sites, each with a potential to generate less than 250 kW, with a total potential to generate 1.4 MW. The only low-temperature recycled energy opportunities in Colorado at sites larger than 250 kW are associated with pipeline transportation. The 56 identified sites that each have a potential of less than 250 kW, combined could generate a total of 1.3 MW from applications including petroleum refining (0.7 MW), food products (0.2 MW), and chemicals (0.1 MW).

Table 9 shows the technical potential breakdown by utility. Combined, the Highline Electric Association, Yampa Valley Electric Association, and Xcel Energy service territories contain roughly 80% of the entire technical potential capacity (5.4 MW, 8.8 MW, and 17.1 MW, respectively). Additionally, as was the case for the high-temperature technical potential, Xcel Energy's service territory again contains almost 40% (28) of the low-temperature candidate sites.

TABLE 8: TECHNICAL POTENTIAL BELOW 450°F BY APPLICATION

SIC	Application	0–50 kW		50–<100 kW		100–<250 kW		250–<1000 kW		≥1000 kW		Total Sites	Total Onsite Potential (kW)
		No. of Sites	Onsite Potential (kW)	No. of Sites	Onsite Potential (kW)	No. of Sites	Onsite Potential (kW)	No. of Sites	Onsite Potential (kW)	No. of Sites	Onsite Potential (kW)		
12	Coal Mining	3	17.8	0	0	0	0	0	0	0	0	3	17.8
20	Food Products	4	124.5	0	0	1	104.1	0	0	0	0	5	228.6
28	Chemicals	4	131.0	0	0	0	0	0	0	0	0	4	131
29	Petroleum Refining	15	383.3	1	66.7	2	269.5	0	0	0	0	18	719.5
33	Primary Metals	1	0.6	0	0	1	105.6	0	0	0	0	2	106.2
38	Measuring, Analyzing, and Controlling Instruments	1	21.4	0	0	0	0	0	0	0	0	1	21.4
49	Pipeline Transport	11	216.9	3	227.5	5	934.4	8	5,146.1	11	31,219.8	38	37,744.7
82	Educational Services	2	48.7	0	0	0	0	0	0	0	0	2	48.7
97	National Security	2	59.4	0	0	0	0	0	0	0	0	2	59.4
	Total	**43**	**1,003.7**	**4**	**294.3**	**9**	**1,413.0**	**8**	**5,146.1**	**11**	**31,219.8**	**75**	**39,076.7**

TABLE 9: ONSITE TECHNICAL POTENTIAL BELOW 450°F BY UTILITY

Utility	0–50 kW		50–<100 kW		100–<250 kW		250–<1000 kW		≥1000 kW		Total Sites	Total Onsite Potential (kW)
	No. of Sites	Onsite Potential (kW)	No. of Sites	Onsite Potential (kW)	No. of Sites	Onsite Potential (kW)	No. of Sites	Onsite Potential (kW)	No. of Sites	Onsite Potential (kW)		
Black Hills	0	0	0	0	1	105.0	1	374.2	0	0	2	479.2
CO Springs Utility	2	59.4	0	0	0	0	0	0	2	2,216.9	4	2,276.3
Delta-Montrose Elec.	2	15.4	0	0	0	0	0	0	0	0	2	15.4
Fountain Electric	0	0	0	0	0	0	1	524.2	0	0	1	524.2
Ft. Morgan Elec.	1	24.8	0	0	1	104.1	0	0	0	0	2	128.9
Grand Valley Rural	1	14.1	0	0	0	0	0	0	0	0	1	14.1
Highline Elec.	1	36.8	0	0	0	0	0	0	1	5,324.8	2	5,361.6
Holy Cross Elec.	1	1.4	0	0	0	0	0	0	0	0	1	1.4
KC Elec.	2	23.4	0	0	0	0	0	0	0	0	2	23.4
La Plata Elec.	3	118.5	0	0	1	169.5	1	727.5	0	0	5	1,015.5
Moon Lake Elec.	2	18.9	0	0	0	0	0	0	0	0	2	18.9
Morgan County Rural Elec.	2	43.5	0	0	0	0	0	0	0	0	2	43.5
Mountain View Elec.	1	14.0	0	0	1	127.5	0	0	0	0	2	141.5
Platte River Power Auth.	2	64.8	0	0	0	0	0	0	0	0	2	64.8
Poudre Valley Rural Elec.	2	46.5	0	0	0	0	0	0	1	1,299.7	3	1,346.2
San Isabel Elec.	1	16.8	0	0	0	0	0	0	0	0	1	16.8
San Miguel Power Assn., Inc.	0	0	0	0	0	0	1	375.6	0	0	1	375.6
Southeast Colorado Power Assn.	0	0	0	0	0	0	1	898.8	0	0	1	898.8
United Power	1	3.4	0	0	1	100.0	0	0	0	0	2	103.4
White River Elec.	1	4.8	1	66.7	1	155.9	0	0	0	0	3	227.4
Xcel Energy	16	460.9	2	150.5	3	651.0	2	1,338.5	5	14,571.4	28	17,172.3
Yampa Valley Elec.	1	2.4	1	77.0	0	0	1	907.4	2	7,806.9	5	8,793.7
Y-W Elec.	1	34.0	0	0	0	0	0	0	0	0	1	34.0
Total	**43**	**1,003.7**	**4**	**294.3**	**9**	**1,413.0**	**8**	**5,146.1**	**11**	**31,219.8**	**75**	**39,076.7**

5 | Economic Potential for Recycled Energy Systems above 250 kW in Colorado

The economic-potential analysis visualizes the distribution of the technical potential in terms of simple payback. Payback is defined as the amount of time (e.g., number of years) required to recover the total installed capital cost of a recycled energy system. For each site included in the technical potential analysis, an economic payback is calculated based on the appropriate recycled energy system cost and performance characteristics, as well as energy rates for that system's size and application.

Recycled energy project economics are site-specific. Utility-specific electricity rates and tariff structures, and site-specific conditions (i.e., space availability and integration into existing thermal and electric systems, permitting, siting, and grid interconnection requirements) all contribute to the unique economics of each recycled energy system.[39] For this analysis, an estimate of economic potential by system size range was developed for this analysis using the following:

- Recycled energy cost and performance characteristics
- Electricity rebates
  - Performed bottom-rate analyses for Xcel Energy and used utility averages for other utilities[40]
- Relevant incentives
  - Xcel Energy production incentive
  - Federal investment tax credit

Simple yearly paybacks were then calculated for each unique customer. Different types of customers will have varying thresholds for economic feasibility. Commercial and industrial customers will typically require paybacks of less than two years. Institutional customers, such as schools or government buildings, have longer payback thresholds. The payback calculation was conducted, and the technical potential in terms of megawatts was categorized into three payback categories representing the degree of economic potential:

- High potential – simple payback <5 years
- Moderate potential – simple payback ≥5 and ≤10 years
- Low potential – simple payback >10 years

For this analysis, ICF International analyzed sites with a potential of 250 kW or larger. This focus reduced the technical potential analyzed from 108 MW to roughly 106 MW and removed 18 sites from the study. This accounts for the difference between the technical potential analysis and the total figures presented in the economic potential results.

Economic Potential Methodology

The economic potential, or payback, or a project is driven by the relationship between the costs and savings of the recycled energy project. In order to estimate the economic potential, the project team used assumptions for three primary categories: electricity rates, recycled energy cost and performance metrics, and any available incentives. This section will provide a brief discussion on the methodology for creating these assumptions.

Electricity Rates

For this analysis, the project team utilized utility-specific EIA industrial and commercial retail electricity prices to apply to each site. In addition, a bottom-up rate analysis, was performed for Xcel Energy, given its prominent status as an electric power provider in the state. Table 10 displays the electricity rates used for the economic analysis by utility. Table 11 shows the breakdown of the Xcel Energy bottom-up rate analysis. The project team used the commercial and industrial rate classification and selected the Secondary General, Primary General, and Transmission General tariffs to analyze for each customer class.[41] The rates shown below reflect the retail electric rates. However, the economics of a recycled energy system can be highly impacted by the amount of the retail rate the system can avoid through onsite power generation versus purchasing grid electricity, otherwise known as the "avoided rate."

A retail customer generating onsite power with a recycled energy system cannot avoid all the charges within the retail rate. Therefore, it is important in evaluating the economic competitiveness of recycled energy to use only that portion of the electric bill that is saved by the operation of recycled energy, defined in this analysis as the *Average Avoidable Rate*. The avoided cost is an important concept for evaluating the treatment of onsite generation by partial-requirement tariff structures. One of the key economic values of onsite

[39] Components such as space availability, interconnection, siting, and permitting are difficult to quantify and were not included in the payback calculations for the study.

[40] The rate analyses used utility-specific commercial and industrial average electricity prices from the EIA *Electric Power Monthly*, Table 8 & Table 7 (April 2015). For more information please see: https://www.eia.gov/electricity/monthly/current_year/april2015.pdf.

[41] For more information, see the Xcel Energy Colorado Tariff Index: https://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/CO-Rates-&-Regulations-Entire-Electric-Book.pdf.

TABLE 10: UTILITY-SPECIFIC RETAIL ELECTRICITY RATES

Utility Retail Electric Rates ($/kWh)					
Utility	**50–500 kW**	**500–1 MW**	**1–5 MW**	**5–20 MW**	**>20 MW**
KC Electric Association	$0.112	$0.101	$0.098	$0.088	$0.078
Black Hills Energy (West Plains Energy)	$0.123	$0.110	$0.102	$0.092	$0.081
Colorado Springs Electric Dept.	$0.076	$0.069	$0.069	$0.062	$0.055
Black Hills Energy (Southern Colorado Power Co)	$0.134	$0.121	$0.108	$0.098	$0.087
Fort Collins Light & Power Dept.	$0.077	$0.070	$0.060	$0.054	$0.048
Fort Morgan Electric Light Dept.	$0.089	$0.080	$0.082	$0.074	$0.066
La Junta City Utilities Co.	$0.109	$0.098	$0.104	$0.094	$0.083
Lamar Utilities Board	$0.109	$0.098	$0.104	$0.094	$0.083
Longmont Electric Utility	$0.074	$0.067	$0.062	$0.056	$0.050
Delta Montrose Elec. Assn.	$0.113	$0.102	$0.081	$0.073	$0.065
Rural Electric Co.	$0.109	$0.098	$0.104	$0.094	$0.083
Meeker Co-op Light & Power	$0.109	$0.098	$0.079	$0.071	$0.063
Southeast Colorado Power Association	$0.134	$0.121	$0.108	$0.098	$0.087
Y-W Electric Association	$0.109	$0.098	$0.104	$0.094	$0.083
Highline Electric Association	$0.117	$0.105	$0.113	$0.102	$0.091
San Isabel Electric Association	$0.150	$0.135	$0.084	$0.075	$0.067
Moon Lake Electric Association	$0.073	$0.066	$0.063	$0.056	$0.050
Xcel Energy	$0.089	$0.089	$0.084	$0.084	$0.075
CO State Average	$0.107	$0.097	$0.103	$0.092	$0.082
La Plata Electric Association	$0.112	$0.101	$0.078	$0.070	$0.062

TABLE 11: XCEL ENERGY RATE ANALYSIS

Standard Customer Retail Rate Analysis					
Rate Classification	SG	SG	PG	PG	TG
Standard Customer Size (kW)	275	750	3,000	12,500	40,000
Voltage Level	S	S	P	P	T
Avg Retail Rate ($/kWh)	$0.0887	$0.0886	$0.0837	$0.0835	$0.0746

Acronyms: SG – Secondary General; PG – Primary General; TG – Transmission General.

TABLE 12: AVOIDED RATE PERCENTAGES

Avoided Rate Percentages					
Utility	50–500 kW	500–1,000 MW	1–5 MW	5–20 MW	>20 MW
Xcel Energy	63%	63%	64%	65%	71%
Typical Average	80%	85%	87%	88%	90%

generation is the displacement of purchased electricity and the avoidance of those costs. Ideally, the reduction in electricity price should be commensurate with the reduction in purchased electricity—if the onsite system reduces consumption by 80%, the cost of electricity purchases would also be reduced by 80%. However, only a portion of the full retail rate is avoided by onsite generation due to fixed customer charges, demand charges, and standby rate structures. The economics of WHP are severely impacted if partial-requirement rates are structured so that only a small portion of the electricity price can be avoided.

Retail electricity customers installing recycled energy are subject to standby charges. In addition, demand charges in a customer's rate are more difficult to avoid for recycled energy. A momentary outage can trigger the demand charge for the entire month. For this particular analysis, the project team assumed standard avoided rate percentages for each recycled energy size range, with the exception of Xcel Energy.[42] As is evident in Table 12, a prospective recycled energy customer in Xcel Energy's territory will not avoid as much of the retail rate as customers in other areas of the state. This is largely due to the amount of fixed and demand charges that a customer must pay in each billing cycle for Xcel Energy. As discussed later in the section, these charges can have a negative impact on the economics of a recycled energy system.

Recycled Energy Cost and Performance

Recycled energy systems use waste heat streams to generate electricity for the customer. The waste heat will generally originate from heat-intensive onsite operations. There are many different technologies and products that are capable of capturing waste heat to generate power. While these technologies differ significantly in how they are configured and how they operate, the economic value of recycled energy depends on key factors common to all WHP technologies:

- Installed capital cost of the system on a unit basis, expressed in dollars ($) per kilowatt-hour (kWh)
- Operation and maintenance costs on a unit basis, expressed in $/kWh including annual costs and amortization of overhaul costs that can be required after a number of years in operation
- Economic life of the equipment.

For this study ICF International used the cost and performance metrics detailed in Table 13 and Table 14. As discussed earlier, an ORC or SRC prime mover technology was chosen based on the application of the system.

TABLE 13: STEAM RANKINE CYCLE COST AND PERFORMANCE

Steam Rankine Cycle					
Recycled Energy Cost and Performance	50–500 kW	500–1,000 MW	1–5 MW	5–20 MW	>20 MW
U.S. Average Installed Cost, $/kW	$3,000	$2,500	$1,800	$1,500	$1,200
Cost Summary	$4,500	$2,500	$1,800	$1,500	$1,200
O&M Costs, $/kWh	$0.013	$0.009	$0.008	$0.006	$0.005
Capacity Factor	80%	80%	80%	85%	92%

[42] These percentages are based off of numerous rate analyses that ICF has conducted for other utility territories throughout the United States.

TABLE 14: ORGANIC RANKINE CYCLE COST AND PERFORMANCE

Organic Rankine Cycle					
Utility	50–500 kW	500–1,000 MW	1–5 MW	5–20 MW	>20 MW
U.S. Average Inst	$4,500	$4,000	$3,000	$2,500	$2,100
Cost Summary	$4,500	$4,000	$3,000	$2,500	$2,100
O&M Costs, $/kWh	$0.020	$0.015	$0.013	$0.012	$0.010
Capacity Factor	80%	80%	80%	85%	92%

Available Incentives

The last piece of the economic potential methodology is to incorporate any available incentives for recycled energy. Recycled energy does not currently qualify for the federal ITC that CHP systems are eligible to receive. However, there are many state, utility, and local incentive programs that can impact the economics of a recycled energy project. As is discussed in the following chapter, Colorado has various programs in place that could help encourage recycled energy installation. One incentive that has been incorporated into the modeling for the economic analysis is the capacity incentive offered by Xcel Energy.[43] The utility will offer $500/kW for each project within its territory that will be paid out over 10 years (annuitized over a 10-year period). Using the same assumptions employed by Xcel Energy in its original incentive calculation—a 70% capacity factor and a 7.4% weighted average cost of capital—Southwest Energy Efficiency Project (SWEEP) calculates the incentive would be $11.83/megawatt-hour over a 10-year period.[44] Projects up to 10 MW in size qualify under the Xcel Energy Program; projects above 10 MW have a different route that they can use to potentially receive incentives. Annually, 20 MW worth of projects can receive funding. The Xcel Energy incentive will only apply to recycled energy projects that do not export, which may limit compressor stations from receiving funding due to their lack of an onsite electric load.

Economic Potential Results

The economic potential results reflect the amount of capacity that is economically feasible. The results take into account many of the costs and potential savings associated with installing a CHP system. As mentioned at the beginning of this section, the economic potential is quantified as the simple payback of the particular system for that site. Paybacks will vary on a site-by-site basis.

Table 15 shows the economic potential by application. In total, 10 sites containing 54% of the technical potential exhibit paybacks of less than five years. Of the 10 sites that fall below the five-year payback period, seven are sites within petroleum refining or non-metallic minerals application. This is likely due to the very high quality and quantity of the heat available from these applications.

TABLE 15: ECONOMIC POTENTIAL BY APPLICATION

SIC	Application	<5 years		5–10 years		>10 years		Total Sites	Total Potential (MW)
		No. of Sites	Economic Potential (MW)	No. of Sites	Economic Potential (MW)	No. of Sites	Economic Potential (MW)		
29	Petroleum Refining	3	10.4	9	23.8	6	4.0	18	38.3
32	Non-Metallic Minerals	4	16.8	1	0.4	1	1.3	6	18.5
33	Primary Metals	1	26.5	0	0.0	0	0.0	1	26.5
49	Pipeline Transport	2	3.7	21	17.7	3	1.1	26	22.5
52	Waste Management	0	0.0	0	0.0	1	0.3	1	0.3
	Total[3]	**10**	**57.4**	**31**	**41.9**	**11**	**6.7**	**52**	**106.1**

[43] See Chapter 9 for more details on the incentive program.

[44] Public Utilities Commission of Colorado "Answer Testimony of Christine Brinker on Behalf of Western Resource Advocates." (2013, December 2).

Table 16 displays the economic potential by utility. There were four unknown utilities that contain eight of the 10 projects with paybacks below five years: Highline Electric Association, Black Hills Energy, Xcel Energy, and Longmont Electric Utility. As indicated when discussing the avoided rates, Xcel Energy's territory does not contain many sites with strong economic potential. Of the 20 sites in Xcel Energy's territory, 17 have paybacks greater than five years. However, three sites still manage to achieve less than five years' payback within the territory. Overall, 54% (57 MW) of the recycled energy technical potential sites exhibit paybacks of less than 10 years. It is important to note that studies have indicated that 50% of the market of potential investors will opt out of installing a recycled energy unit if the payback is greater than two years.

For Colorado, this means that the market adoption of recycled energy could remain fairly low, absent any changes in electricity rates and/or incentives, depending on the distribution of paybacks within this category.

Table 17 shows the economic potential by system size. The sites that have a payback under five years are large sites with more than 5 MW. However, these sites represent more than half of the entire economic potential. The economic potential trends are not unexpected. Small systems are generally unable to achieve the same economies of scale as large systems, making their payback time lines longer on average. The results shown below illustrate this conclusion, as no sites under 500 kW exhibit paybacks below five years.

TABLE 16: ECONOMIC POTENTIAL BY UTILITY

Utility	<5 years		5–10 years		>10 years		Total Sites	Total Potential (MW)
	No. of Sites	Economic Potential (MW)	No. of Sites	Economic Potential (MW)	No. of Sites	Economic Potential (MW)		
Black Hills Energy	3	37.8	0	0.0	0	0.0	3	37.8
CO State Average	2	2.2	7	3.2	0	0.0	9	5.4
Empire Electric Association	0	0.0	1	0.9	0	0.0	1	0.9
Fort Morgan Electric Light Dept.	0	0.0	0	0.0	1	0.4	1	0.4
Highline Electric Association	1	2.6	0	0.0	0	0.0	1	2.6
KC Electric Association	0	0.0	6	6.1	0	0.0	6	6.1
La Plata Electric Association	0	0.0	2	4.2	0	0.0	2	4.2
Longmont Electric Utility	1	2.2	0	0.0	0	0.0	1	2.2
Moon Lake Electric Association	0	0.0	0	0.0	1	0.5	1	0.5
San Isabel Electric Association	0	0.0	2	1.0	0	0.0	2	1.0
Southeast Colorado Power Association	0	0.0	1	0.4	0	0.0	1	0.4
White River Electric Association	0	0.0	3	18.2	1	1.3	4	19.6
Xcel Energy	3	12.6	9	7.9	8	4.5	20	25.1
Total	**10**	**57.4**	**31**	**41.9**	**11**	**6.7**	**52**	**106.1**

TABLE 17: ECONOMIC POTENTIAL BY SYSTEM SIZE

System Size	<5 years		5–10 years		>10 years		Total Sites	Total Potential (MW)
	No. of Sites	Economic Potential (MW)	No. of Sites	Economic Potential (MW)	No. of Sites	Economic Potential (MW)		
250–500 kW	0	0.0	11	4.2	7	2.4	18	6.6
500–1,000 kW	0	0.0	10	7.2	1	0.5	11	7.7
1–5 MW	7	16.6	8	13.6	3	3.8	18	34.0
5–20 MW	2	14.4	2	17.0	0	0.0	4	31.4
>20 MW	1	26.5	0	0.0	0	0.0	1	26.5
Total	**10**	**57.4**	**31**	**41.9**	**11**	**6.7**	**52**	**106.1**

6 | Economic Potential for Recycled Energy Systems below 250 kW in Colorado

This section analyzes sites in Colorado with potential for recycled energy systems of less than 250 kW each – 75 sites were identified. There were 19 sites under 250 kW and at 450°F or higher and 56 sites that were both under 250 kW and below 450°F.

Economic Potential Methodology below 250 kW

For consistency, this analysis utilizes many of the same methodologies and assumptions in Chapter 5. Utility retail electric rates from Table 10 were used, along with the avoided rate percentages from Table 12.

All 56 potential sites under 250 kW and below 450°F were assumed to use Kalina cycle systems. Of the remaining 19 potential sites above 450°F, 17 were assumed to use ORC systems and one as assumed to use a SRC system. For the ORC and SRC sites, the capital cost and operations and maintenance (O&M) cost data for 50–500 kW systems from Tables 13 and 14 were used.

Economic Potential Results below 250 kW

For Kalina cycle systems, research for this analysis found that costs can vary widely from $1,500 per kW to $6,000 per kW. A study of available literature on Kalina capital costs found a 400-kW Kalina plant would range from $2,800–$4,200 per kW in U.S. dollars (an average capital cost of $3,500/kW).[45, 46] Since cost per kW is expected to rise as the size of the plant decreases, an average of $3,750 per kW was used for this study for Kalina cycle systems of less than 250 kW, as shown in Table 18.

Projected O&M costs also varied in available literature on Kalina cycle systems.[47, 48, 49] Therefore, the average of these estimates, $0.033 per kWh, was used in this analysis, which is also shown in Table 18.

The economic potential is quantified as the simple payback of the particular system for that site. Paybacks will vary on a site-by-site basis.

Table 19 shows the economic potential by application. None of the sites with potential for systems less than 250 kW resulted in a payback period of less than five years. In total, 35 sites containing 47% of the technical potential exhibit paybacks between five and 10 years. Of the 35 sites, the 27 sites that fall in the five- to 10-year payback period are sites for petroleum refining or pipeline transport.

Table 20 displays the economic potential by utility. While 17 of the utilities have at least one potential site in their territory, La Plata Electric Association and Y-W Electric Association are the two utilities with more than two potential recycled energy sites. Similar to the economic results in the original study of sites with potential for systems generating more than 250 kW, Xcel Energy's territory contained a large number of the potential sites but all with longer payback periods. All 28 of the potential sites within Xcel Energy's territory had payback periods of more than 10 years.

Table 21 shows the economic potential by system size. While 46 of the 75 potential sites, or 61%, were less than 50 kW, the rest are fairly evenly distributed across sizes and payback potentials.

[45] Sirko Ogriseck, "Integration of Kalina Cycle in a Combined Heat and Power Plant, A Case Study," *Applied Thermal Engineering* 29, no. 14–15 (2009), https://hal.archives-ouvertes.fr/hal-00556850/document.

[46] Based on research of component and installation costs, minimum capital costs for a project were $25,000. This would prevent a 0.5-kilowatt-electric site from showing a theoretical capital cost need of $1,875.

[47] KALiNA Power Limited, "Making Clean Power from Waste Heat in a Range of Industries," (KALiNA Power Limited, May 2016), http://kalinapower.com/assets/documents/Kalina%20PowerASX%20Presentation%204%20May%202016.pdf.

[48] Roy Bandoro Swandaru and Halldór Pàlsson, "Modeling and Optimization of Possible Bottoming Units for General Single Flash Geothermal Power Plants." (April 2010). https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/2611.pdf

[49] Charles Kutscher, "Small-Scale Geothermal Power Plant Field Verification Projects," (presentation, Geothermal Resources Council 2001 Annual Meeting, San Diego, California, August 26–29, 2001), http://www.nrel.gov/docs/fy01osti/30275.pdf.

TABLE 18: KALINA CYCLE COST AND PERFORMANCE

Recycled Energy Cost and Performance	<250 kW
Average Installed Cost, $/kW	$3,750
O&M Costs, $/kW	$0.033

TABLE 19: ECONOMIC POTENTIAL BY APPLICATION

SIC	Application	<5 years		5–10 years		>10 years		Total Sites	Total Potential (kW)
		No. of Sites	Economic Potential (kW)	No. of Sites	Economic Potential (kW)	No. of Sites	Economic Potential (kW)		
12	Coal Mining	0	0	1	10.4	2	7.4	3	17.8
20	Food Products	0	0	1	35.2	4	193.4	5	228.6
28	Chemicals	0	0	3	95.9	1	35.1	4	131.0
29	Petroleum Refining	0	0	13	1,065.0	13	1,042.2	26	2,107.2
33	Primary Metals	0	0	1	105.0	1	0.6	2	105.6
38	Measuring, Analyzing, and Controlling Instruments	0	0	1	21.4	0	0	1	21.4
49	Pipeline Transport	0	0	14	1,156.3	16	1,451.1	30	2,607.4
82	Educational Services	0	0	1	29.5	1	19.1	2	48.6
97	National Security	0	0	0	0	2	59.4	2	59.4
Total		**0**	**0**	**35**	**2,518.7**	**40**	**2,808.3**	**75**	**5,327.0**

TABLE 20: ECONOMIC POTENTIAL BY UTILITY

Application	<5 years		5–10 years		>10 years		Total Sites	Total Potential (kW)
	No. of Sites	Economic Potential (kW)	No. of Sites	Economic Potential (kW)	No. of Sites	Economic Potential (kW)		
Black Hills	0	0	2	264.5	0	0	2	264.5
CO Springs Utility	0	0	0	0	2	59.4	2	59.4
Delta-Montrose Elec.	0	0	1	10.4	1	5.0	2	15.4
Ft. Morgan Elec.	0	0	0	0	2	128.9	2	128.9
Grand Valley Rural	0	0	1	14.1	0	0	1	14.1
Highline Elec.	0	0	1	36.8	0	0	1	36.8
Holy Cross Elec.	0	0	0	0	1	1.4	1	1.4
KC Elec.	0	0	2	182.3	1	0.6	3	182.9
La Plata Elec.	0	0	4	288.1	0	0	4	288.1
Moon Lake Elec.	0	0	0	0	2	18.9	2	18.9
Morgan County Rural Elec.	0	0	2	43.5	0	0	2	43.5
Mountain View Elec.	0	0	2	141.5	0	0	2	141.5
Platte River Power Auth.	0	0	2	64.7	0	0	2	64.7
Poudre Valley Rural Elec.	0	0	2	46.5	0	0	2	46.5
San Isabel Elec.	0	0	1	16.8	0	0	1	16.8
Tri-State Gen.	0	0	0	0	1	3.4	1	3.4
United Power	0	0	1	100.0	0	0	1	100.0
White River Elec.	0	0	2	222.6	1	4.8	3	227.4
Xcel Energy	0	0	0	0	28	2,583.5	28	2,583.5
Yampa Valley Elec.	0	0	1	77.0	1	2.4	2	79.4
Y-W Elec.	0	0	3	217.8	0	0	3	217.8
Other Utilities	0	0	8	792.1	0	0	8	792.1
Total	**0**	**0**	**35**	**2,518.7**	**40**	**2,808.3**	**75**	**5,327.0**

TABLE 21: ECONOMIC POTENTIAL BY SYSTEM SIZE

System Size	<5 years		5–10 years		>10 years		Total Sites	Total Potential (kW)
	No. of Sites	Economic Potential (kW)	No. of Sites	Economic Potential (kW)	No. of Sites	Economic Potential (kW)		
0–50 kW	0	0	19	467.1	27	581.6	46	1,048.7
50–100 kW	0	0	4	315.2	2	150.5	6	465.7
100–150 kW	0	0	6	727.1	2	238.1	8	965.2
150–200 kW	0	0	5	803.9	4	715.3	9	1,519.2
200–250 kW	0	0	1	205.4	5	1,122.8	6	1,328.2
Total	**0**	**0**	**35**	**2,518.7**	**40**	**2,808.3**	**75**	**5,327.0**

7 | Market Penetration of Recycled Energy above 250 kW in Colorado

This section estimates the market penetration potential in Colorado for recycled energy systems above 250 kW. The results indicate approximately 30 MW of potential for recycled energy systems, largely from waste heat streams in primary metals, petroleum refining, and non-metallic minerals industries. More than 50% of this potential occurs in the Black Hills Energy service territory, nearly 25% in the Xcel Energy and White River Electric Association territories, and the remainder distributed among eight additional utility service territories.

Market Penetration Methodology above 250 kW

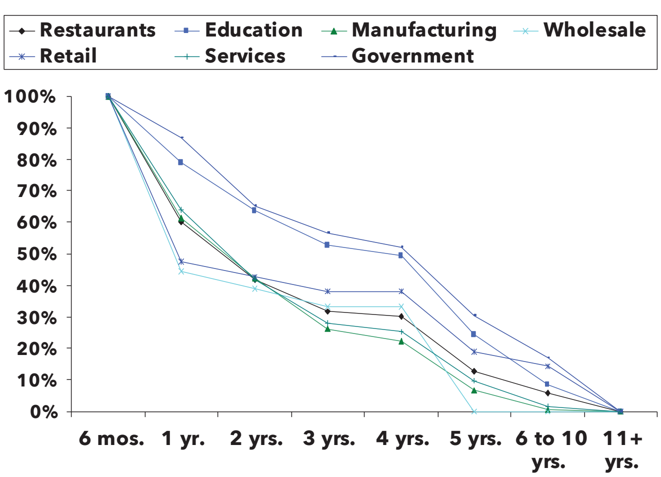
Based on the calculated economic potential, a market diffusion model was used to determine the cumulative recycled energy market penetration over the analysis time frame. The market penetration represents an estimate of recycled energy capacity that will actually enter the market. This value discounts the economic potential to reflect non-economic screening factors[50] and the rate at which recycled energy is likely to actually enter the market.

Rather than using a single yearly payback value as the sole determinant of economic potential, a market acceptance rate has also been included. These acceptance rates are based on a survey of commercial and industrial facility operators, identifying the level of payback required to consider installing recycled energy.

Figure 10 shows the percentage of survey respondents that would accept recycled investments at different payback levels,[52] which is generally consistent, though perhaps even less stringent than industrial payback acceptance rates described in subsequent reports.[53, 54] As can be seen from the figure, more than 30% of industrial customers surveyed would reject a project that promised to return their initial investment in just one year. A little more than half would reject a project with a payback of two years. This type of payback translates into a project with a return on investment of around 50%. Potential explanations for rejecting a project with such high returns include the following:

- The average customer does not believe that the results are valid and is attempting to mitigate this perceived risk by requiring very high projected returns before a project would be accepted.
- The facility has limited capital and is rationing its ability to raise capital for higher-priority projects (i.e., market expansion, product improvement, etc.). As shown in the figure, customers in different application classes exhibit different trends in market acceptance. The acceptance curve for manufacturing customers was used to represent the industrial applications, and the acceptance curve for education was used to model the commercial and institutional applications.

FIGURE 10: MARKET ACCEPTANCE CURVES[51]



Market Penetration Results above 250 kW

The methodology described above was used to estimate how much of the technical potential can be expected to be developed in Colorado. Of the 106 MW of technical potential for systems above 250 kW, roughly 30 MW are estimated to be likely for development under current market conditions. Table 22 shows the distribution of recycled energy

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[50] Examples of non-economic screening factors, such as space availability, interconnection, siting, and permitting, are difficult to quantify and were not included in the payback calculations for this study.

[51] Primen, *Converting Distributed Energy Prospects into Customers: Primen's 2003 Distributed Energy Market Study* (Primen 20013), https://publicdownload.epri.com/PublicDownload.svc/product=000000000001010294/type=Product.

[52] Electric Power Research Institute (EPRI), *Assessment of California CHP Market and Policy Options for Increased Penetration* (Palo Alto, CA: EPRI and Sacramento, CA: California Energy Commission, July 2005), http://www.energy.ca.gov/2005publications/CEC-500-2005-060/CEC-500-2005-060-D.PDF.

[53] Neil Kolwey, *Utility Financing Programs for Industrial Customers* (Boulder, CO: Southwest Energy Efficiency Project, September 2012), 1, http://www.swenergy.org/data/sites/1/media/documents/publications/documents/Utility_Financing_Programs_Industrial1.pdf.

[54] ICF International, *Long-Term Demand Side Management Potential in the Entergy New Orleans Service Area, Final Report* (New Orleans, LA: Entergy Services, Inc., October 2015), http://www.entergyneworleans.com/content/irp/Supplement_1-ENO_DSM_Potential_Study_Report_Final.pdf.

deployment. Roughly 85% (44) of the sites are concentrated in the refining and pipeline transportation application. However, these two applications combined only comprise 36% (11.1 MW) of overall penetration. Conversely, 63% (19.4 MW) of the deployed capacity is distributed among just seven (or 13%) of the 52 identified sites.

Table 23 illustrates the market penetration by utility service territory. Xcel Energy's service territory shows a penetration of 5.2 MW among the 20 sites identified within the territory. Of the 20 sites identified, 19 are those with technical potentials under 5 MW. Black Hills Energy has the highest absolute penetration of 17.8 MW, with recycled energy development opportunities distributed among three sites contained within its territory. Roughly 23 MW of the 30 MW expected to deploy within Colorado are located within these two electric service territories. However, this capacity is constrained to 23 sites, or just more than 50% of the identified candidate sites.

TABLE 22: MARKET PENETRATION BY APPLICATION

SIC	Application	250–500 kW (MW)	500–1,000 kW (MW)	1–5 MW (MW)	5–20 MW (MW)	>20 MW (MW)	Total Penetration (MW)
29	Petroleum Refining	0.1	0.1	1.6	5.6	0.0	7.5
32	Non-Metallic Minerals	0.1	0.0	3.2	3.4	0.0	6.7
33	Primary Metals	0.0	0.0	0.0	0.0	12.7	12.7
49	Pipeline Transportation	0.3	0.6	2.7	0.0	0.0	3.6
49	Waste Management	0.0	0.0	0.0	0.0	0.0	0.0
	Total	**0.5**	**0.7**	**7.5**	**9.0**	**12.7**	**30.4**

TABLE 23: MARKET PENETRATION BY UTILITY

Utility	250–500 kW (MW)	500–1,000 kW (MW)	1–5 MW (MW)	5–20 MW (MW)	>20 MW (MW)	Total Penetration (MW)
Black Hills Energy	0.0	0.0	1.6	3.4	12.74	17.8
CO State Average	0.1	0.2	0.5	0.0	0.00	0.9
Empire Electric Association	0.0	0.1	0.0	0.0	0.00	0.1
Fort Morgan Electric Light Dept.	0.0	0.0	0.0	0.0	0.00	0.0
Highline Electric Association	0.0	0.0	0.7	0.0	0.00	0.7
KC Electric Association	0.1	0.1	1.0	0.0	0.00	1.2
La Plata Electric Association	0.0	0.0	0.6	0.0	0.00	0.6
Longmont Electric Utility	0.0	0.0	0.5	0.0	0.00	0.5
Moon Lake Electric Association	0.0	0.0	0.0	0.0	0.00	0.0
San Isabel Electric Association	0.1	0.1	0.0	0.0	0.00	0.2
Southeast Colorado Electric Association	0.1	0.0	0.0	0.0	0.00	0.1
White River Electric Association	0.0	0.0	0.2	3.0	0.00	3.2
Xcel Energy	0.1	0.2	2.3	2.6	0.00	5.2
Total	**0.5**	**0.7**	**7.5**	**9.0**	**12.74**	**30.4**

8 | Market Penetration of Recycled Energy below 250 kW in Colorado

This section estimates the market penetration potential in Colorado for recycled energy systems under 250 kW. Due to generally longer payback periods that result from harnessing the less energetic, under 450°F waste heat streams, the level of interest in direct investment in these systems by the waste heat stream provider is expected to be low, based on surveys of industry payback acceptance rates. However, alternate business models that do not require the provider to initially fund, own, or operate the systems may provide a viable approach for implementing projects of this scale.

Market Penetration Methodology below 250 kW

As detailed below in Table 24, more than 5,300 kW of generation potential has been identified for opportunities at sites having waste heat streams of less than 450°F and using systems under 250 kW. However, payback periods for these investments are generally well beyond what industrial and commercial businesses typically accept for returns on capital investments, as described in Section 7. Table 24 provides the distribution of potential projects across four payback period categories, divided into shorter intervals to provide closer insight into the five–10 year payback range in particular, as surveys indicate some level of acceptance (on the order of 10%) for investing in projects in the five-to-eight year payback window.

Market Penetration Results below 250 kW

Table 24 shows that five projects totaling 366.5 kW have payback periods that may attract some consideration for investment. There are 30 projects totaling more than 2.1 MW that showed modestly longer payback periods of eight–10 years, while 40 projects totaling about 1.8 MW had longer than 10-year payback periods.

The low expected percent (<10%) of companies that would be interested in the five-to-eight year payback prospects suggests that there is only about a 50% chance of expecting one of these five projects to be implemented, so it is not meaningful to estimate a specific market penetration level. For projects with paybacks beyond eight years, the acceptance rates for direct investment are essentially negligible, such that additional incentives or alternative business models would be required for significant implementation of these projects. Alternative business model options in the form of third-party ownership, financing, and operation are available from firms specializing in recycled energy projects, such as in the form of the Build-Own-Operate-Transfer model for project development. The advantage of this type of model is that the company with the waste heat stream would not need to take responsibility for capital investment or operations of the recycled energy system. However, the model does depend on availability of sufficient utility electric power rates, favorable tariff terms including standby rates, and/or incentives to become a viable proposition for the recycled energy system vendor.

It is important to remember that the figures presented in the Sections 7 and 8 analyses represent market adoption based on current market and policy conditions. Recycled energy faces a number of barriers to entry that, if relieved, could improve project economics and boost development. The following section will discuss the current recycled energy market and policy trends in Colorado that drive the economic potential and market acceptance.

TABLE 24: PAYBACK PERIOD BY INDUSTRY

SIC	Application	5–8 years		8–10 years		10–13 years		Over 13 years	
		No. of Sites	Economic Potential (kW)	No. of Sites	Economic Potential (kW)	No. of Sites	Economic Potential (kW)	No. of Sites	Economic Potential (kW)
12	Coal Mining	0	0	1	10.4	1	5.0	1	2.4
20	Food Products	0	0	1	35.2	2	128.9	2	64.5
28	Chemicals	1	36.8	2	59.1	0	0	1	35.1
29	Petroleum Refining	2	65.2	11	999.9	9	968.9	4	73.1
33	Primary Metals	1	105	0	0	0	0	1	0.6
38	Measuring, Analyzing, and Controlling Instruments	0	0	1	21.4	0	0	0	0
49	Pipeline Transport	1	159.5	13	996.7	3	492.0	13	959.0
82	Educational Services	0	0	1	29.5	0	0	1	19.1
97	National Security	0	0	0	0	0	0	2	59.4
	Total	**5**	**366.5**	**30**	**2,152.1**	**15**	**1,594.9**	**25**	**1,213.3**

9 | Recycled Energy Market and Policy Trends

Identification of Key Barriers and the Current Policy Environment in Colorado

There are a number of barriers that prove limiting to recycled energy projects. These barriers can be categorized as financial, regulatory, or informational in nature. Some of the key barriers to the increased deployment of recycled energy are discussed below. This section also goes on to discuss the policy environment for recycled energy in Colorado. The following chapter will cover opportunities to help address these barriers.

Key Regulatory Barriers

- *Standby rates*: Utility rates and fees can have an impact on recycled energy project economics. While most industrial customers are motivated to install recycled energy systems to meet electricity needs at a lower cost, standby rates or partial-requirements tariffs can be impediments to recycled energy projects if the rates are not properly designed. Standby charges should allow a utility to recover costs from customer classes based on energy-usage patterns for each class. This principle of "cost causation" is implemented through rate designs that fairly allocate costs based on measureable customer characteristics.

- *Environmental permitting and regulatory issues*: Complicated state and federal permitting requirements can impede the adoption of recycled energy projects. The installation of recycled energy systems may require industrial users to modify their process equipment, potentially triggering permitting issues. Ensuring that state permitting processes are straightforward and predictable—clarifying when recycled energy systems would trigger additional permitting requirements—helps to avoid costly delays and uncertainty in the planning process.

- *Lack of recognition of environmental benefits*: Lack of financial value for the potential emissions benefits of recycled energy projects can deter development of recycled energy projects. Treating environmental benefits as an externality that cannot be monetized reduces the value of recycled energy projects. For example, recycled energy projects help reduce CO_2 emissions by using a waste heat stream to generate electricity without additional fuel combustion or emissions. There may be significant value (monetary and shareholder) from such emissions savings in certain markets, such as recycled energy systems receiving CO_2 emissions credits under the Regional Greenhouse Gas Initiative or future federal regulations, as well as in corporate sustainability reporting.

Other Barriers

- *Internal competition for capital*: Payback expectations and capital budget constraints influence recycled energy investment decisions. Facility capital budgets are limited, and there is often strong competition for new capital investment. Even a recycled energy system that has an attractive financial return may not be funded over other capital projects that are closer to a company's core business, such as investments in productivity or product quality or investments to respond to regulatory requirements.

- *Financial risk*: Facilities may have a hard time finding low-cost financing for recycled energy projects due to financial risks. Gaining access to capital at affordable rates can be especially difficult for long-term investments in facility upgrades, such as recycled energy projects. For example, there are complicating factors like lender uncertainty about the recycled energy technology and the viability of process-related changes (e.g., how the system works, how it will be incorporated into the process, and whether it will perform as expected).

- *Access to favorable tax structures*: Lack of inclusion of recycled energy in federal tax incentives such as the federal ITC can prevent further deployment of this technology type. A study by the Heat is Power (HiP) Association found that given equal tax treatment to other clean energy technologies, industrial waste heat could provide enough emissions-free electricity to power 10 million American homes, provide thousands of new American jobs, and support critical U.S. manufacturing industries.[55]

[55] Heat is Power (HiP), "Comments: Energy Tax Reform," in *Waste Heat to Power: Emission-Free Power Generation Industrial Efficiency* (HiP, April 2013), http://www.heatispower.org/wp-content/uploads/2013/04/Heat-is-Power-Association-letter-to-W-and-M-Energy-Tax-Reform-Working-Group-4-15-2013.pdf.

- *Sales of excess power*: The inability to sell excess power or access to reasonable sales agreements for excess power if all of the generation cannot be used onsite can be a barrier. Excess power sales may provide a revenue stream for a recycled energy project, possibly enabling the project to go forward. The inability to sell excess power or to sell excess power at a competitive price can serve as a deterrent to recycled energy projects.
- *Awareness of available incentives:* Insufficient knowledge of federal, state, and utility incentives and eligibility requirements for recycled energy projects can prevent good candidate sites for recycled energy from moving forward with such projects.

Existing Colorado Incentives and Policies for Recycled Energy

There are a number of policies that impact recycled energy opportunities in Colorado. The Colorado RES is the key policy driver for recycled energy project development. The RES requires each qualifying retail utility to generate or acquire sufficient renewable energy credits (RECs) to meet a specified portion of its retail electricity sales by 2020. Investor-owned utilities must acquire 30% of their generation from eligible resources, electric co-operatives (co-ops) that serve 100,000 meters or more must meet a 20% requirement, and electric co-ops serving less than 100,000 meters and each municipal utility serving more than 40,000 meters must meet a 10% requirement. Investor-owned utilities must meet a requirement that 3% of their retail sales by 2020 come from distributed generation (DG); half of this requirement (1.5%) must come from "retail DG"[56] serving onsite load. Co-ops that provide service to 10,000 or more meters must also meet a DG requirement of 1% of retail sales by 2020 (0.5% must come from "retail DG").

As previously noted, the RES currently defines eligible recycled energy as "energy produced by a generation unit with a nameplate capacity of not more than 15 MW that converts the otherwise lost energy from the heat from exhaust stacks or pipes to electricity and that does not combust additional fossil fuels. Recycled energy does not include energy produced by any system that uses energy, lost or otherwise, from a process whose primary purpose is the generation of electricity, including, without limitation, any process involving engine-driven generation or pumped hydroelectricity generation."[57] There are certain REC multipliers for projects that began on or after Jan. 1, 2015, and for projects that are interconnected to electrical transmission or distribution lines owned by a co-op or municipal utility that were installed prior to Dec. 31, 2014. The Trailblazer Pipeline compressor station is the only recycled energy project that has been able to receive RECs under the RES as of the publication of this report. The Trailblazer project generates around 27,600 megawatt-hours per year,[58] which amounts to $600,000 in annual revenues through RECs.[59]

Xcel Energy and Black Hills Energy are required to regularly submit Renewable Energy Compliance Plans to the Colorado Public Utilities Commission (PUC). Neither of the investor-owned utilities have utilized recycled energy projects to help meet their compliance targets to date. However, in response to a push for incentives covering all customer-sited

[56] "Retail Distributed Generation" is defined as a "resource that is located on the site of a customer's facilities and is interconnected to the customer's side of the meter." Presumably, this would include all renewable energy systems that participate in net metering. "Wholesale distributed generation" is defined as a "resource with a nameplate capacity rating of 30 megawatts-electric (MWe) or less and that does not qualify as retail distributed generation." DG systems with a nameplate capacity of 1 MWe or greater must be registered with a Renewable Energy Credit tracking system, which the PUC will select.

[57] Colorado Department of Regulatory Agencies, Public Utilities Commission. "4 Code of Colorado Regulations (CCR) 723-3, Part 3 Rule Regulating Electric Utilities." (2014, June). http://www.sos.state.co.us/CCR/GenerateRulePdf.do?ruleVersionId=5738

[58] U.S. Department of Energy Clean Energy Application Centers, "Recycled Energy Basics and Benefits, Arizona Recycled Energy in Action," Jan. 26, 2012, http://southwestchptap.org/data/sites/1/events/2011-07-13/Recycled_Energy_Basics_and_Benefits.pdf.

[59] Roy L. Hales, "The New Renewables Are Recycled Energy Technologies," *CleanTechnica*, January 17, 2015, http://cleantechnica.com/2015/01/17/new-renewables-recycled-energy-technologies/.

eligible energy resources, Xcel Energy proposed a recycled energy program in its 2014 RES Plan, which was approved with modifications.[60] A dditional proceedings provided more feedback from intervenors and the requirement of developing a new recycled energy tariff proposal. This led Xcel Energy to develop a Recycled Energy Program and a related tariff (Schedule RE) in its 2016 Renewable Energy Plan. The Colorado PUC approved a settlement that included Xcel Energy's new tariff for recycled energy on Nov. 9, 2016, which became effective on Jan. 1, 2017.[61] The program and tariff were further refined through a settlement agreement that addressed many other issues aside from recycled energy and involved numerous parties.[62] The program, which is now being implemented, offers a recycled energy incentive of $500 per kilowatt-electric of recycled energy system capacity installed for up to 20 MW worth of projects annually. The incentive will be paid monthly, over 10 years. This incentive applies to the total recycled energy system output (up to 10 MW capacity), whether used on-site or sold to a utility or other wholesale electricity provider.[63] The recycled energy system's electrical output can be used by any operations belonging to the customer as long as they are behind the customer's meter. The project must enter into a 20-year term that transfers the renewable attributes created by the project to Xcel. The recycled energy tariff also provides each program participant an "Annual Grace Energy amount equal to the Standby Hours times the Contract Standby Capacity without incurring a Daily Usage Demand Charge. After the Annual Grace Energy has been exhausted and the Customer uses Standby Service, the Customer shall pay the Daily Usage Demand Charge."[64]

Concerning other policies in Colorado, DOE's Southwest CHP Technical Assistance Partnership (TAP) has an overview of policies in Colorado impacting CHP, including some policies specifically impacting recycled energy, along with a rating. Interconnection standards in the state list recycled energy projects as eligible for a standardized interconnection process, and systems up to 10 MW in size can interconnect. However, the interconnection standards are criticized due to the additional insurance requirements, whereby owners of grid-tied DG systems must carry their own liability insurance when the rules already have provisions for indemnification. Standby rates in Colorado are also not considered favorable to implementation of CHP or recycled energy. Standby rates are relatively high in Xcel Energy's territory and in some co-op territories. While there have been instances of projects not going forward or shutting down due to these high standby rates, the more favorable terms put forth in Xcel Energy's new recycled energy tariff could help overcome this barrier. There are a few other financial incentives for which recycled energy projects may be eligible. Tri-State provides power to 44 rural cooperatives, including some in Colorado. Tri-State has some financial incentives for its member co-ops to develop distributed and/or renewable energy projects, and recycled energy projects qualify.[65]

To assist in further development of the recycled energy market, the Colorado Energy Office has partnered with the Southwest CHP TAP to offer no-cost feasibility studies to a limited number of facilities in Colorado that are good candidates for recycled energy projects. The feasibility studies will seek to prove the business case for installing recycled energy at those facilities and identify any barriers or risks specific to those locations. The Colorado Energy Office has also partnered with SWEEP on an outreach initiative that aims to increase awareness of recycled energy and relevant incentives in Colorado, and get companies that produce waste heat onto a path toward recycled energy projects.

Another incentive is an ITC that is available through Colorado's Enterprise Zone program for qualified renewable energy investments, which are those that generate electricity from RES-eligible resources, including recycled energy. For projects before 2018, there is an option to for an income tax credit equal to 3% of the investment, up to $750,000. Otherwise, all projects starting in 2015 through 2020 can opt to receive a refund of 80% of the amount of the Enterprise Zone ITC.[66]

Lastly, the Colorado Commercial Property Assessed Clean Energy (C-PACE) program is a financing tool allowing waste heat producers to finance a recycled energy system through a lien on the facility and pay it back at a low-interest rate through a voluntary special assessment on the facility's property tax bill, over a period of up to 20 years. The advantages of C-PACE are that the costs of the project are spread over a longer period than could be obtained with traditional financing, and the facility saves money on its energy bills over the period of the loan. In addition, the C-PACE loan is entirely off the facility's balance sheet.[67]

[60] Colorado Public Utilities Commission, "Recommended Decision of Administrative Law Judge Harris G. Adams Granting Application and Approving Compliance Plan with Modifications," Decision No. R14-0902, July 31, 2014, https://www.dora.state.co.us/pls/efi/efi_p2_v2_demo.show_document?p_dms_document_id=381791&p_session_id=.

[61] Colorado Public Utilities Commission, No.8. Decision/Proceeding Number C16-1075, "Recycled Energy Service."

[62] Colorado Public Utilities Commission, "Decision Granting Motion to Approve Settlement, Granting Motion for Waivers, Denying Motion to Dismiss Application, Ordering Tariff Filings, Addressing New Proceeding on Trial and Pilot Rate Programs, Addressing Recovery of Renewable Compliance Plan Costs, and Addressing Future Resource Acquisitions," Decision No. C16-1075, Nov. 23, 2016, https://www.dora.state.co.us/pls/efi/efi_p2_v2_demo.show_document?p_dms_document_id=854365&p_session_id=.

[63] Any excess electricity generated by the recycled energy system (beyond onsite needs) may be sold to a utility or wholesale provider at a negotiated rate.

[64] Public Service Company of Colorado (Xcel Energy), Schedule of Rates for Electric Service, Sheet 117, https://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/CO-Rates-&-Regulations-Entire-Electric-Book.pdf.

[65] "Colorado," U.S. Department of Energy, Technical Assistance Partnerships, Southwest, accessed May 4, 2017, http://www.southwestchptap.org/states-co.

[66] "Renewable Energy Equipment," Colorado Office of Economic Development and International Trade, Enterprise Zone Tax Credits, accessed March 2, 2017, http://choosecolorado.com/doing-business/incentives-financing/ez/renewable-energy-equipment.

[67] "About C-PACE," Colorado Commercial Property Assessed Clean Energy, accessed May 4, 2017, http://copace.com/about/.

10 | Opportunities for State Involvement in Recycled Energy Market

Evaluation of Potential Options for State Involvement

In Colorado, the key policy in place to encourage recycled energy projects is the designation of recycled energy as an eligible energy resource under the state's RES.[68] Other states can serve as examples for Colorado and inform the state regarding best practices for encouraging further recycled energy deployment. Model state incentives and policies will be described in this section, along with the pros and cons of each approach. Federal drivers for increased development of recycled energy projects are also discussed.

Portfolio Standards

More than a third of states include recycled energy in their Energy Efficiency Resource Standards (EERS) or in their Renewable Portfolio Standards (RPSs), including Colorado. However, Colorado may want to consider increasing the size limit applicable to recycled energy projects or including a specific recycled energy target that utilities must meet. According to HiP,[69] 17 states consider recycled energy projects to be a renewable resource in their state RPS, and three states include recycled energy as an efficiency measure in their Energy Efficiency Resource Standard. Although there are 13 different terms for recycled energy in state RPSs, all specify the generation of electricity from waste heat in their definition. In addition, like Colorado, seven states explicitly exclude waste heat from power generation processes from qualifying as recycled energy.

Colorado may want to consider establishing a carve-out or target solely for recycled energy projects. This would require affected utilities to incentivize a certain amount of recycled energy projects to meet their compliance obligations. Renewable energy advocates also often support the tier/carve-out structure under portfolio standards. Both approaches could boost recycled energy development without detracting from the amount of energy procured from

[68] Colorado Legislature, "Colorado Revised Statutes 2016 – Title 40: Utilities" Statute: 40-2-124, Renewable Energy Standards, https://leg.colorado.gov/sites/default/files/images/olls/crs2016-title-40.pdf.

[69] The Heat is Power Association (HiP), "Waste Heat to Power: Emission Free Power Generation," (Oak Brook, IL: HiP, Sept. 2016), http://www.heatispower.org/wp-content/uploads/2016/01/HiP-WHP-Fact-Sheet-September-2016.pdf.

traditional renewable energy resources such as wind and solar.

Public Benefits Funds

A Public Benefit Fund (PBF) or System Benefits Charge (SBC) is a small monthly surcharge on customers' electricity bills that is collected and used for statewide investments in clean energy supply.[70] Oregon passed restructuring legislation in 1999 that established a PBF in the state. The funds are directed toward renewable and energy efficiency projects and are administered by the Energy Trust of Oregon. CHP and heat recovery technologies are eligible for funding.

In several states, such as California, Connecticut, New York, Maryland, and Hawaii,[71] an opportunity to help finance clean energy projects, such as recycled energy, is emerging through the establishment of "green banks." For example, in Connecticut and New York, SBCs were repurposed and combined with Regional Greenhouse Gas Initiative funds to provide initial capital for the green bank. A "green bank" is typically defined as a public or quasi-public financing institution that provides low-cost, long-term financing to support a wide range of clean energy projects. Green banks often leverage public funds to attract private investment.[72] In Connecticut, the green bank has a CHP pilot program, which could offer insights into how a similar program could be developed for recycled energy. The program is run by the Clean Energy Finance and Investment Authority and provides grants, loans, loan enhancements, and power purchase incentives to CHP projects in the development phase. Systems must be 5 MW or less in size and must be located within certain utility service territories within the state. Financial incentives are capped at $450/kW of nameplate rated capacity.[73]

Establishing a green bank in Colorado is an option for increasing the financing available for recycled energy projects. The recently established green banks also seek to leverage private financing for clean energy projects. However, green banks are a relatively new financing mechanism for clean energy projects, and there are few experiences and/or lessons learned to draw from at this point.

State Tax Credits

Another way to encourage recycled energy projects is through the availability of state tax credits for installing this type of project. Kansas provides a property tax credit for waste heat projects at power generation facilities. The waste heat utilization-system property is exempt from all property taxes levied under Kansas state law for the first 10 taxable years in which construction or installation of the project is complete.[74] For the purposes of this law, a waste heat utilization system includes facilities and equipment for the recovery of waste heat generated in the process of generating electricity and the use of such heat to generate additional electricity or to produce fuels from renewable energy resources or technologies. This Kansas tax credit is not a direct model for Colorado because it applies only to waste heat projects at

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70 Center for Climate and Energy Solutions, "Public Benefit Funds," last modified May 2017, https://www.c2es.org/us-states-regions/policy-maps/public-benefit-funds.

71 "What is a Green Bank?" Coalition for Green Capital, accessed May 4, 2017, http://www.coalitionforgreencapital.com/whats-a-green-bank.html.

72 "What is a Green Bank?" Coalition for Green Capital, accessed May 4, 2017, http://www.coalitionforgreencapital.com/whats-a-green-bank.html.

73 "Combined Heat and Power Pilot Program," Energize Connecticut, accessed May 4, 2017, http://www.energizect.com/your-business/solutions-list/Combined-Heat-Power.

74 "Taxes and Incentives – Waste Heat Utilization System," Kansas Department of Commerce, accessed May 4, 2017, http://www.kansascommerce.com/index.aspx?NID=447.

power generation facilities, and projects at such facilities are explicitly excluded from Colorado's definition of recycled energy. However, it is a useful property tax credit model for Colorado to consider for its eligible opportunities.

Tax credits can serve as an effective way of encouraging clean energy projects. However, at the state level, tax credits are less often used compared to other forms of incentives such as grant and rebate programs. Colorado may want to consider grants, rebates, and tax credits to spur recycled energy project development.

Standby Rates

The way in which utility standby rates are designed has a significant impact on recycled energy project economics. For example, some state standby rates have demand ratchets, meaning that the utility continues to apply some percentage of the customer's highest peak demand in a single billing month for up to a year after its occurrence. Ratcheted demand charges may result in recycled energy customers overpaying for utility-supplied electricity relative to full-requirements customers.

An example of a utility's standby rates that have been deemed favorable for DG projects is Pacific Power's standby rates in Oregon. Pacific Power has established standby rates in Oregon that balance the value of onsite power generation and utility cost recovery needs. Several key elements of these standby rates include the following:

- Pacific Power assesses charges for shared distribution facilities, such as substations and transmission lines, based on 15-minute net demand for the month during on-peak hours. There is no annual ratchet.
- Cost recovery for local distribution facilities is based on the average of the two highest monthly peak demands for the past 12 months.
- Scheduled maintenance service must be planned 30 days in advance. Pacific Power offers customers the option to buy replacement energy at market prices.
- Energy service for unscheduled outages is based on real-time market prices. Demand and transmission charges during scheduled maintenance periods and unscheduled outages are based on daily demands and do not affect charges for transmission and distribution services under the base standby tariff.

While Xcel has adopted more favorable standby rates in their Recycled Energy Service Tariff, Colorado may want to consider conducting a study on standby rate charges by other utilities in the state and make recommendations as to which elements of Colorado's utility standby rates should be reassessed. Revising standby rates to ensure that they are more favorable to forms of DG, like recycled energy projects, can be much more beneficial in encouraging new projects than other types of financial incentives. However, there are often numerous different utility standby rates within a state that may need to be assessed and modified. Implementing a single incentive program for recycled energy projects may be easier from an administrative/rulemaking viewpoint as compared to modifying standby rates to make them more favorable to recycled energy projects.

Excess Power Sales Laws

Another policy that can encourage recycled energy projects is the ability to sell any excess power that is produced and exceeds any onsite demand to adjacent customers. Often, states have policies in place that do not allow recycled energy projects to sell excess generation off-site. Colorado can assess their laws affecting ability of facilities to sell electricity to adjacent customers and consider action to resolve barriers preventing recycled energy projects from participating.

Net Metering

Being explicitly mentioned as an eligible technology under net metering policies is also beneficial to recycled energy projects and other forms of DG. Connecticut is the only state that explicitly calls out waste heat recovery projects as eligible for net metering. Connecticut allows virtual net metering for Class III resources, which is defined as a system that "produces electrical or thermal energy by capturing preexisting waste heat or pressure from industrial or commercial processes" from facilities up to 3 MW in size.[75] If the customer produces more electricity than it consumes, the excess electricity is credited to the account for the next billing period at the retail rate against the generation service component and a declining percentage of the transmission and distribution charges that are billed to the account. Excess credits roll over monthly for one year. The electric distribution company is to compensate the municipal or state host customer for any excess virtual net metering credits that remain at the end of the calendar year, at the retail generation rate and the above-declining percentage of transmission and distribution charges.[76]

Net metering can help the economics of a recycled energy project if that project expects to produce more power than can be used onsite. Most states only allow for small, renewable systems to net meter and set an upper limit on the amount of capacity that can net meter. Extending net metering eligibility to other project types such as recycled energy can help tip the balance in favor of moving forward with such a project.

Financial Incentives

The most popular form of support for recycled energy projects is through financial incentives. Most are offered in

[75] "Net Metering – Connecticut," U.S. Department of Energy, accessed May 4, 2017, https://energy.gov/savings/net-metering-12.

[76] "Connecticut Net Metering," NC Clean Energy Technology Center, DSIRE, last updated Oc.r 4, 2016, http://programs.dsireusa.org/system/program/detail/277.

the form of rebates, with some loans, grants, tax credits, and Property-Assessed Clean Energy (PACE) financing, which is now available in Colorado for recycled energy projects. Some innovative incentive programs under which recycled energy is explicitly called out as eligible are detailed below.

- Illinois Public-Sector CHP Pilot Program – This program provides cash incentive for recycled energy projects that increase energy efficiency of public, state, or federal facilities in Illinois located in the service territories of ComEd, Ameren, Nicor, Peoples Gas, or North Shore Gas. Incentives are capped at $2 million per project or 50% of the cost of the project, whichever is less. There are three different types of incentives available: a design incentive of $75/kW, a construction incentive of $175/kW, and a production incentive of $0.08/kWh for all useful electric energy produced by the recycled energy system. WHP is defined as an integrated system that is located at or near the building or facility on the customer side of the meter, that does the following:[77]
    - Utilizes exhaust heat from an industrial/commercial process and converts that heat to generate electricity (except for exhaust heat from a facility whose primary purpose is the generation of electricity for use on the grid)
    - Utilizes the pressure drop in an industrial/commercial facility to generate electricity through a backpressure steam turbine where the facility normally uses a pressure-reducing valve to reduce the pressure in their facility
    - Utilizes the pressure reduction in natural gas pipelines (located at natural gas compressor stations) before the gas is distributed through the pipeline to generate electricity, provided that the conversion of energy to electricity is achieved without using additional fossil fuels.
- New Jersey Clean Energy Program's CHP Incentives – This New Jersey program provides incentives for heat recovery projects defined as "powered by non-renewable fuel source. Heat recovery or other mechanical recovery from existing equipment utilizing new electric generation equipment (e.g., steam turbine)." Heat recovery projects <1 MW are eligible for an incentive of $1.00/watt (W); incentives are capped at 30% of project costs or $2 million. For heat recovery projects greater than 1 MW, the incentive is $0.50/W; incentives are capped at 30% of project costs or $3 million.[78]

[77] "Public Sector Combined Heat and Power (CHP) Pilot Program, Request for Applications," Illinois Department of Commerce and Economic Opportunity, accessed May 4, 2017, https://www.illinois.gov/dceo/whyillinois/TargetIndustries/Energy/Documents/Final_RFA%20CHP%20Guidelines%207-7-14.pdf.

[78] "Combined Heat & Power – Incentives," New Jersey Board of Public Utilities, Clean Energy Program, accessed May 4, 2017, http://www.njcleanenergy.com/commercial-industrial/programs/combined-heat-power/combined-heat-power.

- New York State Energy Research and Development Authority's (NYSERDA's) GHG Reduction Pilot Program – NYSERDA solicited proposals in 2015 to demonstrate market-ready technologies that reduce GHG emissions from the power sector. Waste heat recovery projects were identified as an eligible technology for reducing the annual emissions rate at New York electricity-generating units with a nameplate capacity of at least 25 MW. The solicitation offered up to $2 million per demonstration project.[79]

- California Self-Generation Incentive Program (SGIP) – California's SGIP offers incentives to a number of project types including recycled energy projects defined as WHP projects. Recycled energy projects are eligible for an incentive of $1.07/W. The incentive payment is capped at 3 MW. (Larger projects are eligible, but they only receive incentives up to this size threshold). The maximum incentive available is $5 million or 60% of eligible project costs.[80]

- Colorado – The state's C-PACE program enables owners of commercial and industrial buildings to finance up to 100% of eligible energy improvements. Financing is provided by private capital providers at competitive rates with repayment terms of up to 20 years. CHP is explicitly called out as an eligible renewable energy improvement, while recycled energy is not.[81]

Nevertheless, energy efficiency organizations such as the American Council for an Energy-Efficient Economy list Colorado PACE laws as including "model language." For example, Colorado House Bill 08-1350, Session Law 299[82] amends county and city authority to create improvement districts specifically for clean energy improvements.[83]

Colorado could consider some of the state incentive programs mentioned above such as Illinois' or New York's CHP incentive programs, in addition to the incentive program that Xcel Energy recently announced in Colorado.[84] The state could draw upon some of the same general design concepts of these other state programs, but it would need to revise some of the elements to reflect the specific types of projects being sought, and to reflect the energy and policy environment in the state.

Federal Proposals Related to Recycled Energy

The federal ITC does not include recycled energy projects. HiP and other organizations have advocated that the ITC be extended to include recycled energy projects, have recommended extending the ITC past 2016, and have suggested increasing the ITC for recycled energy to 30%.[85] The Power Act, which was introduced in 2014 and then reintroduced in 2015, proposed increasing the ITC from 10% to 30%, extending the tax credit through the end of 2018, including recycled energy projects as eligible, and removing size limitations for CHP.[86] The Clean Energy for America Act was introduced in May 2017. The Act would provide a technology-neutral approach to energy tax reform, favoring innovation by providing a sliding scale of incentives based on how clean a power-generating technology is, rather than naming specific technologies. HiP expects additional legislation favorable to recycled energy to be introduced in the near future.

Another tax credit that has been available to encourage CHP projects is the Modified Accelerated Cost Recovery System (MACRS).[87] The MACRS establishes a set of class lives for various types of property (5 years for CHP), over which the property may be depreciated. A number of advocacy groups have proposed that MACRS be expanded to include recycled energy or WHP property as explicitly eligible for depreciation.

Recommendations for Colorado

Table 25 lists the key barriers to greater deployment of recycled energy projects that were discussed in the prior section and recommendations for the State of Colorado on how to address these barriers. The recommendations are discussed in further detail in this section. Based on the above recycled energy state policy examples, Colorado could consider a number of policies to further enhance the development of recycled energy systems. Recommendations for Colorado include, but are not limited to the following:

- Provide utilities with additional financial incentives for recycled energy. (e.g., Recommend that Black Hills Energy develop a recycled energy incentive program similar to Xcel Energy's recent program.)

- Conduct a study of utility standby rates in the state and recommend ways to improve upon existing tariff structures. For example, the

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79 "RFP 2857 Competitive Greenhouse Gas Reduction Pilot Program," New York State Energy Research and Development Authority, accessed May 4, 2017, https://www.nyserda.ny.gov/powergentech.

80 "California, Self-Generation Incentive Program," NC Clean Energy Technology Center, DSIRE, last updated April 18, 2017, http://programs.dsireusa.org/system/program/detail/552.

81 "Eligible Properties and Improvements," Colorado Commercial Property Assessed Clean Energy, accessed May 4, 2017, http://copace.com/resources/#Eligible_Properties.

82 General Assembly of the State of Colorado, "House Bill 08-1350," 2008, http://www.leg.state.co.us/clics/clics2008a/csl.nsf/fsbillcont/E62A0C34C01772C9872573D000830B58?Open&file=1350_enr.pdf.

83 "Property Assessed Clean Energy (PACE)," American Council for an Energy Efficient Economy, accessed May 4, 2017, http://aceee.org/sector/state-policy/toolkit/pace.

84 "Opportunities for Recycled Energy," Colorado Energy Office, accessed May 22, 2017, https://www.colorado.gov/pacific/sites/default/files/atoms/files/Recycled%20Energy%20Fact%20Sheet%20%28Xcel%20Energy%20Customers%29_0.pdf.

85 Heat is Power (HiP), "Comments: Energy Tax Reform," in *Waste Heat to Power: Emission-Free Power Generation Industrial Efficiency* (HiP, April 2013), http://www.heatispower.org/wp-content/uploads/2015/05/Heat-is-Power-Association-Comments-re-Energy-Tax-Reform-to-Hs-WM-5-13-2015.pdf.

86 114th Congress (2015–2016), "H.R. 2657 – Power Act," June 4, 2015, https://www.govtrack.us/congress/bills/114/hr2657/text.

87 "Modified Accelerated Cost-Recovery (MACRS)," NC Clean Energy Technology Center, DSIRE, last updated January 11, 2016, http://programs.dsireusa.org/system/program/detail/676.

Regulatory Assistance Project (RAP) conducted a study in 2014 on utility standby rates that apply to CHP projects and then issued recommendations on how specific utility rates can be improved.[88] Public Service Company of Colorado's standby rates were assessed as part of this RAP study. Their recently enacted Xcel Energy Recycled Energy Services Tariff could be reviewed for responsiveness to the RAP recommendations.

- Consider lowering insurance requirements for interconnection and removing the additional liability insurance requirement. DOE's Southwest CHP TAP states that "customers with grid-tied DG systems already carry their own general liability insurance, and the rules already have provisions for indemnification, making the requirement for additional insurance redundant and an extra, unneeded expense."[89] Currently, Colorado utilities determine insurance requirements for CHP systems greater than 2 MW on a case-by-case basis, and insurance requirements are high compared to other states (e.g., $2 million in insurance is required for systems 2 MW or smaller in size). Establishing maximum insurance requirements for larger systems >2 MW, up to 10 MW, would be helpful, as well as lowering insurance requirements for smaller systems. For example, some states do not require any additional liability insurance for systems under a certain size threshold.
- Consider establishing standardized interconnection procedures for systems larger than 10 MW. Some states have issued guidance for larger-sized systems (>10 MW) that include parameters for interconnection study requirements, technical requirements, insurance, utility approval timelines, and other guidelines. Colorado should consider establishing interconnection standards for systems greater than 10 MW.
- Study whether to include recycled energy systems larger than 15 MW as eligible under the RES.
- Advocate for the extension of federal tax credits to recycled energy projects.
- Consider adopting a state tax credit for recycled energy projects.
- Reinstate the state's PBF and consider directing funds to a recycled energy incentive program.

TABLE 25: LIST OF KEY BARRIERS AND STATE RECOMMENDATIONS

Key Barrier	Recommendation
Standby rates	Conduct a study of utility standby rates in the state and recommend ways to improve upon existing tariff structures
Environmental permitting and regulatory issues	Consider lowering insurance requirements for interconnection Consider establishing standardized interconnection procedures for systems larger than 10 MW
Lack of recognition of environmental benefits	Establish a working group to discuss the inclusion of CHP/recycled energy as a key component of the state's compliance plan with the EPA's Clean Power Plan
Internal competition for capital	Promote alternative ownership and financing models for recycled energy projects
Financial risk	Consider new financial incentive programs to encourage the deployment of recycled energy
Access to favorable tax structures	Advocate for the extension of federal tax credits to recycled energy projects Consider adopting a state tax credit for recycled energy projects
Sales of excess power	PUC can assess restrictions in the state on sales of excess power, and recommend potential ways of eliminating unnecessary restrictions
Awareness of available incentives	Continue outreach and technical assistance to target good existing candidate sites for recycled energy installations, and provide these sites with necessary resources

[88] James Selecky, Kathryn Iverson, Ali Al-Jabir, "Standby Rates for Combined Heat and Power Systems, Economic Analysis and Recommendations for Five States" (Regulatory Assistance Project, February 2014), http://www.raponline.org/document/download/id/7020.

[89] "Colorado: Colorado Policies Affecting CHP," U.S. Department of Energy, CHP Technical Assistance Partnerships, Southwest, accessed June 2015, http://www.southwestchptap.org/states-co.

11 | Summary and Conclusions

Colorado has the potential to further develop recycled energy systems, which could be realized by promulgating new policies and incentives that include this technology type. This study identified 108 MW of recycled energy technical potential at 70 sites above 450°F and 39 MW of recycled energy technical potential at 75 sites below 450°F throughout the state. For sites above 450°F, roughly 53% (58 MW) of the total technical potential are found in systems with capacities greater than 5 MW; however, 65 of the 70 sites have a technical potential smaller than 5 MW. This indicates that there are fewer candidate sites for large systems than there are for low-capacity systems. For sites below 450°F, roughly 80% (31 MW) of the total technical potential is found in systems with capacities greater than 1 MW; however, 64 of the 75 sites have a technical potential smaller than 5 MW. Concerning utilities, Xcel Energy and Black Hills Energy service territories contain roughly 60% (26 MW and 38 MW, respectively) of the entire technical potential capacity for sites above 450°F, whereas for sites below 450°F, Xcel Energy and Black Hills Energy service territories contain roughly 45% (17 MW and 0.5 MW respectively). However, Xcel Energy's service territory contains almost 40% (27) of the candidate sites above 450°F and almost 37% (28) of candidate sites below 450°F within the entire state, making this territory of particular importance for recycled energy potential within the state.

Concerning the economic potential for recycled energy projects above 250 kW, the best applications based on payback expectations are the primary metals and minerals industries. This is likely due to the very high quality and quantity of the heat available from these applications. By utility, Black Hills Energy contains three candidate sites that have a payback under five years. Xcel Energy also has three candidate sites that have a payback under five years. However, 17 of the 20 sites in Xcel Energy's territory have paybacks greater than 5 years. Overall, 54% (57 MW) of the recycled energy technical potential sites exhibit paybacks less than five years. For recycled energy projects below 250 kW, the best applications based on payback expectations are the pipeline transport and petroleum refining industries. By utility, Xcel Energy contains nearly 48% (2,584 kW) of total potential at 28 sites with a payback greater than 10 years. It is important to note that studies have indicated that 50% of the market of potential investors will opt out of installing a recycled energy unit if the payback is greater than two years. For Colorado, this means that the market adoption of recycled energy will remain fairly low absent any changes in electricity rates and major incentives.

Based on the technical and economic potential results, more than 5,300 kW of generation potential has been identified for opportunities at sites having waste heat streams below 450°F and using systems under 250 kW. However, payback periods for these investments are generally well beyond what industrial and commercial businesses typically accept for returns on capital investments. Colorado may want to consider adopting some additional incentive programs to encourage recycled energy, and it may consider revising current policies and tariffs to better promote this technology. Xcel Energy's new incentive of $500/kW for eligible recycled energy projects will likely help achieve greater deployment. Additional incentive programs in other utility territories or a state-level program can supplement this program. Several innovative CHP programs have proven effective that provide for a few incentive payments throughout the project's implementation, e.g., provide an upfront incentive, one during the construction phase, and a final performance based incentive (e.g., California's SGIP and Maryland's EMPOWER program). Colorado may consider adopting a similar recycled energy incentive program. In addition, the Colorado PUC can carefully assess standby rates in the state, and it may consider modifications to these tariff structures to make them technology-neutral enabling more recycled energy projects. A well-designed incentive program applicable to recycled energy projects, along with strategic policy changes, can help improve the economic potential for recycled energy in Colorado.

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