Catalog of CHP Technologies

Section 7. Packaged CHP Systems

U.S. Environmental Protection Agency
Combined Heat and Power Partnership

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The September 2017 revision incorporated a new section on packaged CHP systems (Section 7).

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Section 7. Packaged CHP Systems

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7.1 Introduction

The purpose of this section of the Catalog is to introduce packaged CHP systems and their unique attributes to facility owners and operators, real estate developers, CHP project developers, architects, engineers, and policymakers.

Depending on the application, packaged systems can be cheaper and easier to install and operate than conventional CHP systems (i.e., unique site-specific systems involving the integration of different components — prime mover, generator, heat recovery equipment, electrical switchgear, emissions control devices, and controls). Also, because packaged systems are standardized, they can be good choices for organizations with multiple facilities with similar electrical and thermal requirements.

> This section of the Catalog of CHP Technologies is different than the other sections of the Catalog, in that it addresses a new CHP system configuration, whereas the other sections characterize specific CHP prime mover technologies. Accordingly, this section includes material such as installations and technical potential by market segment, which are not found in the other sections.

Packaged systems include a prime mover (i.e., reciprocating engine, microturbine, or fuel cell), a generator, heat recovery equipment, electrical switchgear, emissions control devices, and controls, sometimes packaged in a weather-resistant sound-attenuating enclosure. These systems can be installed as single units or combined to form larger systems. Product offerings for packaged systems have been focused on relatively small (≤ 500 kW) sizes.

This section of the Catalog provides an overview of packaged systems, including:

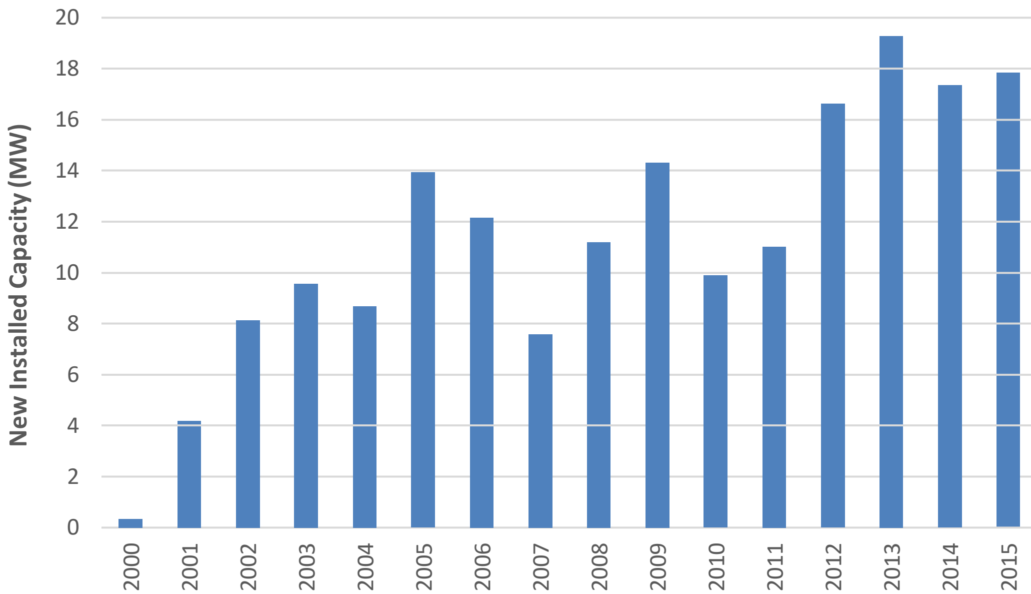
- The evolution of packaged CHP systems
- Significant attributes
- Applications
- Technology description
- Cost and performance characteristics
- Emissions and emissions control options

7.2 The Evolution of Packaged CHP Systems

Until relatively recently, nearly all CHP installations were unique site-specific conventional CHP systems. In the late 1990s, as the market for CHP applications boomed, many manufacturers and developers started offering standardized factory-built, ready-to-install packaged CHP systems that simplified, and shortened the time required for, CHP system procurement and installation. Today there are 27 packaged system vendors in the United States, according to a 2016 survey[103] of the packaged CHP industry.

In 2016 an estimated 950 packaged systems are installed in the United States, totaling 215 MW of capacity.[104] Annual additions of packaged system capacity are increasing, as shown in **Figure 7-1**.[105]

Figure 7-1. Annual U.S. Capacity Additions: Packaged CHP Systems



Source: ICF/U.S. DOE Combined Heat and Power Installation Database, February 2017, https://doe.icfwebservices.com/chpdb/.

103 Compiled by ICF from vendor-supplied data, 2016.
104 ICF/U.S. DOE Combined Heat and Power Installation Database, February 2017, *https://doe.icfwebservices.com/chpdb/*.
105 Ibid.

Examples of Packaged CHP Systems

Figure 7-2. Aegis ThermoPower (TP-75), 75 kW

Figure 7-3. Tecogen Tecopower CM-75, 75 kW

Figure 7-4. MTU 12V400 GS, 358 kW

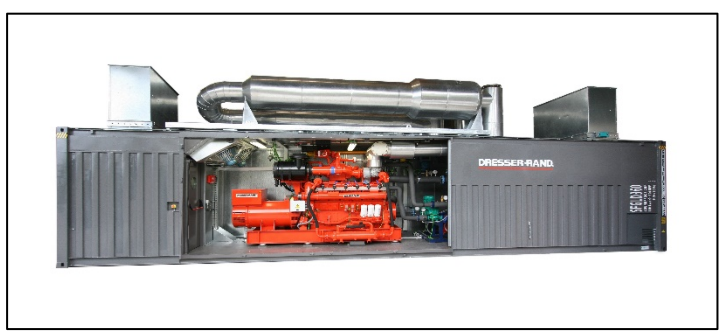
Figure 7-5. Capstone C65 ICHP, 65 kW

Figure 7-6. Amerigen 8150 (Using the MAN E2876 E312 Engine), 150 kW

Figure 7-7. Energy Choice EC 190 Natural Gas system, 190 kW

Figure 7-8. 2G Avus 800, 800 kW

Figure 7-9. Siemens SGE-36SL, 676 kW



7.3 Significant Attributes

Packaged systems have certain important attributes:

- Standardization
- Black start/islanding capability (sometimes optional)
- Acoustic enclosure (sometimes optional)
- Modularity
- Third-party own/operate business arrangements (may be available)
- Replicability

7.3.1 Standardization

Because packaged systems are built and delivered in accordance with published specifications, their configuration and performance can be well understood before the purchase decision is made. This facilitates many elements of the procurement process, including equipment selection, financial analysis before purchase, site-specific engineering, permitting and site modifications, as well as system installation. Site-specific engineering is typically limited to designing connections to the fuel supply, water supply, thermal loads, electrical system, and building control system.

Customers can choose several options. These include:

- Type of generator (synchronous, induction, or inverter)
- Black start/islanding capability
- Enhanced sound attenuation
- Additional emissions controls
- Specialized heat recovery options, such as an absorption chiller to produce chilled water for cooling applications or a steam boiler to make steam from the prime mover exhaust

NYSERDA CHP Program

The standardization of CHP equipment can make it easier for programs such as the New York State Energy Research and Development Authority's (NYSERDA's) CHP Program to pre-approve projects for incentives. Programs like NYSERDA's provide a level of assurance that the pre-approved systems meet the requirements of the approving organization.
Information about NYSERDA's CHP Program is available at:
https://portal.nyserda.ny.gov/CORE_Solicitation_Detail_Page?SolicitationId=a0rt0000000QnqyAAC

7.3.2 Black Start/Islanding Capability

Several packaged system vendors offer models with black start/islanding capability. These systems can disconnect from the utility grid using an automatic transfer switch and run independently during power outages (i.e., in "island mode"). While CHP systems are not typically intended to meet a facility's full load requirements, they can provide electricity to critical loads when the electric grid is not available.

CHP systems with black start/islanding capability can supplement traditional diesel standby generators, providing an added level of redundancy during long-term outages and natural disasters when diesel fuel can become scarce (e.g., Hurricane Sandy). Also, in certain circumstances, CHP can replace diesel standby generators.

Black start/islanding capability requires additional components, which may increase equipment cost and/or installation cost. The extent to which black start/islanding capability adds to installation costs depends on factors such as the existing electrical system in the host facility, the switchgear required, and the size of the electrical loads to be served when the system is islanding.[106]

7.3.3 Acoustic Enclosure

Systems may include a sound attenuation enclosure—as standard equipment or as an option—consisting of sound-absorbing material surrounded by a metal cover. Optional enhanced sound attenuation capability may be available.

7.3.4 Modularity

Because of their modular design, packaged systems can be installed as single units, or several can be connected to create larger multiple-unit systems. Systems using multiple modular units can have a number of additional significant attributes:

- Under certain circumstances, multiple-unit systems can be more efficient than a conventional CHP system of the same size. Conventional systems lose efficiency when slowed down to follow load fluctuations. In multiple-unit systems, individual units can be shut down to reduce system output to follow load fluctuations, allowing remaining operational units to function at higher efficiencies.
- Systems using multiple modular units can also improve reliability and system availability, since one unit can be taken off line for maintenance while the others continue to operate.
- Additional units can be added over time to increase output as electrical and/or thermal loads increase.[107]

CHP Project Development

Taking a CHP project from conception to completion involves five steps:

- Qualification/screening
- Level 1 feasibility analysis
- Level 2 feasibility analysis (investment grade analysis)
- Procurement, including installation
- Operations and maintenance

Depending on the nature of the facility and the performance objectives of a CHP system being considered, each of the five steps may be performed by the facility's manager or agent, consultants, or vendors.
Learn more about these steps, including goals, timeframes, typical costs, and facility level of effort required on the *EPA CHP Partnership website*.

A disadvantage of using multiple modular units instead of one large unit is that the installed cost per kW is typically higher. In addition, in full-load operation, a conventional CHP system will typically be more efficient than a system of equal size comprising multiple packaged system units.

[106] Based on data collected from EPA CHP Partners that manufacture packaged CHP systems.
[107] Often up to five or six units may be operated together, depending on the equipment specifications.

7.3.5 Third-Party Own/Operate Business Arrangements

Many packaged system vendors offer "own and operate" business arrangements, which can be structured as agreed upon by the host facility and the vendor. One model is for the vendor or a third party to install, own, operate, and maintain the system, and provide the system outputs to the host facility under terms established in a contract. In this way, the facility can have on-site power production and other CHP benefits without a capital expenditure or the risks and responsibilities of ownership. The contract may include an option for the host facility to purchase the system at specified terms.

7.3.6 Replicability

Operators of multifamily buildings, big box stores, hotels, restaurants, and supermarkets often manage many buildings with similar electrical and thermal requirements. Because a specific packaged system model will perform consistently when installed in facilities with comparable layouts and electric/thermal requirements, that model can become a known quantity for the building operator. With this experience, the building operator can confidently choose the same system for other buildings with similar electrical/thermal requirements.

7.4 Applications

While conventional CHP applications have been concentrated in the industrial/heavy manufacturing sector, packaged CHP applications are most often used in the commercial, multifamily, institutional, and light manufacturing sectors. Attributes of facilities that make them good matches for packaged systems include:

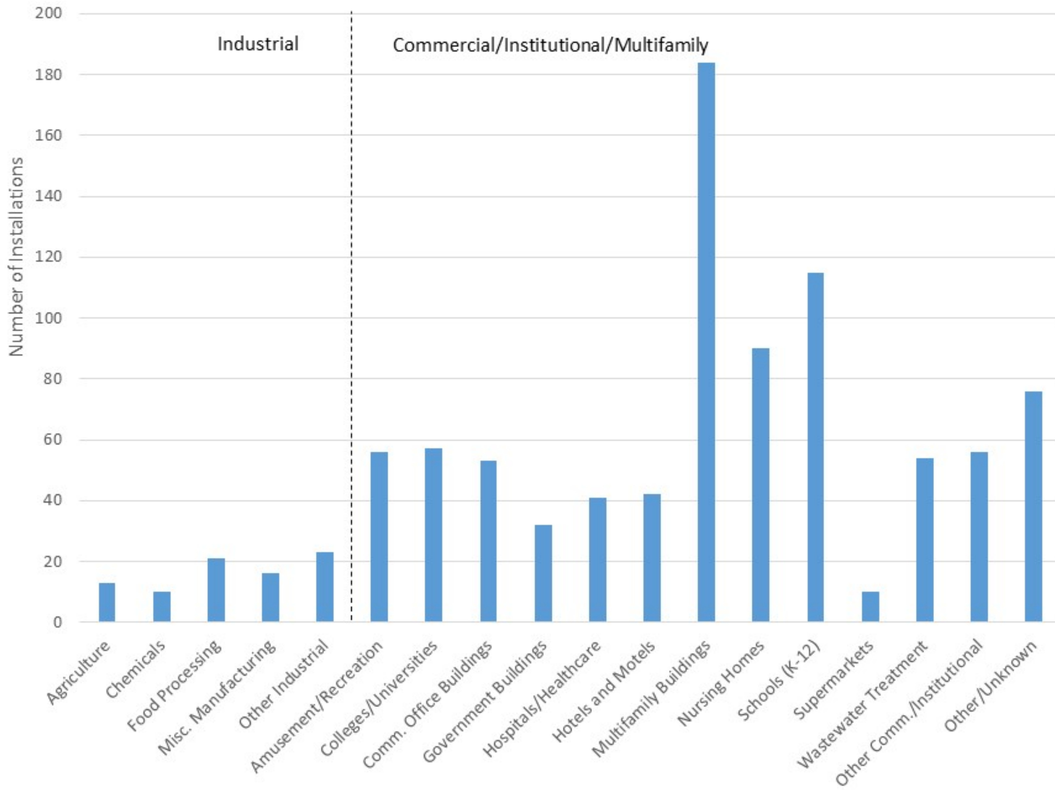
- **Electrical and thermal load and profiles that match packaged system outputs.** Most packaged systems are under 500 kW in size, which is a good match for the electrical and thermal loads of commercial, multifamily, and institutional buildings.
- **Space constraints** – Many facilities have constraints on the physical size of units that can be installed, and packaged systems tend to have a relatively small footprint.
- **Building owners who place a high value on ease of installation and operation** – The standardization of packaged systems means an easier procurement process compared to conventional CHP systems.
- **Need for flexible financing options** – CHP projects are capital-intensive, which can be a problem for some market sectors. Many packaged systems are available through "own and operate" arrangements, where the vendor retains ownership and is responsible for installation, operation, and maintenance, if the building owners do not want to perform this function.
- **A building that is one of several similar facilities in the same enterprise –** If a packaged system is a good fit for one facility, it becomes a known quantity that can be confidently deployed at other facilities with similar load requirements and layouts.

Larger energy users, such as industrial/manufacturing facilities and some large institutional facilities might not find as much value in a packaged system as they would in a custom-engineered conventional CHP system that can be precisely tailored to their specific facility needs.

7.4.1 Installed Packaged Systems

Figure 7-10 presents packaged system installations by market segment, and **Table 7-1** presents total installed packaged system capacity and the median system size by market segment.

Figure 7-10. Packaged System Installations by Market Segment



Source: ICF/U.S. DOE Combined Heat and Power Installation Database, February 2017 https://doe.icfwebservices.com/chpdb/.

Table 7-1. Packaged Systems Total Installed Capacity and Median Size by Market Segment

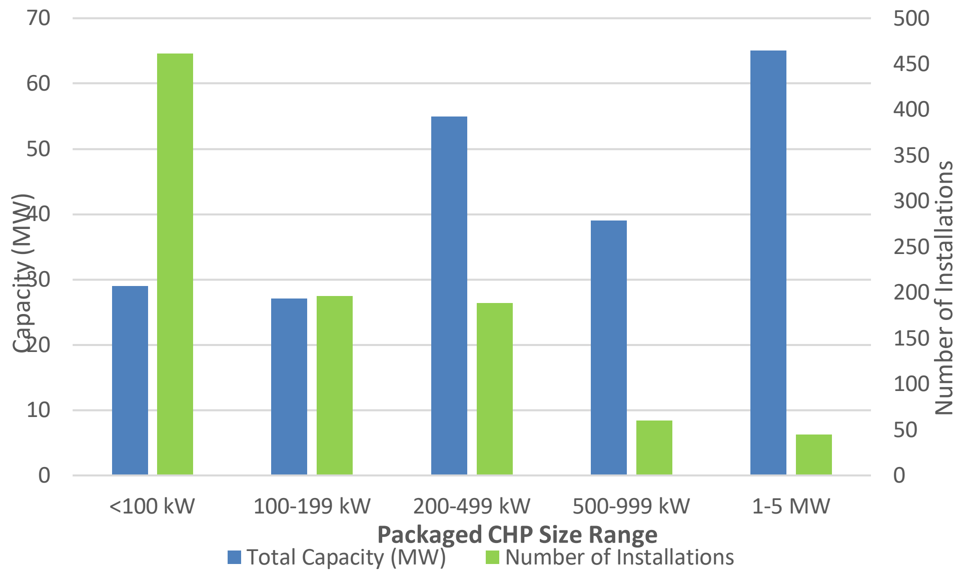
Sector	Market Segment	Installed Capacity (MW)	Median Size (kW)
Industrial	Agriculture	4.5	100
	Chemicals	5.0	180
	Food Processing	10.9	300
	Misc. Manufacturing	8.0	390
	Other Industrial	9.8	180
Commercial Institutional Multifamily	Amusement/Recreation	7.6	75
	Colleges/Universities	14.5	180
	Commercial Office Buildings	21.4	75
	Government Buildings	6.4	90
	Hospitals/Healthcare	15.7	220
	Hotels and Motels	7.8	100
	Multifamily Buildings	22.3	75
	Nursing Homes	10.8	75
	Schools (K-12)	17.7	75
	Supermarkets	4.2	320
	Wastewater Treatment	14.1	130
	Other Comm./Institutional	16.3	170
	Other/Unknown	18.6	140

Source: ICF/U.S. DOE Combined Heat and Power Installation Database, February 2017 https://doe.icfwebservices.com/chpdb/.

The packaged system market has been dominated by market segments in the commercial/institutional/multifamily sector. More than 91 percent of installations are contained in these sectors. Multifamily buildings have the highest number of packaged system installations, followed by schools and nursing homes. These market segments, as well as hotels, government buildings, and amusement and recreation facilities, tend to use smaller systems, with median sizes of 100 kW or less, than the other market segments. Industrial market segments have fewer installations but tend to have larger capacities, with median sizes greater than 100 kW.

Figure 7-11 presents packaged system installations and capacity by size range. Almost 90 percent of the packaged system installations are applications under 500 kW in size (although packaged system are available in sizes up to several MW). Note that the total installed capacity of systems under 500 kW is approximately equal to that of systems > 500 kW.

Figure 7-11. Packaged System Installations and Capacity by Size Range



Source: ICF/U.S. DOE Combined Heat and Power Installation Database, February 2017, https://doe.icfwebservices.com/chpdb/.

7.4.2 Technical Potential

Technical potential is an estimate of market size constrained only by technological limits—the ability of CHP technologies to fit customer energy needs without regard to economic for market factors. For this reason, actual potential will be less than technical potential, but in some cases, it may still be a useful indicator of relative economic potential.

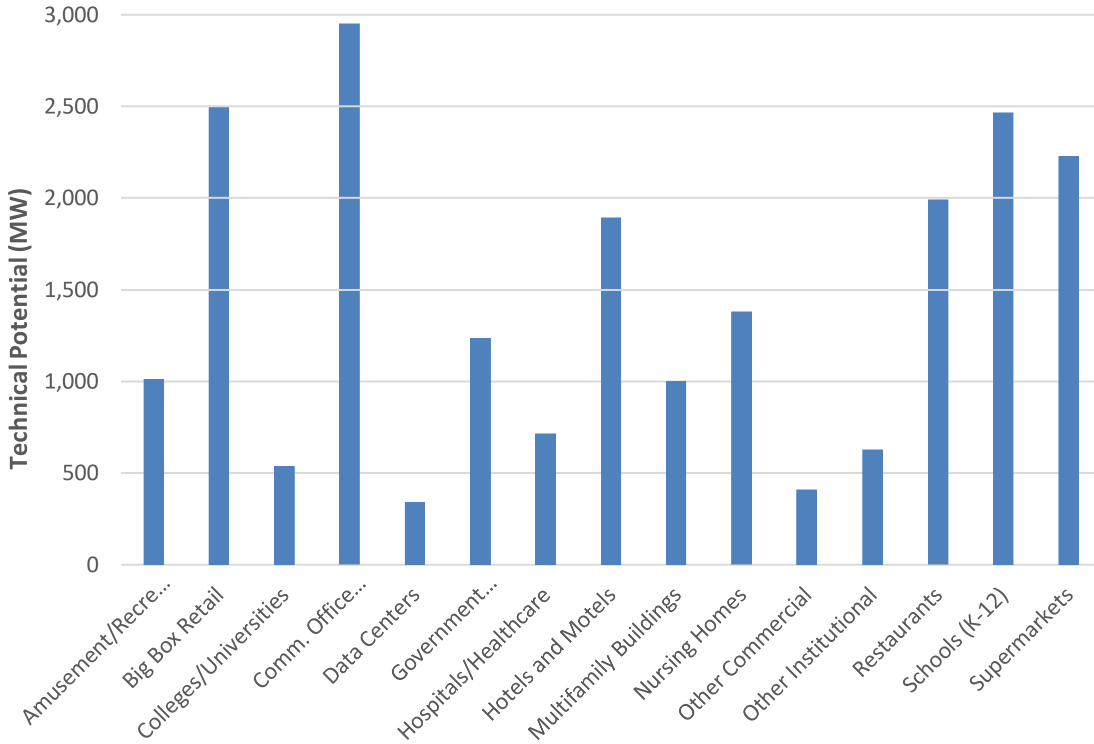
Ninety percent of packaged system installations are units under 500 kW. There is currently 21.3 GW of technical potential for systems under 500 kW in the U.S. commercial, institutional, and multifamily sectors[108], at more than 100,000 facilities. The technical potential for <500 kW packaged system applications is greatest in the following ten market segments:

- Amusement/recreation
- Big box retail
- Commercial office buildings
- Government buildings
- Hotels and motels
- Multifamily buildings
- Nursing homes
- Restaurants
- Schools
- Supermarkets

[108] ICF, CHP Technical Potential Database, 2016.

Each of these market segments is estimated to contain over 1 GW of technical potential for systems <500 kW. **Figure 7-12** breaks down the technical potential for packaged systems <500 kW.

Figure 7-12. Technical Potential for <500 kW Packaged CHP Applications in the Commercial and Institutional Sectors, by Market Segment



Source: ICF, 2016.

More information on the technical potential for CHP applications – including the industrial sector and larger size ranges – can be found in the Department of Energy's 2016 CHP Technical Potential Report.[109]

7.5 Technology Description

The general design of packaged systems is relatively consistent throughout all packaged products. The main components of packaged systems include:

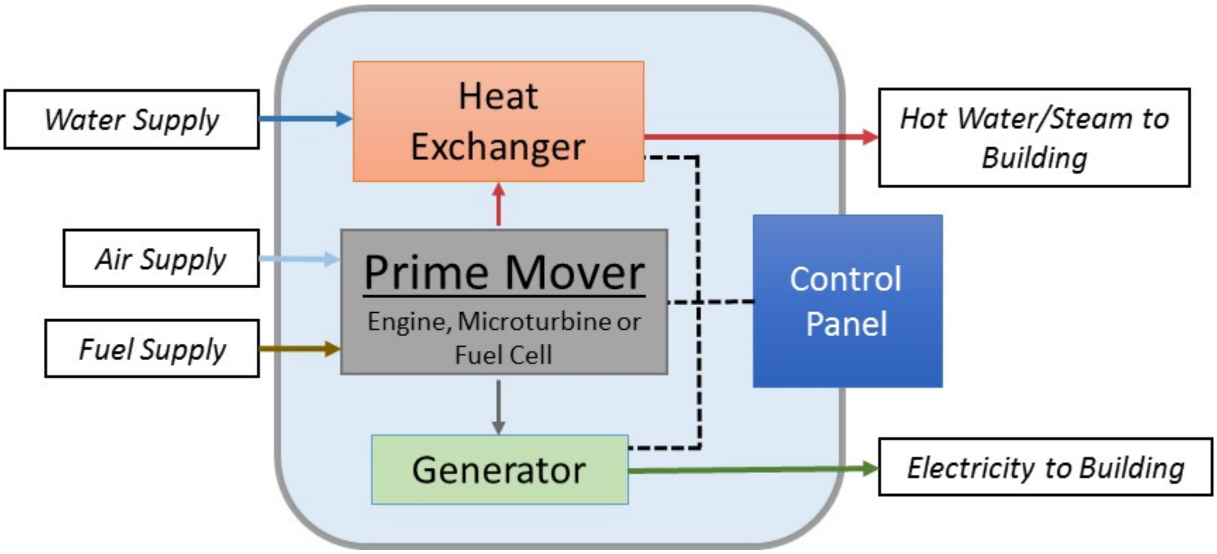
- **Prime mover** – the power-producing machine (or chemical process, in the case of fuel cells) that drives the electric generator.
- **Generator** – a device that converts mechanical energy into electricity.
- **Heat exchanger –** a device that transfers heat from the prime mover exhaust gas and/or the engine block to water, to produce hot water or steam.

[109] U.S. Department of Energy, *Combined Heat and Power (CHP) Technical Potential in the United States,* March 2016, *http://energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20Potential%20Study%203-31-2016%20Final.pdf*.

- **Control panel** – controls and monitoring instruments.

Figure 7-13 provides a process diagram that shows how these different components interact in a packaged system.

Figure 7-13. Packaged CHP System Diagram



Source: EPA CHP Partnership

7.5.1 Heat Recovery

A defining characteristic of CHP systems is their ability to recover and put to beneficial use otherwise-wasted heat. Most packaged systems use recovered heat to produce hot water, but steam and chilled water options are also available.

To produce chilled water, packaged systems are coupled with an absorption chiller, which converts recovered heat into chilled water that can be used for air conditioning or other cooling loads. In this way, more of the system's thermal output can be used, which increases system efficiency. Packaged systems with absorption chillers are well-suited for applications that consistently require chilled water, such as supermarkets and data centers, as well as buildings with seasonal heating and cooling needs, like multifamily buildings, hotels, health clubs and health care facilities.

Specifying Packaged CHP System Capacity Based on Thermal and Electric Requirements

Sizing decisions are best made based on an understanding of facility electrical and thermal loads (hot water, heating cooling), and how they match with the outputs of available packaged systems. Typically, packaged CHP capacity is selected in a way that allows facilities to utilize all of the electric and thermal energy on site, while operating at or near full load. Building energy modeling can be used to determine the system that best meets the facility's needs while operating efficiently and providing an acceptable return on investment. Energy models often used include eQUEST and EnergyPlus.

7.6 Cost and Performance Characteristics

When making a purchase decision, the cost and performance characteristics presented in this section should be considered in conjunction with other factors, such as expected service life, guarantees, and availability of service and support, along with performance characteristics not presented here, such as noise and vibration.

Table 7-2 summarizes the performance characteristics for packaged systems consisting of a single reciprocating engine or microturbine. Data were gathered from the seven EPA CHP Partner companies that manufacture packaged systems and that responded to a data request.[110]

> **Fuel Cells: Efficient Operation and Environmental Benefits**
> Fuel cell CHP systems can be designed to operate with high electric efficiencies—potentially over 50 percent—and can maintain high efficiency at partial loads. Most fuel cells convert natural gas to hydrogen using a reformer, which emits carbon at a lower rate than other prime mover technologies. Nearly all fuel cell CHP is sold as packaged systems.

Table 7-2. Packaged CHP Systems – Performance Characteristics

Performance Characteristic	Size Range (kW)[111]				
	30-99	100-199	200-499	500-1,000	>1,000
Electrical Heat Rate (Btu/kWh), HHV	10,000 - 12,600	9,800 - 12,600	9,200 - 10,800	9,000 - 11,000	8,200 - 10,400
Electrical Efficiency (%), HHV	24-32%	27-35%	32-37%	28-38%	33-41%
Total Heat Recovered (Btu/kWh)	5,300 - 7,000	4,600 – 6,400	3,600 - 5,400	3,600 - 4,700	3,400 - 5,600
Typical form of Recovered Heat[112]	H_2O	H_2O	H_2O	H_2O	H_2O, Steam
Total CHP Efficiency[113] (%), HHV	73-82%[114]	67-86%	76-82%	67-82%	78-87%
Power/Heat Ratio	0.49-0.64	0.52-0.73	0.64-0.95	0.72-0.96	0.61-1.01

Source: Compiled from data supplied by the seven EPA CHP Partner companies that manufacture packaged systems and that responded to a data request.

110 These seven companies manufacture systems using reciprocating engines or microturbines, which account for 97 percent of packaged systems in the United States (fuel cell systems account for the remaining three percent). One additional company, which manufactures packaged systems using fuel cells, responded to the data request. However, because fuel cells have different characteristics, and tend to be used in different applications than reciprocating engine and microturbine systems, they are not a focus of this section. Fuel cell cost and performance characteristics can be found in the Fuel Cells section of the Catalog.

111 Size ranges reflect the large majority of packaged systems sold. However, some vendors sell systems as small as 5 kW.

112 Although hot water is the typical form of recovered heat for most size ranges, steam may be an option for all ranges.

113 Total CHP efficiency for reciprocating engines is approximately 80 percent, while the total CHP efficiency for microturbines tends to be close to 70 percent.

114 One vendor reports offering a 50 kW system with 92 percent efficiency. The system has unique attributes and certain limitations compared to typical systems.

Some key takeaways from **Table 7-2** are:

- Electric efficiencies and total CHP efficiencies tend to increase with system size.
- As systems get larger, the power-to-heat ratio tends to increase (i.e., more electricity is delivered relative to recovered heat).
- Performance varies within a given size range due to different prime mover and heat recovery technologies, and different system designs.
- Recovered heat from packaged systems is typically in the form of hot water.

More details on the characteristics of efficiency, thermal output, and other technical information for reciprocating engines and microturbine technologies are provided in their respective Catalog sections.

7.6.1 Part-Load Operation

In most packaged systems, reciprocating engines or microturbines drive generators at a constant speed to produce steady alternating current (AC) power. As load is reduced, generator speed decreases, the heat rate of the prime mover increases, and electrical efficiency decreases. Electrical efficiency at half load is typically 10 to 25 percent less than full-load efficiency, with efficiencies falling more steeply for loads lower than half of the unit's rated capacity.

Systems comprising multiple units can reduce part-load efficiency penalties, which is especially important for commercial applications. Electric loads for commercial buildings tend to vary more than they do in manufacturing facilities. Because individual units can be put in standby mode when the building load drops, the other units can continue to operate at or near peak efficiency. In the same circumstances, a single-unit system might need to operate at reduced electrical efficiency.

More information on part-load performance for reciprocating engines and microturbines can be found in their respective sections of the Catalog.

7.6.2 Installed Costs

Installed costs include equipment and installation costs. Equipment costs vary depending on factors such as:

- Emissions controls (included as standard equipment or as options)
- Sound attenuation performance level
- Generator type (induction/synchronous/inverter)
- Black start/islanding capability
- Specialized heat recovery equipment (e.g. absorption chiller)

Table 7-3 presents typical equipment costs for packaged systems. These costs represent cost data provided by EPA CHP Partner companies that manufacture packaged systems and reflect difference in features provided as standard equipment.

Installation costs are not presented. Packaged system vendors report large variations in installation costs, based on such factors as:

- Variables based on the location of the equipment, such as ventilation routing, or rigging or cranes that might be required for installation. Also, installation costs may be higher for retrofits of existing buildings compared to new construction.
- Insurance requirements for contractors and subcontractors.
- Bonding requirements.
- Restrictions on working hours and access to site.
- Metering, permitting, and utility interconnection requirements.
- Local labor rates or minimum rates required by the Davis-Bacon and Related Acts, where applicable.
- Black start/islanding capability, which adds to installation costs depending on factors such as the existing electrical system in the host facility, switchgear required, and the size of the electrical loads to be served when the system is islanding.

Installation costs for packaged systems tend to be less than for conventional systems of similar size. For example, for a 1,000 kW packaged system, installation costs can be as low as $150,000 compared to $700,000 for conventional systems.

Table 7-3. Packaged CHP Systems – Equipment Costs

Packaged System Costs	Size Range (kW)				
	30-99	100-199	200-499	500-1,000	>1,000
Equipment Cost ($/kW)	$1,000 - $2,850	$1,400 - $3,100	$1,000 - $2,000	$900 - $1,850	$650 - $1,100

Source: Compiled from data supplied by the seven EPA CHP Partner companies that manufacture packaged systems and that responded to a data request.

7.6.3 Maintenance Costs

Unlike for conventional systems, maintenance for packaged systems is typically performed by the system vendor or a third party. Maintenance costs vary depending on factors such as type of CHP technology, remote monitoring, and performance guarantees. The ranges of maintenance costs for different sizes of packaged system reciprocating engines and microturbines are shown in **Table 7-4** (while costs here are presented in $/kWh, note that some vendors price maintenance in $/run hour, not $/kWh). For more information on maintenance requirements for reciprocating engines and microturbines, refer to their respective sections of the Catalog.

Table 7-4. Packaged CHP Systems – Maintenance Costs

	Size Range (kW)				
	30-99	100-199	200-499	500-1,000	>1,000
Maintenance Costs ($/kWh)	$0.013 - $0.025	$0.018 - $0.025	$0.017 - $0.021	$0.010- $0.016	$0.002- $0.016

Source: Compiled from data supplied by the seven EPA CHP Partner companies that manufacture packaged systems and that responded to a data request. vendors.

7.6.4 Fuels

Packaged systems generally use natural gas as fuel. However, other fuels, such as propane and biogas, can be used. Biogas fuels (e.g., anaerobic digester gas and landfill gas) may require pretreatment to remove moisture, hydrogen sulfide and siloxanes. The extent of pretreatment depends on the quality of the fuel and the prime mover technology. More details on fuels that can be used for different prime movers can be found in their respective technology characterizations in the Catalog.

7.7 Emissions, Emissions Control Options, and Prime Mover Certification

Most CHP systems emit certain pollutants–carbon dioxide[115], oxides of nitrogen (NO_X), carbon monoxide (CO), and volatile organic compounds. Emissions can vary depending on the prime mover technology, fuel type, and the emissions controls that are applied. Many packaged systems are equipped with emissions controls to reduce NO_X, CO and VOC emissions. Additional emissions controls may be available as options.

Packaged system vendors may offer systems with engines certified to comply with U.S. EPA regulations for stationary engines. A certificate of conformity with the Clean Air Act is supplied with these engines. Owners of systems with non-certified engines are responsible for having the engines individually performance-tested using the required EPA-approved test protocol (some vendors who sell uncertified systems perform emissions testing on systems after they are installed).

A thorough discussion of emissions and control options for each prime mover technology is provided in its respective technology characterization sections of the Catalog.

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115 While there is no currently viable technology to reduce CO_2 emissions from fossil fuel combustion, emissions can be reduced by increasing the useful outputs from a given amount of fuel burned. CHP is a highly cost-effective way to achieve this objective.