ENERGY AND ENVIRONMENTAL ANALYSIS, INC.

Integration and Installed Costs for Small Combined Heat and Power Systems

Submitted to:

Patti Garland
Oak Ridge National Laboratory
901 D Street, S.W.
Washington, DC

Draft Interim Report
March 2005

Submitted By:
Energy and Environmental Analysis, Inc.
1655 N. Fort Myer Drive, Suite 600
Arlington, Virginia 22209
(703) 528-1900

Table of Contents

TABLE OF CONTENTS **1**

LIST OF FIGURES **3**

LIST OF TABLES **4**

EXECUTIVE SUMMARY **5**

PROJECT BACKGROUND **5**

TECHNICAL APPROACH 5
RESULTS 5
OBSERVATIONS AND CONCLUSIONS 6

INTRODUCTION **8**

OBJECTIVE 8
BACKGROUND 8
COMPONENTS OF CHP INSTALLED COSTS 9
IMPORTANCE OF INSTALLED COSTS IN CHP PROJECT ASSESSMENT 10
Installed Costs and Simple Payback *10*
Installed Costs and COE *11*
ISSUES AFFECTING COST REDUCTION 12
REPORT ORGANIZATION 13

REVIEW OF CHP TECHNOLOGY AND COSTS CHARACTERIZATIONS **14**

NREL GAS-FIRED DISTRIBUTED ENERGY RESOURCE TECHNOLOGY CHARACTERIZATIONS 14
Reciprocating Engines *14*
Gas Turbines *16*
Microturbines *17*
Fuel Cells *18*
EPRI INSTALLATION, OPERATION, AND MAINTENANCE COSTS FOR DISTRIBUTED GENERATION TECHNOLOGIES 20
Approach and Breakdown of Installed Costs Used *21*
Reciprocating Engines *21*
Gas Turbines *23*
Microturbines *25*
Fuel Cells *27*

SMALL CHP FACILITY SURVEY OF INSTALLATION COSTS **31**

FACILITY SURVEY TECHNICAL APPROACH 31
Survey *32*
FACILITY SURVEY RESULTS 34
BREAKDOWN COSTS FOR EACH TECHNOLOGY 38
Reciprocating Engines *38*
Microturbines *41*
Fuel Cells *42*
Small Steam Turbines *43*

REPORTED CAPITAL COSTS OF CALIFORNIA SELF-GENERATION INCENTIVE PROGRAM **45**

CHANGES IN SGIP SINCE COLLECTION OF DATA 46

SGIP CHP PROJECT CAPITAL COSTS **46**

SUMMARY OF INSTALLATION COST COMPARISON **49**

RECIPROCATING ENGINES INSTALLED COSTS DATA AND ESTIMATES 49
GAS TURBINES INSTALLED COST DATA AND ESTIMATES 50
MICROTURBINE INSTALLED COST DATA AND ESTIMATES 51
FUEL CELL INSTALLED COST DATA AND ESTIMATES 52

POTENTIAL FOR INSTALLED COSTS REDUCTION 54

STANDARDIZATION OF DESIGN AND SHARED EXPERIENCES WITH "SOFT COSTS" 54
MODULAR PACKAGED SYSTEM APPROACHES 55
EXPERIENCE CURVE 55
R&D AND TECHNOLOGY BREAKTHROUGHS 58
QUANTITY PRODUCTION 58

REFERENCES 59

APPENDIX: SITE SURVEY DATA 60

List of Figures

FIGURE 1: SENSITIVITY OF SIMPLE PAYBACK TO INSTALLED COSTS 11
FIGURE 2: INSTALLED COSTS AND LEVELIZED COST OF ELECTRICITY 12
FIGURE 3: EPRI RECIPROCATING ENGINE BREAKDOWN OF INSTALLED COST ESTIMATE 23
FIGURE 4: EPRI SMALL GAS TURBINE BREAKDOWN OF INSTALLED COST ESTIMATE 25
FIGURE 5: EPRI MICROTURBINE BREAKDOWN INSTALLED COST ESTIMATE 27
FIGURE 6: RANGE OF TOTAL INSTALLED COST OF SURVEY SAMPLE 35
FIGURE 7: EQUIPMENT AND NON-EQUIPMENT COSTS OF SURVEY SAMPLE 36
FIGURE 8: TOTAL INSTALLED COST VERSUS CHP FACILITY SIZE 37
FIGURE 9: NON-EQUIPMENT COST VERSUS CHP FACILITY SIZE 38
FIGURE 10: DISTRIBUTION OF MEDIAN INSTALLED COST COMPONENTS FOR SMALL RICH BURN ENGINES. 39
FIGURE 11: DISTRIBUTION OF MEDIAN INSTALLED COST COMPONENTS FOR MID-SIZE LEAN BURN ENGINES 40
FIGURE 12: DISTRIBUTION OF MEDIAN INSTALLED COST COMPONENTS FOR LARGE LEAN BURN ENGINES 40
FIGURE 13: DISTRIBUTION OF MEDIAN INSTALLED COST COMPONENTS FOR SMALL MICROTURBINES 41
FIGURE 14: DISTRIBUTION OF MEDIAN INSTALLED COST COMPONENTS FOR MID-SIZED MICROTURBINES. 42
FIGURE 15: DISTRIBUTION OF MEDIAN INSTALLED COST COMPONENTS FOR MCFC 43
FIGURE 16: DISTRIBUTION OF MEDIAN INSTALLED COST COMPONENTS FOR STEAM TURBINES 44
FIGURE 17: COMPARISON OF TOTAL INSTALLED COSTS FOR RECIPROCATING ENGINES 49
FIGURE 18: COMPARISON OF TOTAL INSTALLED COSTS FOR GAS TURBINES 50
FIGURE 19: COMPARISON OF TOTAL INSTALLED COSTS FOR MICROTURBINES 51
FIGURE 20: COMPARISON OF TOTAL INSTALLED COSTS FOR FUEL CELLS 52
FIGURE 21: EXPERIENCE CURVE EFFECT IN STEAM TURBINE GENERATORS 57

List of Tables

TABLE ES-1: SUMMARY OF INSTALLED COST DATA 6
TABLE 1: NREL TECHNOLOGY CHARACTERIZATION RECIPROCATING ENGINE CHP INSTALLED COST ESTIMATE 16
TABLE 2: NREL TECHNOLOGY CHARACTERIZATION SMALL GAS TURBINE CHP INSTALLED COST ESTIMATE 17
TABLE 3: NREL TECHNOLOGY CHARACTERIZATION MICROTURBINE CHP INSTALLED COST ESTIMATE ... 18
TABLE 4: NREL TECHNOLOGY CHARACTERIZATION FUEL CELL CHP INSTALLED COST ESTIMATE 20
TABLE 5: EPRI RECIPROCATING ENGINE INSTALLED COST ESTIMATE 22
TABLE 6: EPRI SMALL GAS TURBINE INSTALLED COST ESTIMATE 24
TABLE 7: EPRI MICROTURBINE INSTALLED COST ESTIMATE 26
TABLE 8: DOD PAFC STANDARD INSTALLED COST ESTIMATE 28
TABLE 9: DOD PAFC OPTIONAL AND ADDITIONAL COMPONENTS INSTALLED COST ESTIMATE 29
TABLE 10: MCFC INSTALLED COST ESTIMATES 30
TABLE 11: RECIPROCATING ENGINE INSTALLED COSTS SURVEY DATA REQUEST 33
TABLE 12: AVERAGE COSTS ($/KW) OF SAMPLE 36
TABLE 13: INSTALLED COSTS COMPONENTS OF RECIPROCATING ENGINE SYSTEMS FROM CHP FACILITY SURVEY 39
TABLE 14: INSTALLED COSTS COMPONENTS OF MICROTURBINE SYSTEMS FROM CHP FACILITY SURVEY . 41
TABLE 15: INSTALLED COSTS COMPONENTS OF FUEL CELL SYSTEMS FROM CHP FACILITY SURVEY 42
TABLE 16: INSTALLED COSTS COMPONENTS OF STEAM TURBINE SYSTEMS FROM CHP FACILITY SURVEY 43
TABLE 17: CALIFORNIA SELF-GENERATION INCENTIVE PROGRAM SUMMARY 45
TABLE 18: CALIFORNIA SELF-GENERATION INCENTIVE PROGRAM RECIPROCATING ENGINE CAPITAL COSTS 47
TABLE 19: CALIFORNIA SELF-GENERATION INCENTIVE PROGRAM MICROTURBINE CAPITAL COSTS 47
TABLE 20: CALIFORNIA SELF-GENERATION INCENTIVE PROGRAM MICROTURBINE CAPITAL COSTS 47
TABLE 21: CALIFORNIA SELF-GENERATION INCENTIVE PROGRAM FUEL CELL CAPITAL COSTS 48
TABLE 22: SUMMARY OF INSTALLED COST DATA 52

Executive Summary

Project Background

The first costs of CHP projects represent a significant economic factor in the purchase decision process. First costs include factory on board (FOB) costs of equipment, installation costs, and integration soft costs (e.g., permitting, utility negotiations, engineering, commissioning, etc.). There is typically a large variation in installation costs due primarily to the non-equipment costs of installation that varies from site to site.

The objectives of this project was to quantify the range of small CHP installation costs experienced in the field, document the driving factors for those costs, and identify areas and approaches for cost improvements. For the purposes of this project, small is defined as less than 3 MW. The purpose is to develop a consistent and complete understanding of the installed costs of CHP projects based on various generation technologies with information from actual installations that have been completed within three recent years (2001-2003).

Technical Approach

The analysis was based on reviewing a sample of recent actual CHP installations. The sample of systems analyzed was identified through various public and private databases and industry contacts. The survey results were compared to recent technologies characterizations done by EPRI and the National Renewable Energy Laboratory (NREL) and reported costs of CHP systems installed under the California Self-Generation Incentive Program (SGIP) during the 2001-2004 timeframe. The key distinction between the primary research completed for this project and the referenced technology characterizations is the emphasis on costs reported by actual customers and end-users rather than reported estimates by equipment suppliers and project developers.

Results

Notable observations and clear trends in components of installed costs across CHP technology classes in the survey sample indicate the following:

- In all technology classes the largest component of installed costs is equipment; the only case in which non-equipment costs were approximately equal to equipment costs is with small microturbines
- In all technology classes installation materials and labor was by far the largest non-equipment cost component.
- In technology classes where there are multiple size ranges such as reciprocating engines and microturbines, the proportion of total installed costs attributable to non-equipment components decreases with size

- In the emerging technologies such as microturbines and fuel cells the percentage of installed costs attributable to equipment is significantly higher than similarly sized traditional equipment (e.g., reciprocating engines)
- Installation materials and labor as a percentage of total installed costs is largest in microturbine projects; ranging from 27 to 38%.
- Engineering (and feasibility study) costs as a percentage of total installed costs is largest in reciprocating engine projects; as high as 15% in mid-seized lean burn engines.
- Fuel cells had high miscellaneous costs primarily attributed to project finance costs by all three facilities; however, on a percentage of total installed costs basis (~4%) this was consistent with the other technology classes.

Table ES-1 summarizes of the range of total installed costs for the CHP prime mover technology classes in the <3 MW market. This is based on data from the facility survey, the reported costs of the California Self-Generation Incentive Program and estimates by National Renewable Energy Laboratory and EPRI.

CHP Technology	Facility Capacity Range (kW)	Median Total Installed Costs ($/kW)	Total Installed Cost Range ($/kW)
Reciprocating Engine	60-3000	2150	566-6467
Gas Turbine	1200-3800	1910	746-4481
Microturbine	28-950	3072	657-7758
Fuel Cells	200-1000	6956	3986-12800

Source: EEA

Table ES-1: Summary of Installed Cost Data

Observations and Conclusions

Selected observations include:

- Total installed costs of CHP systems less than 3 MW on a per KW basis are still high relative to larger systems.
- Not surprisingly reciprocating engine and gas turbine installed costs are considerably lower than the emerging and newly commercial technologies
- The installed cost data for gas turbines of this size (<3 MW) is very limited. The low number of data points from the SGIP (especially relative the number of reciprocating engine and microturbine sites in the program) is consistent with the attempts in this project to find a reasonable number gas turbine facilities to include in the sample. This is due the dominant competitive

economic position of reciprocating engines over gas turbines in the size range assessed. Heat recovery and/or emissions control can add significantly to the cost of gas turbine systems.

- Estimates from both NREL and EPRI for reciprocating engines systems appear lower than the actual recent market activity. The SGIP and facility survey data show installed costs substantially higher than both industry estimates,
- Microturbine installed costs were actually considerably higher than manufacturer price quotes and forecasts over the timeframe assessed. The data from actual facility applications demonstrate significantly higher costs than for mature technologies.
- Fuel cell installation costs are shown to be high but are still uncertain. All the actual facility installations with fuel cells had some form of subsidy. Many were part of demonstration programs that have additional costs and technical features associated with them that would not be part of a truly commercial project.

The high costs of small CHP systems have been a historical barrier to widespread market adoption despite numerous studies identifying high technical market potential. Methods and opportunities to reduce to reduce these costs include:

- Industry Standardization of Design and Shared Experiences on “Soft Costs”
- Modular Packaged Systems Approaches
- Experience/Learning Curve
- R&D and Technology Breakthroughs
- Quantity Production

Introduction

This report documents the work, results and conclusions by Energy and Environmental Analysis, Inc. (EEA) for Task 2 of Oak Ridge National Laboratory (ORNL) under Subcontract 40002512. This project represents one of several tasks completed by EEA in Combined Heat and Power (CHP) related analysis of technologies and markets.

Objective

The objective of this task was to quantify the range of small CHP installation costs experienced in the field, document the driving factors for those costs, and identify areas and approaches for cost improvements. For the purposes of this project, small is defined as less than 3 MW. The purpose is to develop a consistent and complete understanding of the installed costs of CHP projects based on various generation technologies with information from actual installations that have been completed within three recent years (2001-2003).

The analysis was based on reviewing a sample of recent actual CHP installations. The sample of systems analyzed was identified through the EEA Installed CHP Database work, contacts made through EEA's DG reliability effort, project feasibility projects that have recently been installed and various industry contacts. The survey results were compared to recent technologies characterizations done by EPRI and the National Renewable Energy Laboratory (NREL) and reported costs of CHP systems installed under the California Self-Generation Incentive Program (SGIP) during the 2001-2004 timeframe. The key distinction between the primary research completed for this project and the referenced technology characterizations is the emphasis on costs reported by actual customers and end-users rather than reported estimates by equipment suppliers and project developers.

Background

The first costs of CHP projects represent a significant economic factor in the purchase decision process. First costs include factory on board (FOB) costs of equipment, installation costs, and integration soft costs (e.g., permitting, utility negotiations, engineering, commissioning, etc.). There is typically a large variation in installation costs due primarily to the non-equipment costs of installation that varies from site to site.

Manufacturers are developing small DG/CHP systems with improved performance and reduced cost. These improvements will enhance the market for small-scale CHP, but it is also critical that installation costs come down as well. Some cases have been documented with the total installed cost for specific CHP projects as much as three times the cost of the basic equipment package. There is also a wide variability of installation costs site to site based on site-specific, technology-specific, region-specific, and a variety of other factors such as infrastructure development, utility attitudes and commercial status of the technology. Identifying and then understanding these costs is the first step to controlling them so that future projects can be much more cost effective.

In determining the economic feasibility of CHP systems, a clear and accurate estimation of total installed costs is required. In many cases, failure to include all components of capital costs as well as the often overlooked "soft costs", such as engineering and administrative labor and fees, project development costs, permitting costs, legal costs, financing costs, land costs, and contingencies, result in an inaccurate portrayal of total installed costs. In the case of CHP, where in many cases the application is part of a retrofit or renovation to an existing facility, understanding what the installation costs are and identifying areas for cost reduction can help in the development of the total CHP market.

Components of CHP Installed Costs

The "installed cost" of a CHP system is the power generation equipment cost plus the "installation cost". In general, the power-generation equipment costs for DG technologies are widely known or relatively easy to obtain. The opposite is true for installation cost. Because of the many and varied fees, labor costs, extraneous parts and material costs, the installation can be difficult to quantify. The focus of this section is on defining the components of the installation cost.

Installation costs for emerging technologies such as microturbines and fuel cells are relatively high and unpredictable compared to more mature CHP systems, such as reciprocating engines and gas turbines. However, as microturbines and fuel cells approach full-scale commercialization, it is expected that these costs will decline and become more consistent. The installation costs for a DG system can be categorized as follows:

- Project engineering – includes additional engineering of the system outside of the packaged unit. In some cases the heat recovery system or the gas compressor are separate units and require additional design for implementation. Additional project engineering costs may include planning, project management, site design, fuel system design, thermal system design, interconnection design, and customer load profiling.
- Permitting – includes all fees associated with permitting the unit for installation (e.g., basic site installation, mechanical, electrical, emissions, noise).
- Site preparation/placement – includes any concrete work, fencing, noise reduction enclosures or structures, equipment rental, labor, and additional site preparation.
- Mechanical, including thermal recovery system – includes additional system components and the connection of the thermal recovery system to both the power generation unit and the end use of the thermal energy.
- Fuel supply system – includes components such as piping, regulators, and meters, and the labor to installs these components between the fuel source and the power generation module.

- Electrical – includes components such as meters, wiring, controls, and system connections.
- Site commissioning/startup – includes any additional costs associate with the startup of the system, e.g., emissions testing and verification.
- Other – may include emissions control systems and other exhaust aftertreatment as well as shipping or additional components not included in one of the above categories.

Importance of Installed Costs in CHP Project Assessment

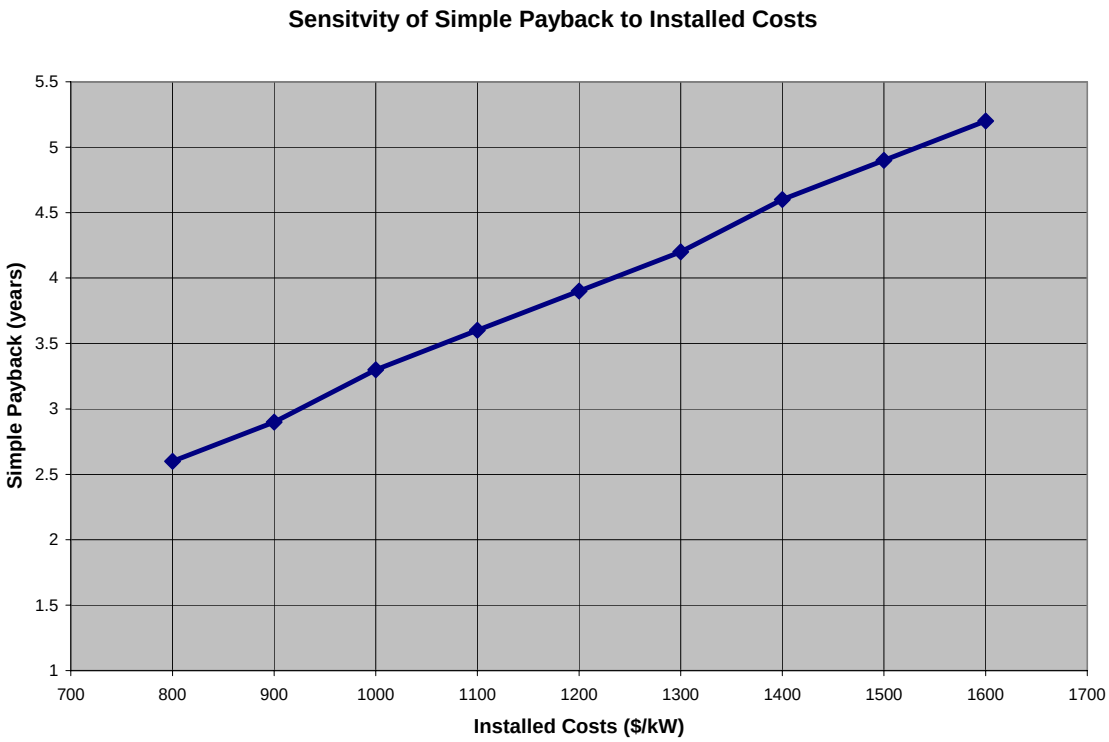
There are several ways to evaluate the economic viability of a potential CHP project investment and compare multiple energy investment options. The most common approaches require determining costs, revenues, and savings attributable to the project, costs attributable to a baseline or alternative case, and developing net annual cash flows (pro forma). Simple Payback analysis is one of the more common methods used to assess the financial viability of CHP projects. The levelized cost of electricity (COE) is another means of comparing generation options. Depending on the duty cycle of the application, the installed costs can make up the most significant component of COE.

Installed Costs and Simple Payback

Companies frequently require that the initial outlay of any project be recoverable within some specified cutoff period of time. This is defined as the payback period. It is calculated by determining the number of years it takes before the cumulative cash flows equal the initial investment. Some consider just a "simple payback" where no discount rate is applied. Others use a "discounted payback" that recognizes the time value of money. Discounted payback determines how long the project pays back in terms of present value. In simple terms, simple payback can be defined as:

Simple Payback Period (years) = Investment Costs ($)/Annual Savings ($/yr)

If a payback rule is utilized, a company has typical cutoff period (e.g., three years) and will not accept projects whose payback takes longer than the cutoff. One of the pitfalls of using a payback rule is that a company will tend to accept too many short-lived projects and too few longer ones despite the fact that they may have positive net present values. Figure 1 shows an example of simple payback sensitivity to installed costs for a 450 kW engine based CHP at a nursing home. It is obvious from the graph that if the simple payback criterion is the sole basis for a project moving forward, the lowest possible installed costs are desired.



Source: EEA

Figure 1: Sensitivity of Simple Payback to Installed Costs

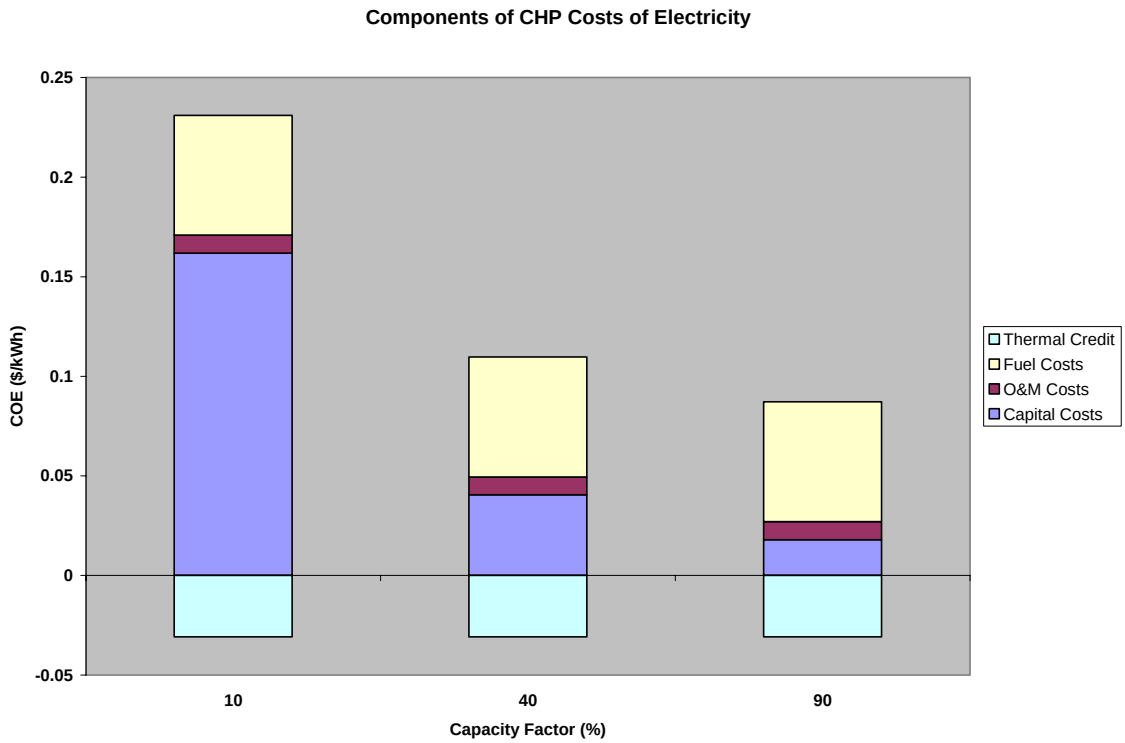
Installed Costs and COE

In order for a CHP system to be cost competitive with central power generation, the overall cost to produce electricity must be lower that that provided by the power grid. For CHP systems, COE is comprised of four primary components:

- Capital and installation (C&I)
- Operation and maintenance (O&M)
- Fuel (F)
- Thermal Energy Credit

If these components are known, the cost of electricity can be estimated for a given CHP project. The capital and installation costs can be amortized over the life of the equipment, and each cost component can be reduced to the cost ($) per kilowatt-hour of electricity produced, or $/kWh. As the typical COE unit states explicitly this is cost per kWh. Consequently, low capacity factor projects (i.e., those with fewer hours of operation) have a larger installed or capital cost component of COE. In many commercial CHP projects the equipment is not fully baseloaded due to facility demands and loads. Figure 2 shows the COE for a hypothetical 1000 kW gas reciprocating engine example operating under different capacity factors. The intermediate duty (40% capacity

factor) COE has twice the capital costs component than the baseload case (90% capacity factor) and the peaking case (10% capacity factor) has a capital costs component three times the intermediate duty case.



Source: EEA

Figure 2: Installed Costs and Levelized Cost of Electricity

Issues Affecting Cost Reduction

CHP systems have widely varying installation costs. These costs are often underestimated or overlooked in many discussions related to CHP system costs. Emerging DG technologies such as microturbines and fuel cells tend to have higher costs than their more mature counterparts (e.g., reciprocating engines). Both mature and emerging DG technologies are anticipated to eventually penetrate a significant portion of the small CHP market. The factors that will contribute to lower installation costs and higher predictability include:

- Increased population of trained installation and maintenance personnel
- Increased competition between companies that install and maintain equipment
- Well-developed and uniform standards that govern installation requirements

- Improved reliability of equipment as delivered by manufacturers

Report Organization

This report is intended to provide the best information available in attempt to quantify the installation costs of small CHP systems. It is broken down into the following sections:

- Review of installation and capital cost components of recent technology characterizations of CHP systems
- Documentation of the survey approach and results used in this project to assess the installation costs of recent small CHP projects
- A review of the reported capital costs of the California Self-Generation Incentive Program (SGIP) in the 2001-2004 timeframe
- A summary comparison of these three primary sources of installation costs and recommendations for future installation cost reduction.
- An assessment of potential approaches and opportunities for cost reduction.

Review of CHP Technology and Costs Characterizations

Two recent technologies characterizations have been done that contain significant efforts to estimate the total installed costs of CHP and distributed generation systems. One was completed by EPRI and the other by the National Renewable Energy Laboratory (NREL). Key findings relative to CHP installed costs are documented in this section.

NREL Gas-Fired Distributed Energy Resource Technology Characterizations

In an effort to document the status of distributed energy resource (DER) technologies, the US Department of Energy (DOE) directed NREL to lead an effort to develop and publish technology characterizations on natural gas-fired DER technologies that would provide the department and the energy community with a consistent set of cost and performance data. Technologies reviewed included reciprocating engines, small gas turbines, microturbines, small steam turbines, fuel cells, and stirling engines. Performance and cost estimates were developed for power only and CHP applications for the current state-of-the-art and various out-year projects.

The approach used by the NREL team was composed of three steps:

- Literature review by the authors to identify the best available information which was then reviewed by an external group of experts
- Extensive internet peer review of the draft characterizations by technology manufacturers, equipment packagers, component packagers, end-users, industry associations, researchers, and consultants
- Final round of technical workshops with authors and selected external reviewers

This section will only summarize the installed cost estimates done by NREL for CHP applications less than 3 MW based on reciprocating engines, gas turbines, microturbines, and fuel cells. The NREL report provides the following caveat regarding the cost estimates, "*These are 'typical' budgetary price levels to the end user. Installed costs can vary significantly depending on the scope of the plant equipment, geographical area, competitive market conditions, special site requirements, emissions control requirements, prevailing labor rates, and whether the installation is new or a retrofit*."

Reciprocating Engines

Capital and installed cost estimates were developed for five prototypical reciprocating engine-based CHP systems. Four of the five are in the size range relevant to this project.

The main factors affecting reciprocating engine capital costs are:

- Engine size
- Speed

- Type (compression ignition or spark ignition)
- Production volume
- Manner of production (automated assembly line versus built-to-order with more labor-intensive manufacturing, cast iron block versus rolled steel block, etc.)

Engine generator sets do not show the economies of scale that are typical of industrial equipment of varying sizes. In contrast to other types of power generation equipment, engines exhibit negative economies of scale ($/kW cost increases with size). This is a consequence of the reduction in crankshaft speed (causing a decrease in power output per unit of cylinder displacement) and increased engine mass.

Generally, a company's most expensive engines are large, low-speed, state-of-the-art engines that are also its most efficient and lowest emission engines. Its lower cost models tend to be its older, smaller, higher-speed, reliable, rugged, and more popular engines that are often adaptations of high production volume automotive of truck engines.

Table 1 presents the NREL cost estimates for reciprocating engine CHP systems less than 3 MW. All the systems are assumed to produce hot water with a heat recovery system consisting of an exhaust gas heat exchanger (exhaust heat recovery), a process heat exchanger (engine jacket coolant heart recovery), a circulation pump, a control system, and piping. Installed costs include additional engineering to integrate the CHP system with the processes and systems. Several rules of thumb used that are based on experience include labor and material costs for civil, mechanical and electrical work ranging from 35-55% of total equipment costs, project and construction management equal to 10% of total equipment costs, engineering and permitting ranging from 8-10% of total equipment costs and a contingency costs of 5% of total equipment costs.

	100 kW System	**300 kW System**	**1,000 kW System**	**3,000 kW System**
COSTS ($/kW)				
Equipment				
-Genset	500	350	370	440
-Heat Recovery	Included	180	90	65
-Inteconnect/Electrical	250	150	100	75
Total Equipment	750	680	560	580
Labor and Materials	413	306	240	220
Project and Construction Management	75	70	56	58
Engineering and Fees	75	70	56	48
Project Contingency	38	34	28	28
TOTAL INSTALLED COSTS	1,350	1,160	945	935

Source: NREL

Table 1: NREL Technology Characterization Reciprocating Engine CHP Installed Cost Estimate

Gas Turbines

Installation and capital costs estimates were developed for five gas turbine-based CHP configurations ranging form 1-40 MW. Only one prototype system is applicable to the small (< 3 MW) CHP size range considered for this project.

The main factors affecting combustion turbine (CT) capital costs are:

- Size (output power rating)
- Type (aeroderivative or industrial)
- Added features (e.g., heat-recovery steam generation (HRSG), steam injection, combined cycle, cogeneration)

Unlike reciprocating engines, gas turbines exhibit the economics of scale ($/kW cost decreases with size). The NREL report provides notes that ancillary equipment such as HRSG, gas compressor, water treatment and electrical equipment cost much les per unit of output for larger (>5 MW) gas turbine systems.

In the case of CHP systems, heat-recovery steam generators (HRSGs) in the exhaust flow add to the complexity and cost of the system, and slightly reduce the performance of the gas turbine itself due to added pressure drop in the exhaust flow. NREL offers the following relationship to scale costs of gas turbine plants.

$$Cost_a \times (Size_b/Size_a)^{0.82} = Cost_b$$

Table 2 presents the NREL cost estimates for the sole gas turbine CHP system less than 3 MW in the NREL technology characterizations. The costs are based in part on the use of the GRI/EPRI developed SOAPP CT.25 cost and performance model.

	1 MW System
COST ($/kW)	
Equipment	
-Gas Turbine	660
-HRSG	245
-Water Treatment System	25
-Electrical Equipment	125
-Other Equipment (e.g., fuel compressor)	120
Total Equipment	1,175
Materials	135
Labor	341
Project and Construction Management	118
Engineering and Fees	82
Project Contingency	59
Total Plant Costs	1,910

Source: NREL

Table 2: NREL Technology Characterization Small Gas Turbine CHP Installed Cost Estimate

Microturbines

With regard to capital and installed costs, microturbines, due to their simplicity and few moving components, have the potential for simple installation and low capital costs. The achievement of this potential hinges on installation experience in demonstration and early commercial products and on rapidly growing sales to support high volume production, and continued technology development. The NREL report correctly describes the largely varying accuracy of manufacturer's costs. Some of this variability is attributable to lack of consistency in the buildup of capital/installed costs and some due to the use of projected prices as opposed to actual cost plus profit determinations. Many of these costs forecasts are significantly lower than the costs actually seen in the market during these early years of microturbine commercialization.

The NREL installed costs estimates are presented in Table 3 for CHP configurations based on four microturbine prototypes ranging from 30-100 kW. The estimates for costs to install a microturbine based CHP system increase the total costs by approximately 60-70% of equipment costs. These costs are described as being based on a simple installation with minimal site preparation required and include provisions for grid interconnection and paralleling. Labor and materials costs are estimated to range from 35-45% of total equipment costs. Project and construction management are estimated to be 10% of total equipment costs. Engineering and permitting fees are estimated to range between 8-10% of equipment costs depending on size. A contingency is assumed to be 5% of equipment costs.

	30 kW System	**70 kW System**	**80 kW System**	**100 kW System**
COSTS ($/kW)				
Equipment				
-Microturbine	1,100	1,070	1,000	920
-Gas Booster Compressor	180	Included	75	75
-Heat Recovery	100	Included	Included	Included
-Additional Controls/Interconnection	180	115	115	100
Total Equipment	1,560	1,185	1,190	1,095
Labor/Materials	655	444	445	403
Project and Construction Management	156	119	119	108
Engineering and Fees	156	95	95	88
Project Contingency	109	83	83	75
Total Plant Costs	2,636	1,926	1,932	1,769

Source: NREL

Table 3: NREL Technology Characterization Microturbine CHP Installed Cost Estimate

Fuel Cells

There are four predominant types of fuel cells, each in various stages of development and commercialization, and each named for the type of electrolyte and materials employed in its construction:

- Molten Carbonate Fuel Cell (MCFC)
- Phosphoric Acid Fuel Cell (PAFC)
- Polymer Electrolyte Membrane Fuel Cell (PEMFC)
- Solid Oxide Fuel Cell (SOFC)

With the exception of PAFC technology and MCFC, fuel cells remain in the testing and demonstration phase. There is limited data on the costs required to procure and install a fuel cell system. Capital and installation costs are commonly unique to each individual installation. Fuel cell developers frequently adjust the price between each field demonstration based on a number of factors, including:

- *Additional system options requested* – Certain applications may require high-grade heat recovery, an absorption chiller, installation of a water storage tank, water purification systems, etc. Each of these items increases the cost of the system.
- *Geographical location of the demonstration* – The performance of a fuel cell system may be significantly affected by geography and climate (e.g., temperature, altitude, earthquakes, snow, rain, sunshine, etc.). The developer may need to incorporate upgrades into the design of the system in order to meet the climatic requirements. Geographical location may also impact the costs of delivery, installation, support services, and maintenance.
- *Overall size of the commitment* – Fuel cell developers generally offer a lower sale price to strategic partners that have committed to long-term support in technology development, manufacturing, and/or marketing. Also, a commitment to demonstrate several fuel cell systems usually equates to a much lower per unit price than an order for a single fuel cell system.
- *Experience* – Based on field experience gained thus far, some fuel cell developers have been able to lower their prices over the past few years. Others have increased their prices due to losses incurred during early demonstrations.

The NREL installed costs estimates are presented in Table 4 for CHP configurations based on six fuel cell prototypes ranging from 10-2000 kW. The report states that while not all these systems are commercialized, these estimates represent initial market entry costs. Costs and pricing estimates were developed across five major component groups to determine the package cost of each system. The five major component groups used were:

- Stack Subsystem
- Fuel Processing Subsystem
- Power and Electronic Subsystem
- Thermal Management Subsystem
- Ancillary Subsystem (e.g., process air blowers, waster treatment, and cabinet ventilation)

In general, the stack subsystem was estimated to comprise 25-40% of equipment costs, the fuel processing subsystem 25-30% of equipment costs, power and electronics subsystem 10-20% of equipment costs, thermal management system 10-20% of equipment costs, and ancillary subsystems 5-15% of equipment costs. With regard to non-equipment costs, the remaining installation costs of fuel cell-based CHP systems were assumed to be similar to those of like-sized engine-based CHP systems.

	200 kW PAFC System	10 kW PEMFC System	200 kW PEMFC System	250 kW MCFC System	2000 kW MCFC System	100 kW SOFC System
COSTS ($/kW)						
Equipment						
-Package	4,500	4,700	3,120	4,350	2,830	2,850
-Grid Isolation/Breakers	100	250	100	100	20	120
Total Equipment	4,600	4,950	3,220	4,450	2,850	2,970
Materials and Labors	300	100	300	300	230	330
Project and Construction Management	150	280	130	100	90	150
Engineering and Fees	60	90	60	60	30	80
Project Contingency	90	90	90	90	50	90
Total Plant Costs	5,200	5,500	3,800	5,000	3,250	3,620

Source: NREL

Table 4: NREL Technology Characterization Fuel Cell CHP Installed Cost Estimate

EPRI Installation, Operation, and Maintenance Costs for Distributed Generation Technologies

In the EPRI project, installed costs data along with operating and maintenance costs were obtained directly from the manufacturers and/or distributors of internal combustion (IC) engines, combustion turbines, microturbines, and fuel cells. Field installation and maintenance data were also obtained through the EPRI Microturbine Field Demonstration project. These values were supplemented with published information and contacts with other organizations such as DOE and the Department of Defense (DOD). The DOD provided data for fuel cell installations. The various installation cost components were categorized for each of the four technologies.

Estimating the costs for distributed resources projects can be difficult. Capital equipment costs are generally well known, at least for mature DG technologies. However, installed costs are frequently underestimated especially for emerging DG technologies. This report provides a frame of reference for comparing and estimating IOM costs. The cost data provided in this EPRI project are based primarily on firm quotes and field data from actual installations.

Microturbine costs are quite high and situation dependent. However, it is believed that within the next five years these costs can stabilize and be reduced to ranges that are more consistent with mature DG technologies. Fuel cell IOM costs are also very high. The most significant factor in fuel cell maintenance cost is the stack replacement. For both microturbines and fuel cells, the actual costs are higher than common quotes or estimates.

Approach and Breakdown of Installed Costs Used

The installation costs refer to all costs beyond the power generation equipment that are required for the complete project or installed cost. The installation costs included the following components:

- Project engineering
- Permitting
- Site preparation/placement
- Mechanical, including thermal recovery system
- Fuel supply system
- Electrical
- Site commissioning/startup
- Other

Installation costs include both materials/parts and labor. The parts and materials can include items such as concrete for the installation pad to complex heat recovery equipment. The labor costs can also include different components such as concrete work, electrical, and mechanical. Each of these labor rates can be significantly different, and can also vary based on location. Capital or power generation equipment costs were developed and presented for comparison or completeness, but power generation equipment costs were not the major focus. Installed costs were developed for four CHP/DG prime mover technologies:

- Reciprocating Engines
- Gas Turbines
- Microturbines
- Fuel Cells

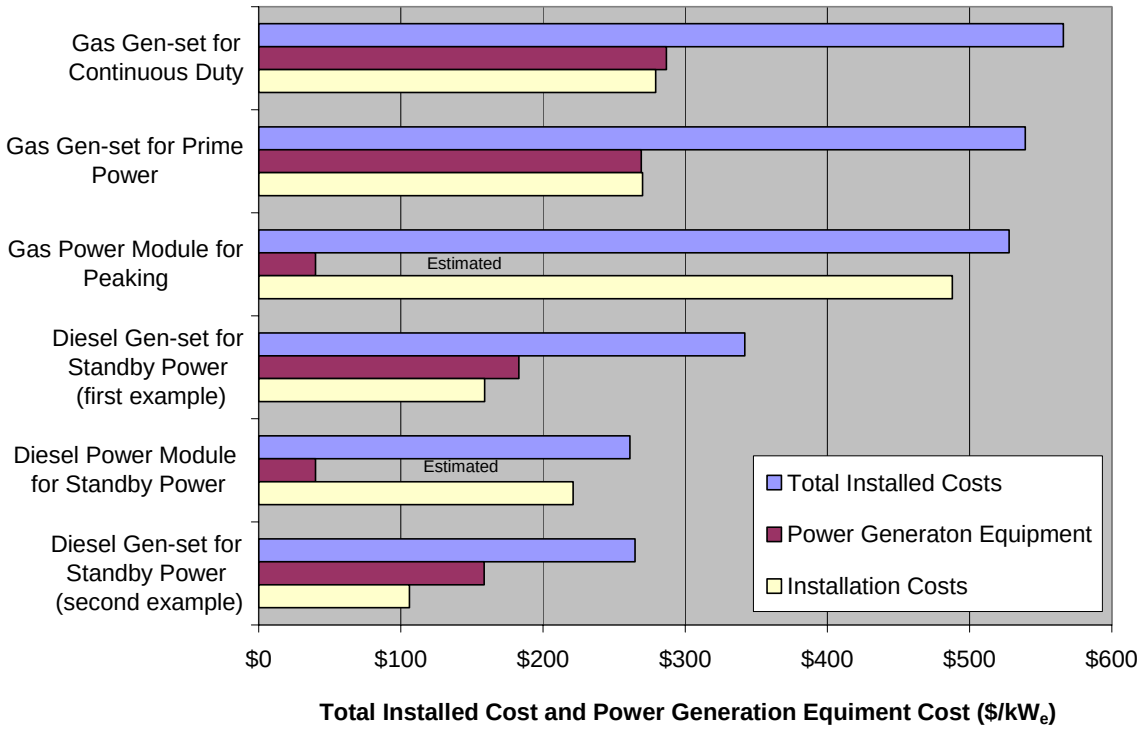
Reciprocating Engines

A summary of the installed costs developed are shown in Table 5 and Figure 3. The greater than 1 MW size range that was used reflects the electric utility perspective. Typically, electric utilities look at a minimum of 1 MW to have a measurable impact on their transmission and distribution system. They also consider peaking applications as mutually beneficial to both themselves and their customers and generally less threatening than continuous duty prime power and CHP applications. In fact, CHP applications were not included in the analyses.

Engine Type	Gas Gen-set for Continuous Duty	Gas Gen-set for Prime Power	Gas Power Module for Peaking	Diesel Gen-set for Standby Power	Diesel Gen-set for Standby Power
Fuel	Natural Gas	Natural Gas	Natural Gas	Diesel	Diesel
Application	Continuous Duty	Prime Power	Peaking	Standby	Standby
Rating (kW_e)	1,300	1,400	1,250	2,000	2,000
Major / Minor Cost Component	**Cost ($/$kW_e$)**	**Cost ($/$kW_e$)**	**Cost ($/$kW_e$)**	**Cost ($/$kW_e$)**	**Cost ($/$kW_e$)**
Engine / Generator / Base / Safety System	286.78	269.14		183.01	158.63
Project Engineering					15.00 (not included)
Permitting	Not included	Not included	Not included	Not included	Not included
Site Preparation / Placement / Enclosures	Included	Included	Included	Included	38.09 (excl. site preparation & placement)
Fuel Supply System	1.21 (Installation included below)	1.13 (Installation included below)	Included	0.35 (Installation included below)	19.34
Electrical	20.35 (Installation included below)	18.89 (Installation included below)	Included	16.06 (Installation included below)	36.20 (installation of switchgear and controls not included)
Mechanical (cooling and exhaust connections)	Included	Included	Included	Included	$6.50
Site Commissioning / Startup	Included	Included	Included	Included	$6.00
Other (Equipment and Installation of SCR System)					106.03 (not included)
Estimated Installation Costs	279.25	270.02		158.91	106.13
Total Project Costs	566.03	539.16	527.83	341.91	264.75

Source: EPRI

Table 5: EPRI Reciprocating Engine Installed Cost Estimate



Source: EPRI

Figure 3: EPRI Reciprocating Engine Breakdown of Installed Cost Estimate

Major conclusions in the review of reciprocating engines were that equipment costs per kW generally increase with size, so that the cost per kW of a 10-MW system is about twice the cost per kW of a 2-MW system; however, installation costs are different. The installation cost per kW of a 10-MW system is about the same (or slightly less) than the cost per kW of a 2-MW system.

Gas Turbines

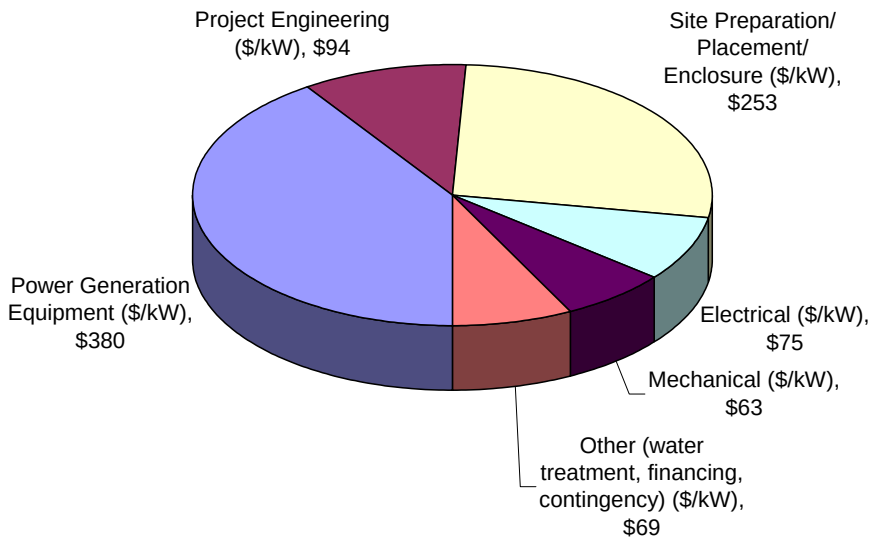
A summary of the installed costs developed are shown in Table 6 and Figure 4. The total installed cost is composed of the cost of the power generation unit (equipment-only) and the installation costs. The installation costs of larger gas turbine systems are typically 60 to 80% of the cost of the power generation unit. Because DG-size gas turbine systems are usually packaged and modularized, the power generation units are the dominant part of total installed cost. The power generation unit for a basic generator set package includes the gas turbine, generator, and controls. Similarly to the reciprocating engine assessment, CHP applications were not included in the analyses.

Rating (MW_e)	1.2	1.9	3.8
Cost Component	Cost ($/kW$_e$)	Cost ($/kW$_e$)	Cost ($/kW$_e$)
Engine / Gen./ Base / Safety System	563	197	440
Project Engineering	157	74	Included
Permitting	Included	Included	Included
Site Preparation / Placement / Enclosures	410[1]	203	Included
Fuel Supply System	Included	Included	Included
Electrical	125	28	Included
Mechanical (cooling and exhaust connections)	121	144	Included
Site Commissioning / Startup	Included	Included	Included
Other	413[2]	100[3]	Included
Estimated Installation Costs	1226	549	340[4]
Total Installed Costs	1788	746	780

Source: EPRI

Table 6: EPRI Small Gas Turbine Installed Cost Estimate

[1] Includes all installation labor and miscellaneous materials
[2] Includes equipment costs for HRSG, water treatment system, project financing costs, and contingency
[3] Estimate for permitting, mechanical and electrical installation labor, site commissioning and startup
[4] Includes HRSG with bypass, simple electrical switchgear, and simple structure



Source: EPRI

Figure 4: EPRI Small Gas Turbine Breakdown of Installed Cost Estimate

Microturbines

A summary of the installed costs developed are shown in Table 7 and Figure 5. Most of the data used in the EPRI assessment came form the EPRI Microturbine Generator Field Test Program. All the prototype units in the table are based on the 30 kW Capstone product. The first configuration system includes a thermal heat recovery unit and has the highest overall installation cost. Model 2 has the lowest installation cost, primarily because the host donated a significant part of the installation labor and some materials.

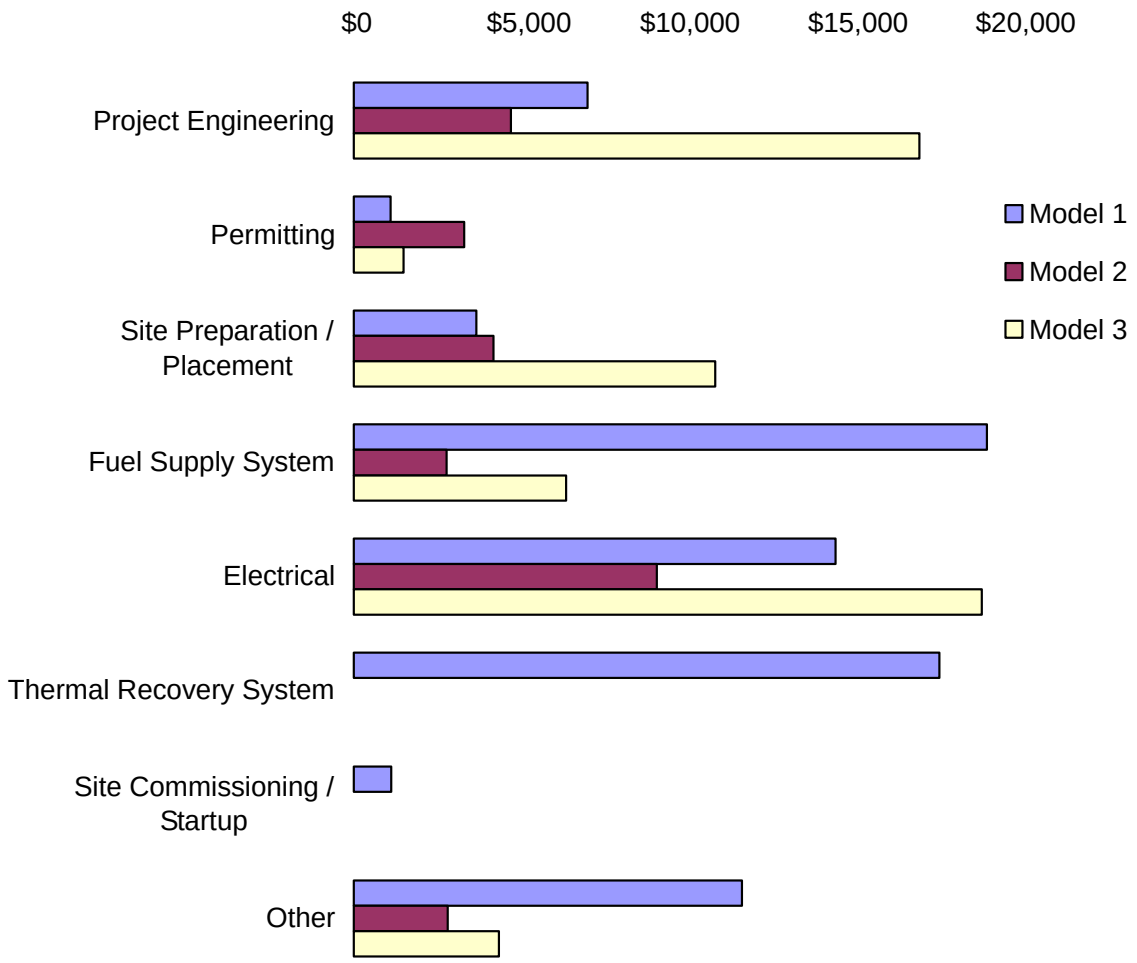
Cost Components and the Impact on Total Installation Cost ($/kW)

Cost Component	Model 1 Natural Gas w/ CHP		Model 2 Natural Gas		Model 3 Diesel Oil	
Microturbine power generation unit only	***1,000***		***1,000***		***1,000***	
	Labor[5]	**Materials**	**Labor**	**Materials**	**Labor**	**Materials**
Fuel system	567	105	34	65	120	90
Electrical	366	145	172	150	427	195
Remaining installation materials and labor	40	829	156	376	387	725
Heat recovery	214	408	---	---	---	---
Sub-total	*1,187*	*1,487*	*362*	*590*	*934*	*1,010*
Total installation cost	***2,674***		***952***		***1,944***	
Project Total ($/kW)	**3,674**		**1,952**		**2,944**	

Source: EPRI

Table 7: EPRI Microturbine Installed Cost Estimate

[5] Based on a labor rate of $50 per hour



Source: EPRI

Figure 5: EPRI Microturbine Breakdown Installed Cost Estimate

A significant observation is the discrepancy between manufacturer estimates and actual installation costs at the demonstration projects. Manufacturers are predicting that the installation cost of microturbines as a mature technology will be approximately 20-30% of the capital cost. This contrasts with demonstration installations that are anywhere from 100 to 250% of the capital equipment costs. One reason for high costs in the early installations is that many auxiliary components were not packaged with the microturbine unit as a complete system. Auxiliary components suitable for packaging include the gas compressor, heat recovery, and associated piping and wiring, and standardized interconnection hardware.

Fuel Cells

Fuel cells remain in the testing and demonstration phase; hence, there is limited data on the costs required to procure and install a fuel cell system. Capital and installation costs

are commonly unique to each individual installation. A summary of the installed costs developed are shown in Tables 8 thru 10. Phosphoric acid fuel cell data is from the U.S. Department of Defense (DOD). DOD conducted a demonstration program with PAFC systems throughout the 1990s. Thirty PC25 fuel cell systems manufactured by UTC Fuel Cells (formerly ONSI and International Fuel Cells) were installed at DOD bases in seventeen states between 1994 and 1997. MCFC data is from Los Angeles Department of Water and Power and Fuel Cell Energy. At the time of the report, the molten carbonate fuel system developed by Fuel Cell Energy was just entering the early stages of commercialization.

DOD Fuel Cell Program – PC25 Standard Package Costs

Item	Cost ($)	Cost ($/kW)
Power Plant Equipment Cost	$636,525	$3,182.63
Installation Cost (including 1-year maintenance package)	$160,727	$803.63
Total Installed Cost	**$797,252**	**$3,986.26**

Source: EPRI, U.S. Department of Defense, Army Corps of Engineers, Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL)

Table 8: DOD PAFC Standard Installed Cost Estimate

DOD Fuel Cell Program – PC25 Optional & Add-on Costs

Item	Cost ($)	Cost ($/kW)
Additional 2-Year Maintenance Package	$52,936	$265
Additional Maintenance (per month)	$2,263	$11
Grid Independent	$33,675	$168
Transformer	$32,968	$165
High-Grade Heat	$12,768	$64
Second Low Grade Heat	$24,675	$123
Second Thermal Loop	$25,197	$126
Storage Tank	$21,350 + $15.6547 per additional gallon over 1,000 gallons	$107+
Dual Fuel Option	$15,000	$75
20-ton Absorption Chiller	$70,000	$350
30-ton Absorption Chiller	$100,000	$500
Alaska Differential	$36,203	$181

Source: EPRI U.S. Department of Defense, Army Corps of Engineers, Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL)

Table 9: DOD PAFC Optional and Additional Components Installed Cost Estimate

DFC® 300 Total Installed Costs (Actual)

Item	LADWP 2001[6]		OCC 2002[7]		LADWP 2003[8]		Commercial Installation 2002	
	($)	($/kW)	($)	($/kW)	($)	($/kW)	($)	($/kW)
Capital	$2,400,000	$9,600			$1,225,000	$4,900		
Installation	$800,000	$3,200			$612,500[9]	$2,450		
Total	**$3,200,000**	**$12,800**	**$1,650,000**	**$6,600**	**$1,837,500**	**$7,350**	**$3,800,000**	**$7,600**

Source: EPR1, Los Angeles Department of Water and Power and Fuel Cell Energy

Table 10: MCFC Installed Cost Estimates

One of the observations was that the actual costs reported for the installation (non-equipment costs) of fuel cell systems range between $800 and $3,200 per kilowatt. The low end figure of $800/kW represents the standard installation cost negotiated for the DOD PAFC demonstration program. It does not include any of the options that were commonly added in the installation of PC25 units for that program. It is estimated that the average installation cost (non-equipment) for the DOD program was $1,479. The high-end figure of $3,200/kW represents the installation costs incurred by LADWP last year in the deployment of a Fuel Cell Energy DFC®300 system. However, this figure includes engineering and site preparation for three microturbines that were installed at the same site. This may lead one to believe that the installation cost for just the fuel cell system may have been lower than $3,200. On the other hand, many of the installation support services provided by Fuel Cell Energy (e.g., worker training, assistance in with engineering and site preparation, etc.) were included in the capital cost contract, which totaled $9,600 per kilowatt.

[6] The $2.4 million capital cost represents LADWP's contract cost to Fuel Cell Energy. In addition to the actual DFC®300 system cost, the contract included support services throughout the demonstration period. The additional $800,000 in installation costs included engineering, site preparation, and construction for three Capstone microturbines that were installed at the same site as the fuel cell system.
[7] Ocean County College in Toms River, New Jersey, August 2002.
[8] The $1.225 million in actual capital costs does not include any support services from Fuel Cell Energy. Based on the lessons learned and training provided by Fuel Cell Energy throughout the first demonstration, LADWP will install, operate, and maintain two new DFC®300 systems in 2003.
[9] Assumes an installation cost equal to 50% of the capital cost.

Small CHP Facility Survey of Installation Costs

The technical approach for the primary research of this task was based on identifying recently installed CHP applications for gas turbine, reciprocating engine, microturbine, and fuel cell based systems, contacting those sites willing to provide installation costs on an anonymous basis, and assessing those costs with regard to potential for reduction. Small CHP systems are defined in this task as less than 3 MW. A sample of sites installed in the last three years was the focus. Telephone interviews and surveys were conducted with key contacts at these sites. Key components of total installed costs for each technology-based system were identified. From that data, EEA quantified the range of installation costs experienced in the field. Every reasonable effort was made to ensure that all technologies were included in the target sample size of 15-18 CHP facilities. The target sample size was achieved; however, not all technologies are represented. One small gas turbine facility had initially expressed willingness to provide data. However, upon reviewing the data request, declined to participate even under the condition of confidentiality.

Facility Survey Technical Approach

The technical approach the facility survey was developed

Task 1: Develop a sample of twelve to fifteen CHP sites with the following characteristics:

- Installed in the last three years.
- Distributed regionally, to the extent possible.
- Include the four types of technologies - Gas Turbine, Reciprocating Engine, Microturbine, Fuel Cell

Task 2: Identify contacts and secure participation in the cost survey

- Use databases, publications, industry contacts
- Determine willingness to provide cost data on a confidential basis
- Negotiate any needed non-disclosure agreements

Task 3: Develop and conduct survey and telephone interviews

- Develop survey and interview guide to address, but not limited to, the installation cost components listed
    1. Generator set equipment
    2. Heat recovery equipment
    3. Water Treatment Systems
    4. Fuel compression equipment
    5. Fuel processing subsystem and controls
    6. Power electronics subsystem
    7. Switchgear
    8. Utility interconnection
    9. Emissions control
    10. Ancillary subsystems (safety controls and monitoring, cabinet ventilation fans, and other miscellaneous components)

11. Installation
12. Engineering and fees
13. Soft costs (project development costs, permitting costs, legal costs, financing costs, and land costs)
14. Contingencies

- Based on survey and interviews, tabulate representative costs for total installed costs of each technology's installation in a CHP application
- Facility names and names of equipment vendors, engineering firms, and other service providers will not be identified.

Task 4: Characterize installed costs and identify areas for potential cost reduction

- Breakdown costs for each technology
- Calculate average and range of CHP total installed costs for each technology
- Assess what drives key cost components
- Identify cost components that can be reduced and possible strategies

Survey

Table 11 is an example of the cost survey forms completed by the participating sites. In addition to this data request, the following qualitative data was requested.

- Rated Capacity of Generator Set
- Date of Installation
- Customer Sector
- Use of recovered heat (e.g., flow and conditions of hot water/steam)
- Indoor or Outdoor Installation
- Retrofitted to existing facility/process or New installation; difficulty of site conditions and construction, and need for site preparation (e.g., Simple – Greenfield site, no siting issues; Normal – in plant, normal site connections, placement in existing building or minimal outdoor preparation; Complex – unusual conditions, new building or space required)
- Total actual costs relative to estimated costs at project approval
- Time to complete process (from feasibility to completion of commissioning)
- Costs that could be reduced and extent of reduction (using hindsight)
- Steps in installation process that could be shortened or streamlined

Item	**Actual Costs ($)**
Equipment	
• Generator Set Package	
• Fuel Gas Compressor (specify suction side and pressure side pressures)	
• Heat Recovery Unit (specify steam/hot water conditions and if integrated into packages system)	
• Heat Recovery Ducting/Valves	
• Controls and Monitoring (incremental to generator set package standard controls)	
• Electrical Interconnection and Switchgear Systems	
• Utility Tie-In (specify generator type (synchronous or induction) and blackstart capability)	
• Fuel Systems (e.g., enhancements to gas service, additional metering, fuel cleanup)	
• Emissions Controls and Monitoring (if applicable, specify control technology and level of emissions required)	
• Water Treatment Equipment (if applicable, specify requirement and type of equipment used)	
• Miscellaneous Equipment (e.g., safety controls and monitoring, cabinet ventilation fans, and other miscellaneous components)	
• Miscellaneous Warranties	
Equipment Installation Labor/Materials	
• Civil Installation	
• Electrical Installation	
• Mechanical Installation	
• Site Restoration	
• Miscellaneous Materials (specify)	
Project and Construction Management	
Engineering and Fees	
• Feasibility Studies	
• Interconnection Studies	
• Conceptual Design	
• Final Design and Engineering	
Regulatory and Building Code Approvals	
• Air Permit	
• Emissions Testing	
• Miscellaneous Inspections/Approvals (specify)	
Project Financing (Interest during construction)	
Start Up and Commissioning	
Contingency	
Grants, Government Incentive Programs (specify if state of federal program)	

Source: EEA

Table 11: Reciprocating Engine Installed Costs Survey Data Request

Facility Survey Results

Sixteen sites elected to participate in this project. Sizes range from 28 to 3000 kW. The sites are not identified by name in this report. They are listed below by their sector descriptions:

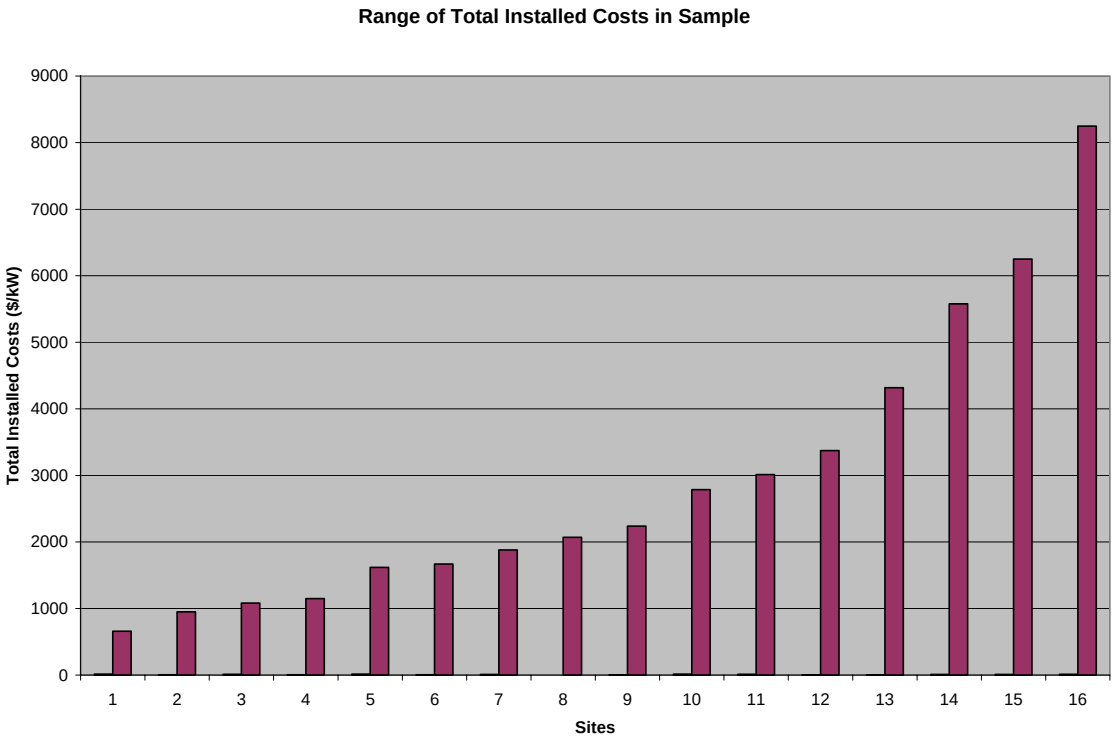
- Commercial Carwash
- Hotel
- Industrial Food Facility
- Hotel
- College
- Museum
- Airport
- Hotel
- Hotel
- Hospital
- Commercial Building
- College
- IT Company Campus
- Health Club
- Industrial Facility
- Industrial Plastics Facility

With regard to prime mover technology, the sample is distributed as follows:

- 4 Reciprocating Engine Projects
- 8 Microturbine Projects
- 3 Fuel Cell Projects
- 1 Small Steam Turbine Project

The actual cost surveys of all the sites are shown in Appendix A.

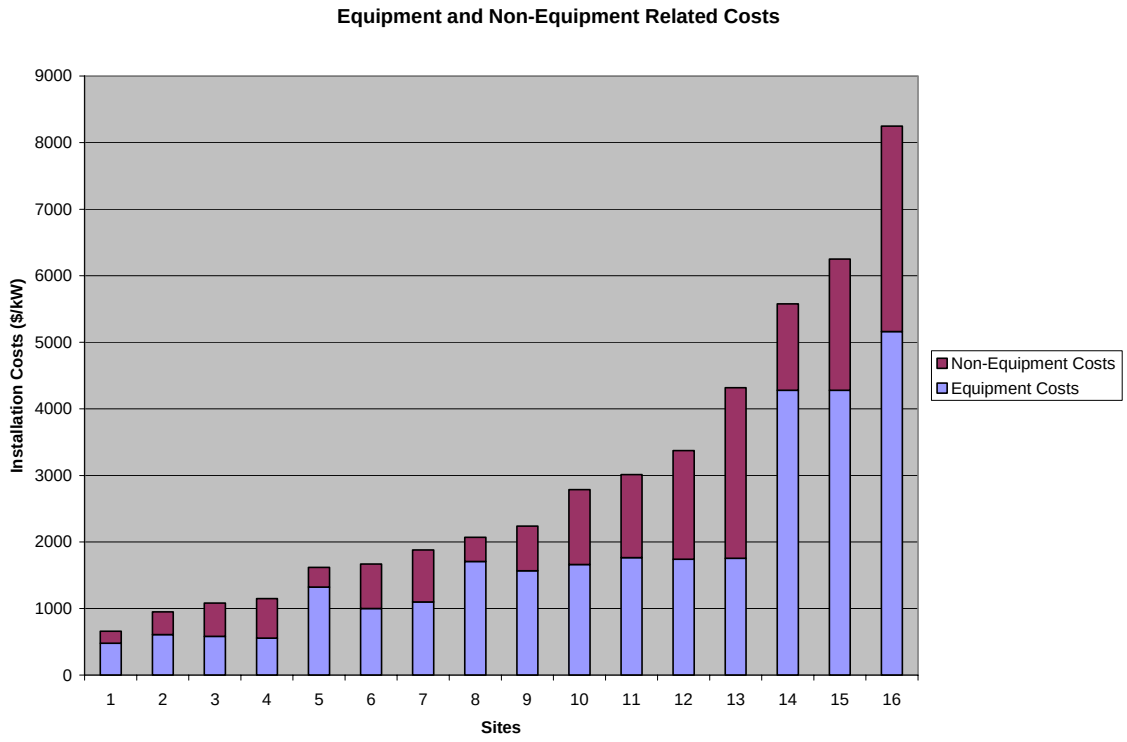
The distribution of total installed costs for the sample is shown in Figure 6.



Source: EEA

Figure 6: Range of Total Installed Cost of Survey Sample

The relative split between equipment costs and non-equipment costs (installation and integration/soft costs) are shown in Figure 7.



Source: EEA

Figure 7: Equipment and Non-Equipment Costs of Survey Sample

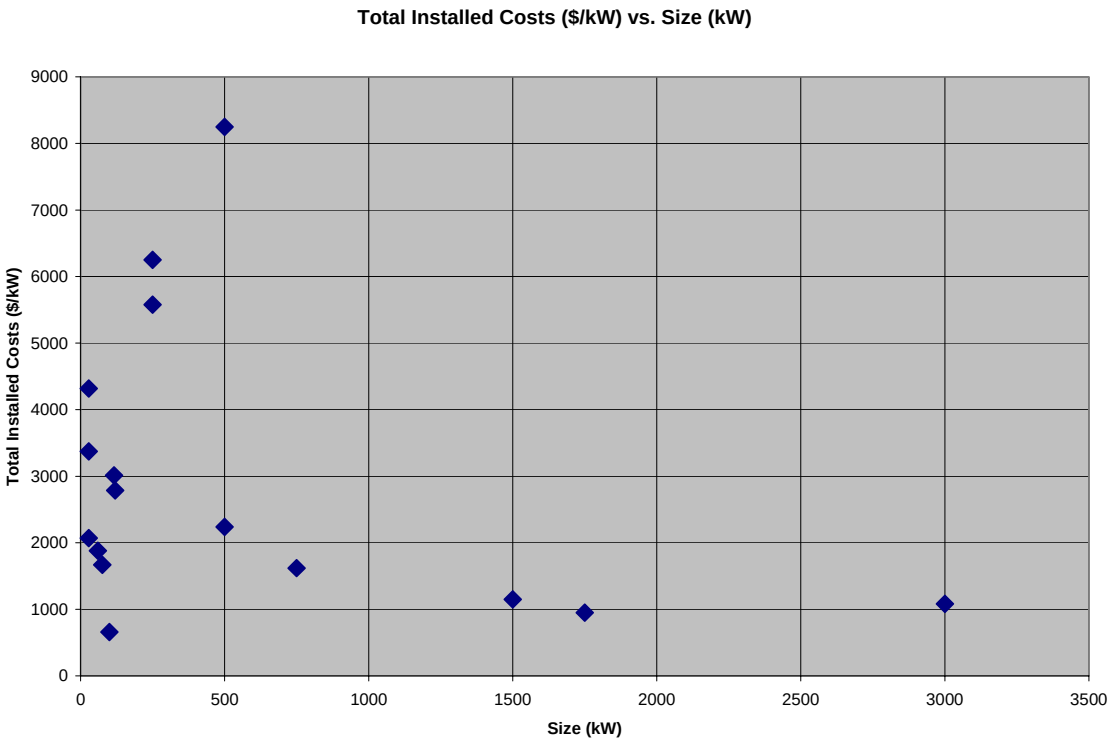
Average cost data from the entire survey sample is shown in Table 12.

Cost Category	Average	Minimum	Maximum
Equipment	1848	480	5160
Installation	679	137	2015
Integration/Soft	402	40	2766
TOTAL	2930	657	8249

Source: EEA

Table 12: Average Costs ($/kW) of Sample

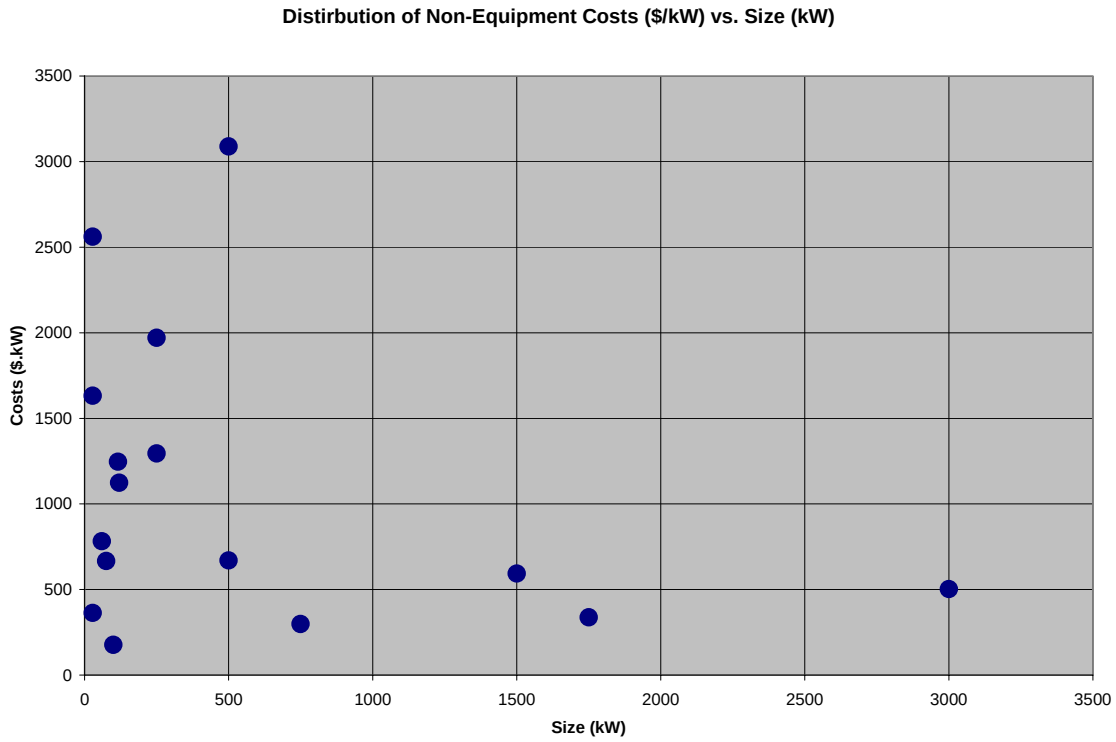
The distribution of total installed costs versus size is shown in Figure 8.



Source: EEA

Figure 8: Total Installed Cost versus CHP Facility Size

The distribution of non equipment costs versus size is shown in Figure 9.



Source: EEA

Figure 9: Non-Equipment Cost versus CHP Facility Size

Breakdown costs for each technology

The following sections provide the breakdown of installed costs for each technology class in the sample. The average and range of CHP total installed costs for each technology along with the identification of key cost components.

Reciprocating Engines

Table 14 and Figures 10 thru 12 illustrate the components of installed costs of CHP plants using reciprocating engines in the facility survey sample. Classes of reciprocating engines include:

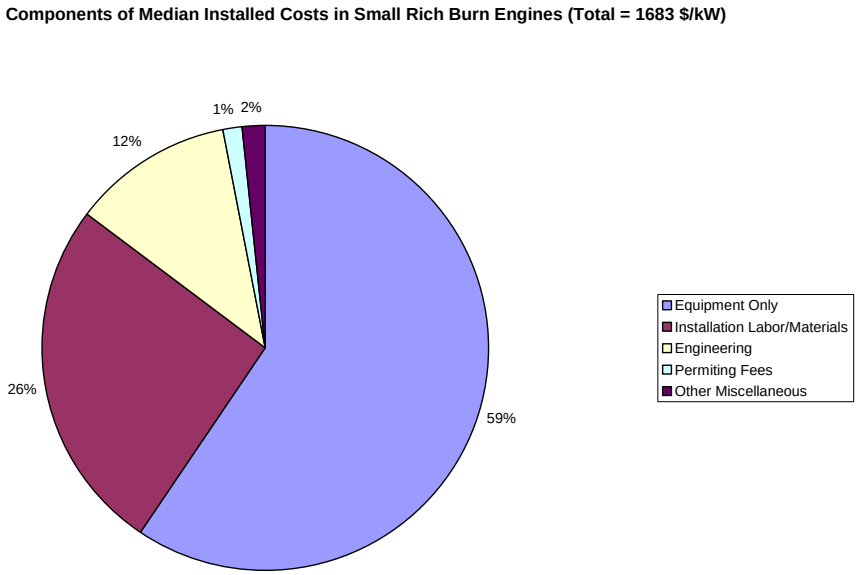
- Small Rich Burn Engines (70-100 kW)
- Mid-Sized Lean Burn Engines (100-500 kW)
- Large Lean Burn Engines (>1000 kW)

Reciprocating Engines

	Median Costs ($/kW)
Small Rich Burn RE 70-100 kW (n=1)	
Equipment Only	1000
Installation Labor/Materials	433
Engineering	200
Permiting Fees	20
Other Miscellaneous	30
TOTAL	1683
Midsized Lean Burn RE 100-500 kW (n=2)	
Equipment Only	1062
Installation Labor/Materials	333
Engineering	248
Permiting Fees	20
Other Miscellaneous	30
TOTAL	1694
Large Lean Burn RE >1000 kW (n=1)	
Equipment Only	611
Installation Labor/Materials	284
Engineering	11
Permiting Fees	3
Other Miscellaneous	40
TOTAL	948

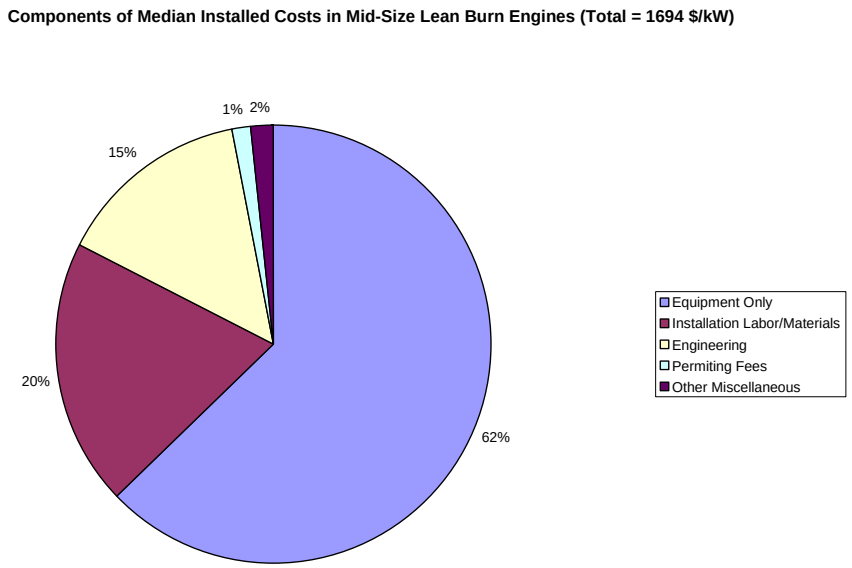
Source: EEA

Table 13: Installed Costs Components of Reciprocating Engine Systems from CHP Facility Survey



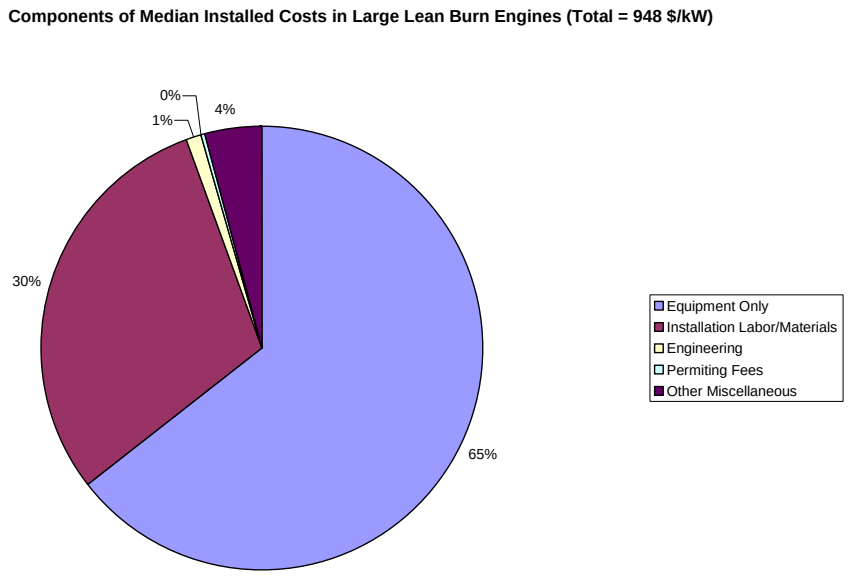
Source: EEA

Figure 10: Distribution of Median Installed Cost Components for Small Rich Burn Engines



Source: EEA

Figure 11: Distribution of Median Installed Cost Components for Mid-Size Lean Burn Engines



Source: EEA

Figure 12: Distribution of Median Installed Cost Components for Large Lean Burn Engines

Microturbines

Table 15 and Figures 13 thru 14 illustrate the components of installed costs of CHP plants using microturbines in the facility survey sample. Classes of microturbines include:

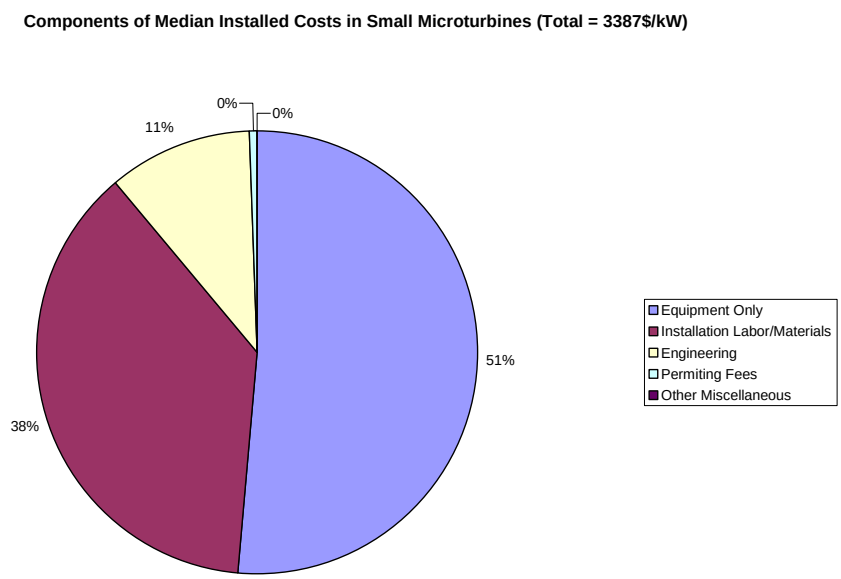
- Small Microturbines (<70 kW)
- Mid-Sized Microturbines (70-100 kW)

Microturbines

	Median Costs ($/kW)
Small MT <70 kW (n=3)	
Equipment Only	1740
Installation Labor/Materials	1275
Engineering	357
Permiting Fees	15
Other Miscellaneous	0
TOTAL	3387
Midsized MT 70-100 kW (n=5)	
Equipment Only	1321
Installation Labor/Materials	531
Engineering	132
Permiting Fees	17
Other Miscellaneous	0
TOTAL	2000

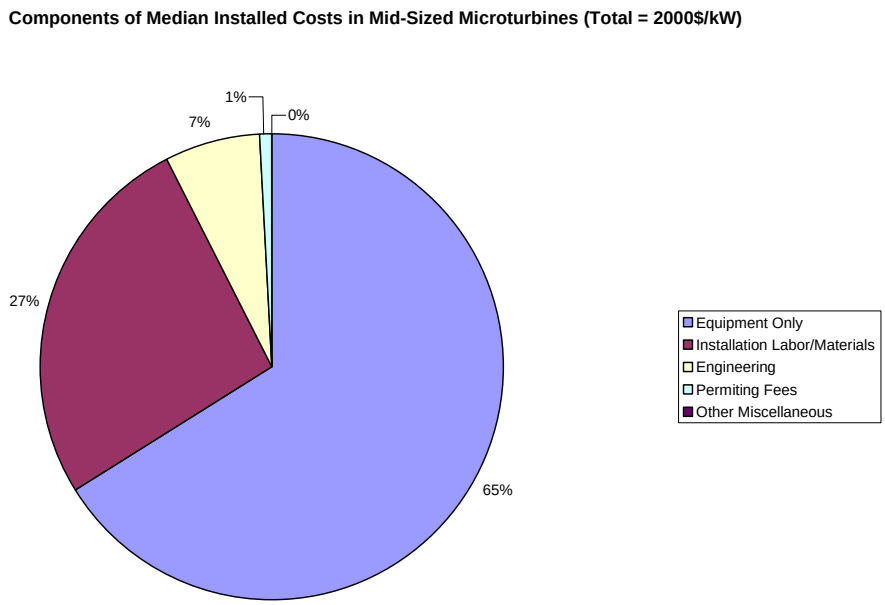
Source: EEA

Table 14: Installed Costs Components of Microturbine Systems from CHP Facility Survey



Source: EEA

Figure 13: Distribution of Median Installed Cost Components for Small Microturbines



Source: EEA

Figure 14: Distribution of Median Installed Cost Components for Mid-Sized Microturbines

Fuel Cells

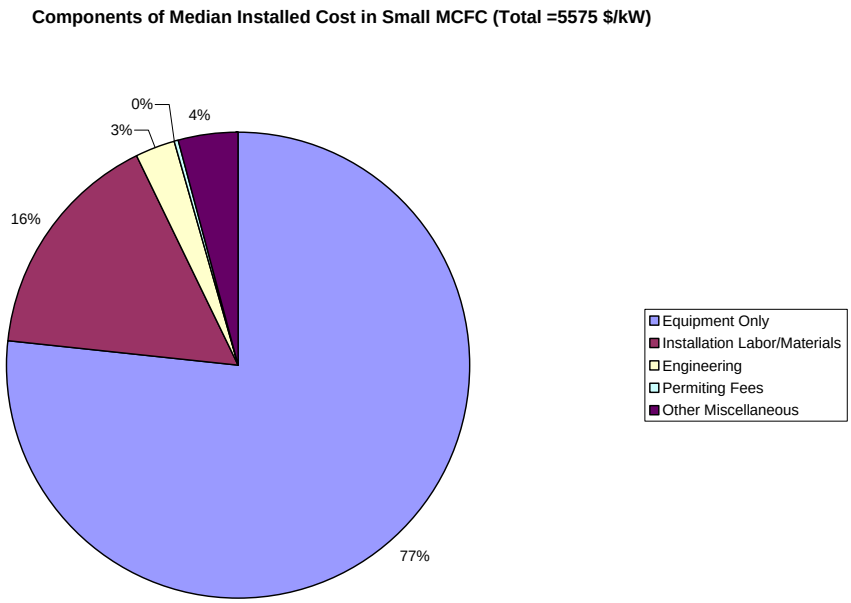
Table 16 and Figures 15 illustrate the components of installed costs of CHP plants using fuel cells in the facility survey sample. All the fuel cells in the sample are 250 kW MCFC.

250 kW MCFC (n=3)

	Median Costs ($/kW)
Equipment Only	4280
Installation Labor/Materials	895
Engineering	156
Permiting Fees	16
Other Miscellaneous	228
TOTAL	5575

Source: EEA

Table 15: Installed Costs Components of Fuel Cell Systems from CHP Facility Survey



Source: EEA

Figure 15: Distribution of Median Installed Cost Components for MCFC

Small Steam Turbines

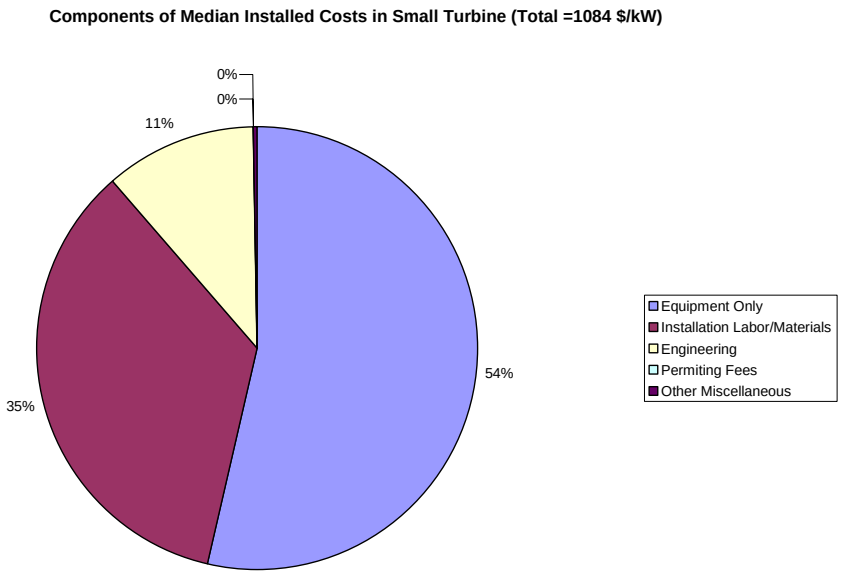
Table 17 and Figures 16 illustrate the components of installed costs of CHP plants using small steam turbines (<3000 kW) in the facility survey sample. The steam turbine system in the sample was retrofitted to a college facility.

Small Steam Turbine < 3000 kW (n=1)

	Median Costs ($/kW)
Equipment Only	582
Installation Labor/Materials	379
Engineering	120
Permiting Fees	0
Other Miscellaneous	3
TOTAL	1084

Source: EEA

Table 16: Installed Costs Components of Steam Turbine Systems from CHP Facility Survey



Source: EEA

Figure 16: Distribution of Median Installed Cost Components for Steam Turbines

Notable observations and clear trends in components of installed costs across CHP technology classes in the survey sample indicate the following:

- In all technology classes the largest component of installed costs is equipment; the only case in which non-equipment costs were approximately equal to equipment costs is with small microturbines
- In all technology classes installation materials and labor was by far the largest non-equipment cost component.
- In technology classes where there are multiple size ranges such as reciprocating engines and microturbines, the proportion of total installed costs attributable to non-equipment components decreases with size
- In the emerging technologies such as microturbines and fuel cells the percentage of installed costs attributable to equipment is significantly higher than similarly sized traditional equipment (e.g., reciprocating engines)
- Installation materials and labor as a percentage of total installed costs is largest in microturbine projects; ranging from 27 to 38%.
- Engineering (and feasibility study) costs as a percentage of total installed costs is largest in reciprocating engine projects; as high as 15% in mid-seized lean burn engines.
- Fuel cells had high miscellaneous costs primarily attributed to project finance costs by all three facilities; however, on a percentage of total installed costs basis (~4%) this was consistent with the other technology classes.

Reported Capital Costs of California Self-Generation Incentive Program

On March 27, 2001, the California Public Utilities Commission (CPUC) announced new incentive programs to encourage residential and commercial electricity customers to install grid-tied renewables and clean distributed-generation (DG) systems. The Self-Generation Incentive Program (SGIP) offers incentives to encourage customers to produce electricity with microturbines, small gas turbines, wind turbines, photovoltaics (PV), fuel cells and internal combustion engines. The incentive payments range from $1/W - $4.50/W, depending on the type of system, and will be funded through the end of 2007. Table 13 provides a summary of the incentive amounts and caps of the various classifications of technologies and applications at the time frame relevant to this project.

Eligible Technologies	Incentive Offered ($/W)	Maximum $ of Project Cost (%)	System Size
Photovoltaics Fuel cells operating on renewable fuel Wind turbines	4.50	50	30 kW - 1 MW
Fuel cells operating on non-renewable fuel and using waste heat recovery	2.50	40	up to 1 MW
Microturbines Internal combustion engines Small gas turbines (All use waste heat recovery and meeting reliability criteria)	1.00	30	up to 1 MW

Source: SDREO

Table 17: California Self-Generation Incentive Program Summary

AB 1685 of 2003 provided funding of approximately $500 million and extended the program expiration date from December 31, 2004 to January 1, 2008. The bill also expanded some program requirements, as well as the definitions of "ultra clean" and "low-emission" DG. For this project, capital costs for CHP projects under the SGIP in the 2001-mid-2004 timeframe were reviewed and are summarized in this section. PG&E, SCE, and SoCal Gas administer the incentive program in their service territories, and the San Diego Regional Energy Office administers the program in SDG&E's territory

Changes in SGIP since Collection of Data

On December 16, 2004, the CPUC approved a decision adopting a number of important modifications to the SGIP. The decision includes the following provisions:

1. A new incentive structure and payment amounts eliminated the percentage of project-cost cap (effective for all projects not already holding an approved conditional reservation on the date of the decision).
2. The SGIP rebate will be considered the "last rebate" applied in cases where other incentives will be obtained. Projects receiving incentives based on future performance of the system are not eligible to receive a SGIP rebate.
3. The maximum eligible system size was increased to 5 MW, although the incentive payment remains capped at 1 MW.
4. The annual maximum Corporate/Government Parent limit per service territory was increased from 1 MW to 4 MW. (This provision is subject to clarification by the CPUC).
5. Recommendations for an exit strategy and a declining rebate schedule recommendation will be developed with public input.
6. The SGIP procedures and rules handbook will be modified to (a) address the certification of projects to meet new emission standards required by AB 1685, (b) eliminate the requirement that proponents of projects reapply for incentives in the subsequent funding cycle, and (c) include procedural or financial mechanisms to deter inappropriate reservation requests.

The December 2004 CPUC decision is not clear concerning the new incentive amounts granted for several technology categories. The SGIP Working Group has requested clarification from the CPUC. In the meantime, the following technologies and corresponding incentive amounts apply:

- PV (Level 1) - $3.50/W
- Fuel cells using renewable fuels (Level 1) - $4.50/W
- Fuel cells using non-renewable fuels (Level 2) - $2.50/W

SGIP CHP Project Capital Costs

The data provided by the CEC on the SGIP CHP projects does not breakdown the total project costs as done in the previous chapters (i.e., technology and cost characterizations and facility cost survey). Total costs are provided. As described above, the total project costs are part of the basis for the size of the incentives. To maximize the incentive payment there was no motivation to minimize project costs. The December 2004 changes in the program, in particular the elimination of the project-cost component should help mitigate this feature.

Tables 18 thru 21 summarize the project costs and incentives provided based on classes of technologies. Incentive payments ranged from 23% to 48% of capital costs. Nearly all non-fuel cell projects, with the exception of renewably -fueled microturbines, had incentives tightly scattered around 30% of capital costs.

		Capital Costs ($/kW)				
	N	Mean	Median	Min	Max	Average SGIP Incentive
Small Rich Burn RE						
60-75 kW	23	3,052	2,983	2,067	4,995	916
140 kW	5	1,709	1,667	1,230	2,374	513
150 kW	10	1,602	1,550	1,200	2,150	481
200 kW	26	2,261	2,150	1,643	2,806	678
250 kW	13	2,369	2,145	850	6,250	711
350 kW	7	2,122	2,060	1,270	3,365	637
Small RE EGR						
260 kW	1	1,481	1,481	1,481	1,481	444
Mid Size Rich Burn RE						
375 kW	17	2,610	2,493	1,470	4,379	783
750 kW	6	2,909	2,909	1,644	3,981	873
Mid Size Lean Burn RE						
1000 kW	9	2,176	2,094	1,527	2,850	653

Source: SDG&E, Mid-Atlantic CHP Application Center

Table 18: California Self-Generation Incentive Program Reciprocating Engine Capital Costs

		Capital Costs ($/kW)				
	N	Mean	Median	Min	Max	Average SGIP Incentive
1.2 MW	1	3388	3388	3388	3388	1000
1.4 MW	2	3591	3591	2701	4481	1000

Source: SDG&E, Mid-Atlantic CHP Application Center

Table 19: California Self-Generation Incentive Program Microturbine Capital Costs

		Capital Costs ($/kW)				
	N	Mean	Median	Min	Max	Average SGIP Incentive
30 kW	15	3617	3010	1224	10146	1000
60 kW	62	3673	3535	1040	7758	1000
70 kW Renewable	7	4648	4810	2473	6609	1500
70 kW	5	2710	2205	1850	4521	813
80 kW	3	2488	2605	2099	2760	746
100 kW	4	2450	2175	1950	3500	735
200 kW	1	2890	2890	2890	2890	867
250 kW Renewable	1	3400	3400	3400	3400	1360
250 kW	1	3193	3193	3193	3193	958
250 kW	1	1579	1579	1579	1579	474

Source: SDG&E, Mid-Atlantic CHP Application Center

Table 20: California Self-Generation Incentive Program Microturbine Capital Costs

	N	Capital Costs ($/kW)				
		Mean	Median	Min	Max	SGIP Incentive
250 kW MCFC (Natural Gas)	1	6979	6979	6979	6979	2500
250 kW MCFC (Renewable)	2	9352	9352	9304	9400	4500
1000 kW MCFC	1	7000	7000	7000	7000	2500
200 kW PAFC	3	10677	7098	6934	18000	2500

Source: SDG&E, Mid-Atlantic CHP Application Center

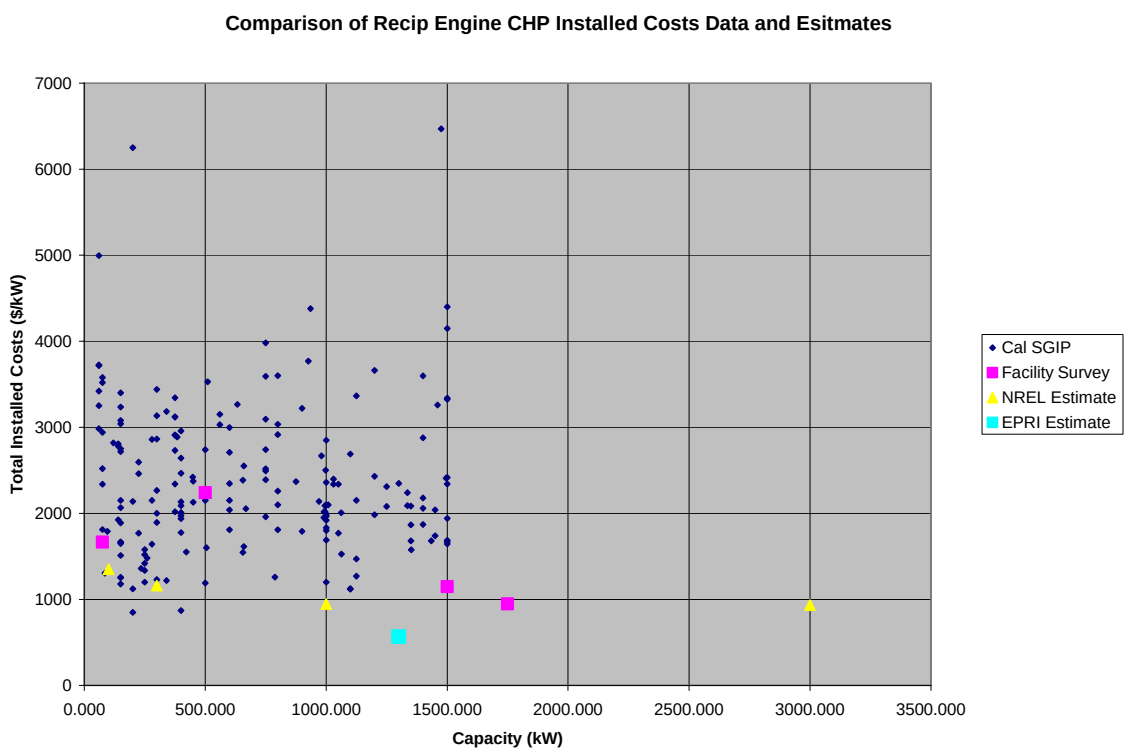
Table 21: California Self-Generation Incentive Program Fuel Cell Capital Costs

Summary of Installation Cost Comparison

In this chapter of the report, the installed cost estimates and data reviewed for this project are consolidated. Due to the different components/categories of installed costs used by the various sources, only total installed costs are compared. It is clear that installation costs can have significant variation from one project to another. Figures 17 thru 20 show the variation in installation cost ranges for the four primary sources covered in this report for various CHP technology classes. Table 22 summarizes the total cost data from the sources.

- NREL DER Technology Characterizations
- EPRI DG Installation, Operations and Maintenance Costs
- CHP Facility Survey
- California Self-Generation Incentive Program

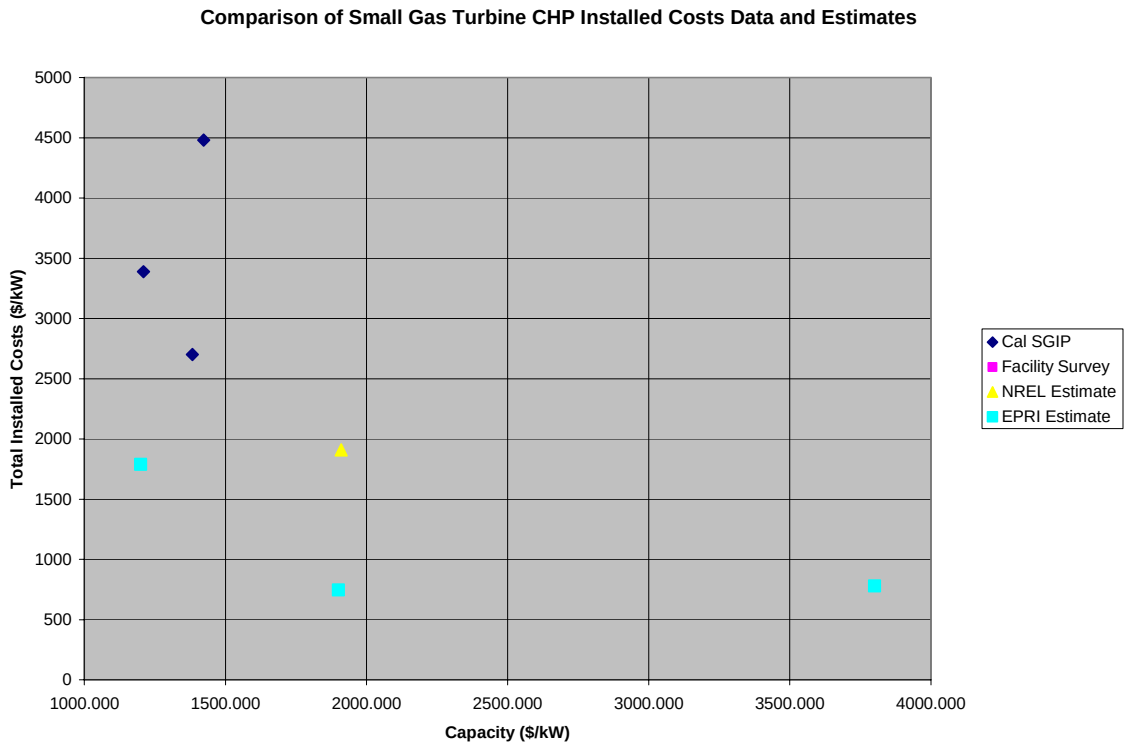
Reciprocating Engines Installed Costs Data and Estimates



Source: EEA

Figure 17: Comparison of Total Installed Costs for Reciprocating Engines

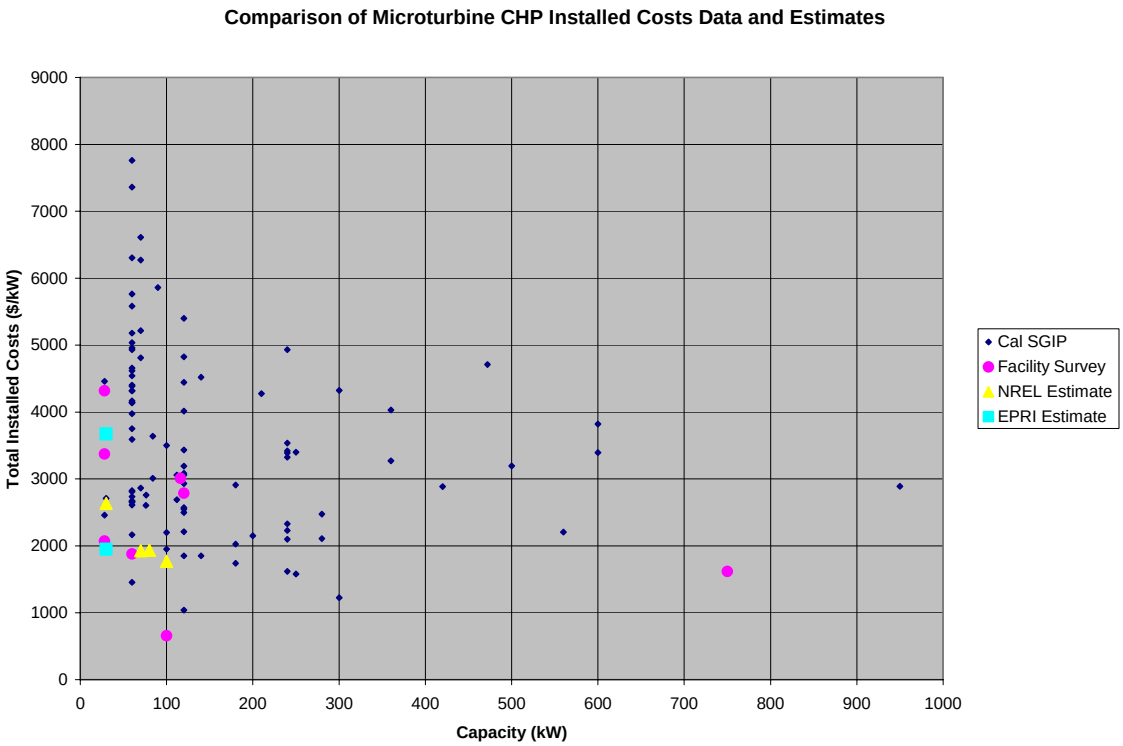
Gas Turbines Installed Cost Data and Estimates



Source: EEA

Figure 18: Comparison of Total Installed Costs for Gas Turbines

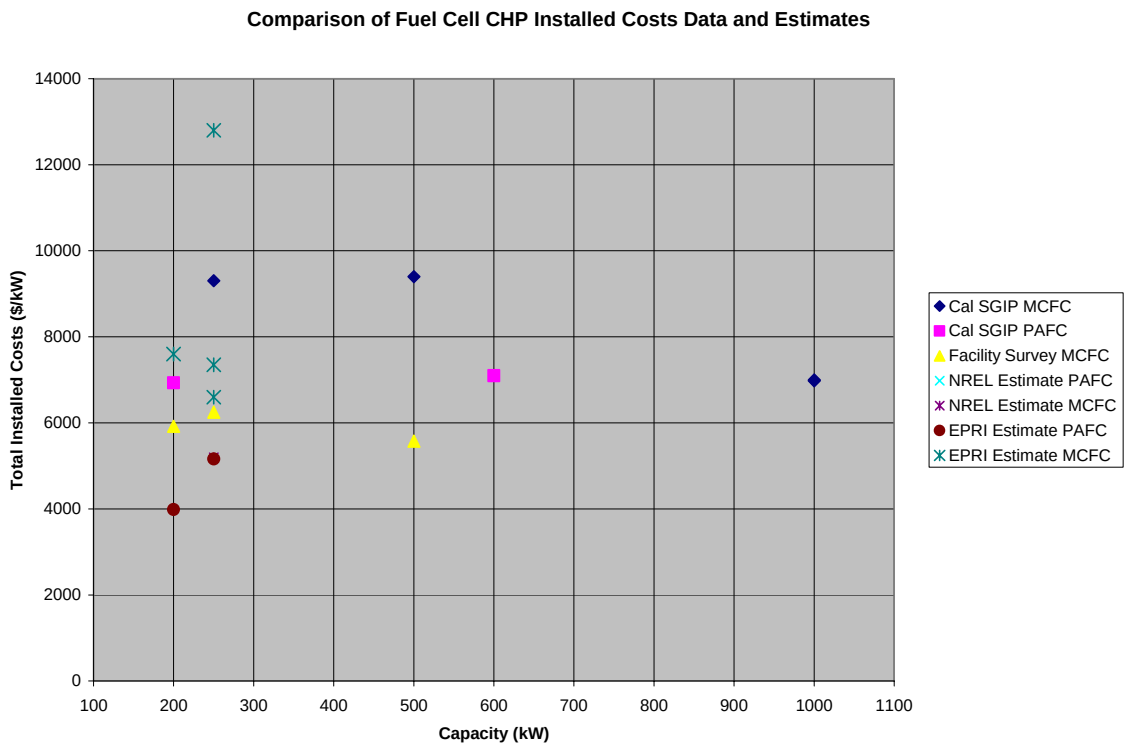
Microturbine Installed Cost Data and Estimates



Source: EEA

Figure 19: Comparison of Total Installed Costs for Microturbines

Fuel Cell Installed Cost Data and Estimates



Source: EEA

Figure 20: Comparison of Total Installed Costs for Fuel Cells

Cost Ranges ($/kW)

CHP Technology	Facility Capacity Range (kW)	Median Total Installed Costs ($/kW)	Total Installed Cost Range ($/kW)
Reciprocating Engine	60-3000	2150	566-6467
Gas Turbine	1200-3800	1910	746-4481
Microturbine	28-950	3072	657-7758
Fuel Cells	200-1000	6956	3986-12800

Source: EEA

Table 22: Summary of Installed Cost Data

Selected observations include:

- Total installed costs of CHP systems less than 3 MW are still high.
- Not surprisingly reciprocating engine and gas turbine installed costs are considerably lower than the emerging and newly commercial technologies
- The installed cost data for gas turbines of this size (<3 MW) is very limited. The low number of data points from the SGIP (especially relative the number of reciprocating engine and microturbine sites in the program) is consistent with the attempts in this project to find a reasonable number gas turbine facilities to include in the sample. This is due the dominant competitive economic position of reciprocating engines over gas turbines. Heat recovery and/or emissions control can add significantly to the cost of gas turbine systems.
- Estimates from both NREL and EPRI for reciprocating engines systems appear lower than the actual recent market activity. The SGIP and facility survey data show installed costs substantially higher than both industry estimates,
- Microturbine installed costs were actually considerably higher than manufacturer price quotes and forecasts over the timeframe assessed. The data from actual facility applications demonstrate significantly higher costs than for mature technologies.
- Fuel cell installation costs are shown to be high but are still uncertain. All the actual facility installations with fuel cells had some form of subsidy. Many were part of demonstration programs that have additional costs and technical features associated with them that would not be part of a truly commercial project.

Potential for Installed Costs Reduction

As documented above, CHP systems have high installed costs. These costs have been a historical barrier to widespread market adoption despite numerous studies identifying high technical market potential. The high costs to implement a project are due to several factors:

- Most project are developed on a customer or site specific basis this results in a lack of standardization of design and packaging
- The current small CHP market comprised of component suppliers who are the dominant players in the market and a diverse set of system integrators that on their own cannot achieve quantities of sales to reduce costs
- While traditional CHP technologies such as reciprocating engines and gas turbines have proven levels of performance and established sales/support networks that provide some degree of certainty to equipment and installation costs, the emerging technologies are still experiencing notable "growing pains" and are still developing their costs
- Costs are typically assessed on a $/kW basis. This obviously penalizes the smaller CHP systems which may have many of the same installation requirements of smaller systems but a lower output capacity on which to spread those costs.

There are several approaches and opportunities that offer the potential for significant potential for reducing installed costs. They include:

- Industry Standardization of Design and Shared Experiences in "Soft Costs"
- Modular Packaged Systems Approaches
- Experience/Learning Curve
- R&D and Technology Breakthroughs
- Quantity Production

Standardization of Design and Shared Experiences with "Soft Costs"

The current small CHP market is primarily is "project-based" rather than "product-based". Due to the unique features of most installations with regard energy loads, physical constraints (especially with retrofit projects), utility tariffs, and price and access to fuel systems are for the most part custom built. The process of identifying, evaluating, developing conceptual design, engineering, and integrating the CHP components is done on a project by project basis. This barrier to increased deployment is inherent in most commercial and industrial equipment/facility retrofit markets.

Several components are on track to improved standardization – switchgear/interconnect and fuel compressors. With recent interconnection standards, declines in both the equipment and process should be reduced. Heat recovery units and emissions control aftertreatment can be further integrated and standardized. Methods to achieve this include harmonization of emissions requirements across broader geographical areas and clearer understanding the thermal loads of specific small CHP target markets. Universal

standardization in likely not possible due to the diversity of the customers, but sector-specific or region-specific standardization would enhance the market.

Periodic documentation and transfer of the lessons learned on project "soft costs" through national or regional industry associations would help standardize the project develop process and avoid financial pitfalls. "Soft costs" include labor, fees for permits and construction financing interest. As seen in this project, these "soft costs" become a driver when they begin to exceed the expected norm for various reasons. They increase both as active costs to complete the project or as simple holding costs until the project is complete and project revenues begin. The later was particularly true for fuel cell projects in the facility survey.

Modular Packaged System Approaches

This concept is a natural follow up and complement to the standardization discussion above. For enhanced marketability, small CHP component manufacturers need to create integrated systems that can easily and simply match the generation and heat recovery/utilization components together,. Some refer to this as "plug-and-play" modular systems. These potential systems have the following attributes:

- The power and thermal loads are well matched within the system
- Effective and standardized communication protocols between components within the system
- Standardized communication with external energy control devices

Designing modular packaged systems for small CHP systems will go a long way toward reducing the time and effort required to integrate system components. Universal connection standards would greatly simplify installation and maintenance. Simplified, pre-engineered, skid-mounted CHP systems would make building owners responsible only for connecting power, piping, and ducting. Controls may be connected to a local network, permitting onsite personnel to operate the equipment either directly or remotely from a PC.

Industry, government and academia have recognized the need for such systems. The U.S. Department of Energy (DOE) has an ongoing program with private industry partners to develop modular packaged systems.

Experience Curve

Experience curve is the name applied in 1966 to overall cost behavior by The Boston Consulting Group (BCG). The name was selected to distinguish this phenomenon from the well known and well documented learning curve effect. The two are related, but quite different. It has been known for many years that labor hours per unit declined on repetitive tasks. This effect was particularly easy to observe in such things as aircraft production in wartime. The rate of labor decrease was characteristically 10-15 percent approximately per doubling of experience. This expectation has long been a part of

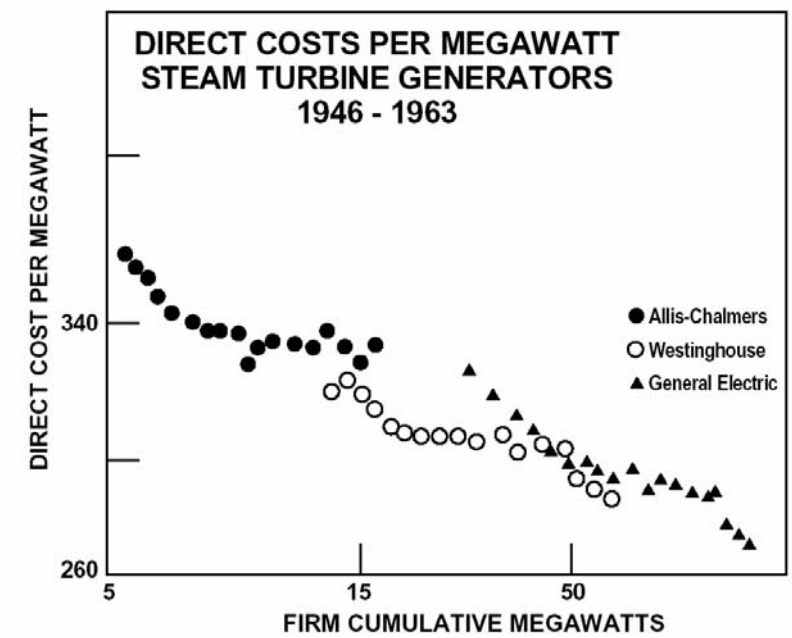
military contracting. The so-called learning curve effect apparently had somewhat limited application, however. It only applied to direct labor. Unless the job changed, this meant the time required to obtain a given cost decline tended to double each cycle of experience. This masked the far reaching implication of the possibilities of job element management with volume changes. Experience curve effect extends the same basic principle beyond simply labor. BCG's first effort to formulate the experience curve concept was an attempt to explain cost behavior over time in a process industry. Empirical data has historically shown that production cost decline by certain percentage for each doubling of cumulative quantity.

The experience curve and learning curve apply in most situations. They include:

- Labor Efficiency - Workers become mentally more confident and spend less time hesitating, learning, experimenting, or making mistakes. Over time we learn short-cuts and improvements. This applies to all employees and managers, not just those directly involved in production.
- Standardization, Specialization, and Methods Improvements - As processes, parts, and products become more standardized, efficiency tends to increase. When employees specialize in a limited set of tasks, they gain more experience with these tasks and operate at a faster rate.
- Technology-Driven Learning - Automated production technology and information technology can introduce efficiencies as they are implemented and people learn how to use them efficiently and effectively.
- Changes in the Resource Mix - As a company acquires experience, it can alter its mix of inputs and thereby become more efficient.
- Product Redesign - As consumers have more experience with the product, they can suggest improvements. This filters through to the manufacturing process
- Value Chain Effects - Experience curve effects affect suppliers and distributors will also ride down the learning curve, making the whole value chain more efficient.
- Shared Experience Effects - Experience curve effects are reinforced when two or more products share a common activity or resource. Any efficiencies learned from one product can be applied to the other products.

The experience curve effect canbe observed and measured in almost any business or industry. Different products proceed along their own experience curves. A study by Gas Research Institute[10] in the late 1980's found that prepackaged cogernation unit manufacturing had an 85-90% experience curve, i.e., decreases of 10-15% in cost with each doubling of cumulative production. Figure 21 shows the experience curve effect in early steam turbine generators.

[10] GRI-88/0053 *Cost Reduction in the Manufacture and Installation of Gas-Fired Prepackaged Cogeneration Systems*



Source: Boston Consulting Group

Figure 21: Experience Curve Effect in Steam Turbine Generators

In the application to small CHP, we have a relatively complex system of components (both equipment and process) each with their own experience curve. This means for example that while some prime mover technologies such as autoderivative reciprocating engines may have clear and established experience curves coupled with high historical cummulative production, other components such as low volume small absorption chillers may not have progressed far at all along their experience curve.

An example of this phenomenon was discussed in earlier in the report with regard to small reciprocaitng engines. In contrast to other types of power generation equipment, engines exhibit negative economies of scale ($/kW cost increases with size). Generally, a company's most expensive engines are large, low-speed, state-of-the-art engines that are also its most efficient and lowest emission engines. Its lower cost models tend to be its older, smaller, higher-speed, reliable, rugged, and more popular engines. The lower cost models are often rich burn (while the most expensive gas engines are lean-burn), have lower BMEP, lower compression ratio, and less advanced engine control systems.

A follow-up study could assess the experience curve of CHP systems, not necessarily their individual equipment components. The results of this study provide the baseline of information which could be periodically updated to determine cost improvements.

R&D and Technology Breakthroughs

Technology breakthroughs in both products and production methods can reduce costs. For example, fuel cells stack costs were reducted ten-fold with research and development that led to a dramatic decrease in platinum loading. Production and process improvements due to enabling manufacuturing technologies enhance productivity.

With regard to installion costs and in following up with the previous discussion on modular packaged systems, research and development in universal communications and controls that allow for actual “plug and play” CHP systems and simple integration with existing facility/building contol systems.

Research and development in heat recovery and utilization tecnologies can bring down costs of thermally activated technologies such as absorption cooling and desiccant dehumidification that may enhance small CHP marketability.

Quantity Production

The experience curve effect produces reduces unit costs as more units are produced. However, there are other forces that will also allow the cost per unit to decrease when the quantity involved increases. For example, there is the "quantity discount" effect. The average unit cost can be lowered as the quantity involved increases, but not for the reason of "learning." Items that are standard and have already been produced in large quantities may have reached "standard time" for the production process, with little room left for learning. In this case, the predominant influence on cost reductions may become the quantity discount that the manufacturer is willing to "pass-along" due to:

- Competition,
- Economies of scale, and
- Reduced fixed cost per unit.

Some components of the small CHP systems may have reached this level, e.g., components of engines used in a wide variety and much larger applications than simply CHP. Continually increasing production volumes of some components are will inevitably reduce unit costs.

References

Gas Research Institute, GRI-88/0053, *Cost Reducion in Manufacture and Installation of Gas-Fired Prepackaged Cogeneration Systems*, 1988.

Bautista, P.J., "The U.S. Stationary Fuel Cell Market: What Does the Future Hold?", POWER-GEN International, December 2004.

Cordova, C.J., Bautista, P.J., Darrow, K.G., *Market Potential for Thermally Activated Building Combined Heat and Power in Five National Account Sectors*, Oak Ridge National Laboratory, May 2003.

Cordova, C.J., Bautista, P.J., Darrow, K.G., *National Account Energy Sector Profiles*, Oak Ridge National Laboratory," April 2003.

Bautista, P.J., Fay, J.M., "The Drive to DG Project Implementation Efficiency – Benefits and Best Practices," Electric Power, March 2003.

Installation, Operation, and Maintenance Costs for Distributed Generation Technologies, EPRI, Palo Alto, CA, 2002.

Onsite Energy, Bautista, P.J., Freedman, S.I., "*Small Gas Turbines for Distributed Generation Markets – Technology, Products, and Business Issues*," EPRI/GTI, GTI-00/0219, December 2000.

National Renewable Energy Laboratory, Gas-Fired Distributed Energy Resource Technology Characterizations, October 2003.

Boston Consulting Group, Perspectives No. 125: The Experience Curve Reviewed, 1973.

Margolis, R.M., Photovoltaic Technology Experience Curves and Markets, NCPV and Solar Program Review Meeting, March 2003.

Reicher, Curtis, McNamara, *Energy User News*, Risk and Cost in Small-Scale DG Projects, July 2003.

Cooling, Heating, and Power of Buildings Website, www.bchp.org.

Binder, M.J., Taylor, W.R., Holcomb, F.H., Experience with the DOD Fleet of 30 Fuel Cell Generators, Proceedings from International Gas Research, November 2001.

San Diego Regional Energy Office Website, www.sdreo.org.

Appendix: Site Survey Data

Microturbine Installed Costs
30 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	30,945		
Fuel Gas Compressor	None	Specify suction side and pressure side pressures	
Heat Recovery Unit	8,256	Specify steam/hot water conditions, and if integrated into packages system	Heat exchanger is separate and genertes 130 F hot water
Heat Recovery Ducting/Valves	365		
Controls and Monitoring (incremental to generator set package standard controls)	1,684		
Electrical Interconnection and Switchgear Systems			
Utility Tie-In	800	Specify generator type, and blackstart capability	
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)	525		
Miscellaneous Equipment (e.g. safety controls and monitoring, cabinet ventilation fans, and other misc components)			
Miscellaneous Warranties	5,250	Specify miscellaneous warraties	
		Specify site conditions and physical constraints	
Installation Labor/Materials			
Civil Installation			
Electrical Installation	3,522		
Mechanical Installation	2,890		
Site Restoration			
Miscellaneous Materials	897	Specify miscellaneous materials	
Engineering and Fees			
Feasibility Studies	2,000		
Interconnection Studies			
Conceptual Design			
Final Design and Engineering	445		
Regulatory and Building Code Approvals			
Air Permit (if applicable)			
Miscellaneous Inspections/Approvals	426	Specify misc inspections/approvals	
Miscellaneous Subcontracts		Specify misc subcontracts	
Project Financing		Specify interest during construction	
Start Up and Commissioning			
Contingency			
Grants, Gov't Incentive Programs		Specify if state or federal programs	
California Sales Tax	3,023		
	61,028		

Microturbine Installed Costs
30 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	$36,110		
Fuel Gas Compressor		Specify suction side and pressure side pressures	
Heat Recovery Unit	$10,489	Specify steam/hot water conditions, and if integrated into packages system	hot water system used to heat swimming pool
Heat Recovery Ducting/Valves			
Controls and Monitoring (incremental to generator set package standard controls)	$225		
Electrical Interconnection and Switchgear Systems			
Utility Tie-In		Specify generator type, and blackstart capability	Capstone Model 330 Low Pressure Grid Connected Microturbine System
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)	$300		
Miscellaneous Equipment (e.g. safety controls and monitoring, cabinet ventilation fans, and other misc components)	$1,590	Silencer	
Miscellaneous Warranties		Specify miscellaneous warranties	NA
Total Equipment Cost	$48,714		
		Specify site conditions and physical constraints	Installed on roof of hotel
Installation Labor/Materials			
Civil Installation			
Electrical Installation			
Mechanical Installation			
Site Restoration			
Miscellaneous Materials		Specify miscellaneous materials	
Total Installation Cost	$35,698		
Engineering and Fees			
Feasibility Studies			
Interconnection Studies			
Conceptual Design			
Final Design and Engineering	$10,000		
Regulatory and Building Code Approvals			
Air Permit (if applicable)			
Miscellaneous Inspections/Approvals		Specify misc inspections/approvals	
Miscellaneous Subcontracts		Specify misc subcontracts	NA
Project Financing		Specify interest during construction	NA
Start Up and Commissioning			
Contingency			
Grants, Gov't Incentive Programs		Specify if state or federal programs	NA
	$94,412		

Reciprocating Engine Installed Costs

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	400000		
Fuel Gas Compressor		Specify suction side and pressure side pressures	
Inlet Air Conditioning		Specify cooling or filtration etc	
Heat Recovery Unit	100000	Specify steam/hot water conditions, and if integrated into packages system	150 psig steam from hrsgs and 210 F hot water from engines' jacket water
Two Yazaki Absorbers + Installation	45000		
Heat Recovery Ducting/Valves	5000		
Controls and Monitoring (incremental to generator set package standard controls)			
Electrical Interconnection and Switchgear Systems			
Utility Tie-In	73000	Specify generator type, and blackstart capability	Induction Generators
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)	5000		
Emissions Controls and Monitoring		Specify control technology and level of emissions required	
Water Treatment Equipment		Specify requirement and type of equipment used	
Miscellaneous Equipment			
Miscellaneous Warranties	156600	Specify miscellaneous warraties	Maintenance Contract
		Specify site conditions and physical constraints	
Installation Labor/Materials			
Civil Installation			
Electrical Installation			
Mechanical Installation			
Site Restoration			
Miscellaneous Materials	189000	Specify miscellaneous materials	Total Installation
Engineering and Fees			
Feasibility Studies	28000		
Interconnection Studies			
Conceptual Design			
Final Design and Engineering	100000		
Regulatory and Building Code Approvals			
Air Permit			
Emissions Testing			
Miscellaneous Inspections/Approvals	18000	Specify misc inspections/approvals	All Permits
Miscellaneous Subcontracts		Specify misc subcontracts	
Project Financing		Specify interest during construction	
Start Up and Commissioning			
Contingency			
Grants, Gov't Incentive Programs		Specify if state or federal programs	

Microturbine Installed Costs

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	33,165		
Fuel Gas Compressor	Incl	Specify suction side and pressure side pressures	
Heat Recovery Unit	13,575	Specify steam/hot water conditions, and if integrated into packages system	
Heat Recovery Ducting/Valves			
Controls and Monitoring (incremental to generator set package standard controls)			
Electrical Interconnection and Switchgear Systems			
Utility Tie-In	800	Specify generator type, and blackstart capability	
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)	1,630		
Miscellaneous Equipment (e.g. safety controls and monitoring, cabinet ventilation fans, and other misc components)			
Miscellaneous Warranties		Specify miscellaneous warraties	
		Specify site conditions and physical constraints	Built in an existing parking structure, there was a long run from the heat exchanger to the existing pool heaters.
Installation Labor/Materials			
Civil Installation			
Electrical Installation			
Mechanical Installation			
Site Restoration			
Miscellaneous Materials		Specify miscellaneous materials	
Total:	56,424		
Engineering and Fees			
Feasibility Studies			
Interconnection Studies			
Conceptual Design			
Final Design and Engineering	12,386		
Regulatory and Building Code Approvals			
Air Permit (if applicable)			
Miscellaneous Inspections/Approvals	2,897	Specify misc inspections/approvals	Building Permit
Miscellaneous Subcontracts		Specify misc subcontracts	
Project Financing		Specify interest during construction	
Start Up and Commissioning			
Contingency			
Grants, Gov't Incentive Programs		Specify if state or federal programs	SoCalGas Self Generation Program Grant
	120,877		

Reciprocating Engine Installed Costs
75 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	50000		
Fuel Gas Compressor		Specify suction side and pressure side pressures	
Inlet Air Conditioning		Specify cooling or filtration etc	
Heat Recovery Unit		Specify steam/hot water conditions, and if integrated into packages system	Hot waster heat recovery 470,000 Btu/hr
Heat Recovery Ducting/Valves			
Controls and Monitoring (incremental to generator set package standard controls)	7500		
Electrical Interconnection and Switchgear Systems	10000		
Utility Tie-In	7500	Specify generator type, and blackstart capability	Induction, no blackstart
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)			
Emissions Controls and Monitoring		Specify control technology and level of emissions required	
Water Treatment Equipment		Specify requirement and type of equipment used	
Miscellaneous Equipment			
Miscellaneous Warranties		Specify miscellaneous warranties	
		Specify site conditions and physical constraints	
Installation Labor/Materials			
Civil Installation			
Electrical Installation	15000		
Mechanical Installation	17500		
Site Restoration			
Miscellaneous Materials		Specify miscellaneous materials	
Engineering and Fees			
Feasibility Studies			
Interconnection Studies			
Conceptual Design	7500		
Final Design and Engineering	7500		
Regulatory and Building Code Approvals			
Air Permit			
Emissions Testing			
Miscellaneous Inspections/Approvals	1500	Specify misc inspections/approvals	Electric and gas permits
Miscellaneous Subcontracts		Specify misc subcontracts	
Project Financing		Specify interest during construction	
Start Up and Commissioning	1000		
Contingency			
Grants, Gov't Incentive Programs		Specify if state or federal programs	

Gas Engine Installed Costs
1750 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	$ 516,729.00		
Fuel Gas Compressor	N/A	Specify suction side and pressure side pressures	
Inlet Air Conditioning	N/A	Specify cooling or filtration etc	
Heat Recovery Unit	$ 128,000.00	Specify steam/hot water conditions, and if HRSG is fired or unfired	80 PSI Steam
Heat Recovery Ducting/Valves			4000 lb/hr
Controls and Monitoring (incremental to generator set package standard controls)	$ 21,875.00		
Electrical Interconnection and Switchgear Systems	$ 209,560.00		Cummins QSV91GB
Utility Tie-In	$166,000.00	Specify generator type, and blackstart capability	1,750 no black start
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)	$ 26,500.00		
Emissions Controls and Monitoring		Specify control technology and level of emissions required	Lean Burn
Water Treatment Equipment	$500.00	Specify requirement and type of equipment used	
Miscellaneous Equipment	N/A		
Miscellaneous Warranties		Specify miscellaneous warranties	
		Specify site conditions and physical constraints	In existing building
Installation Labor/Materials			
Civil Installation	$ 69,099.00		
Electrical Installation	$ 206,800.00		
Mechanical Installation	$ 220,500.00		
Site Restoration			
Miscellaneous Materials		Specify miscellaneous materials	
Engineering and Fees			
Feasibility Studies			
Interconnection Studies			
Conceptual Design	$ 8,287.00		
Final Design and Engineering	$ 10,187.00		
Regulatory and Building Code Approvals			
Air Permit			
Emissions Testing			
Miscellaneous Inspections/Approvals	$ 5,000.00	Specify misc inspections/approvals	
Miscellaneous Subcontracts	$ 70,000.00	Specify misc subcontracts	
Project Financing		Specify interest during construction	
Start Up and Commissioning			
Contingency			
Grants, Gov't Incentive Programs	$ 1,840,684.00	Specify if state or federal programs	

Reciprocating Engine Installed Costs
***Costs are per unit (2 units)** 1500 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	376700		
Fuel Gas Compressor		Specify suction side and pressure side pressures	Not Required
Inlet Air Conditioning		Specify cooling or filtration etc	Not Required
Heat Recovery Unit	25200	Specify steam/hot water conditions, and if integrated into packages system	hot water used to heat boiler loop and absorber
Heat Recovery Ducting/Valves			
Controls and Monitoring (incremental to generator set package standard controls)	99100		
Electrical Interconnection and Switchgear Systems	139500		
Utility Tie-In	50000	Specify generator type, and blackstart capability	750 kW synchronous - parallel Yes blackstart capable
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)			
Emissions Controls and Monitoring	5000	Specify control technology and level of emissions required	Testing only
Water Treatment Equipment	10000	Specify requirement and type of equipment used	Filter
Miscellaneous Equipment	127200		
Miscellaneous Warranties		Specify miscellaneous warranties	
		Specify site conditions and physical constraints	Limited access site.
Installation Labor/Materials			
Civil Installation			
Electrical Installation	136700		
Mechanical Installation	296500		
Site Restoration			
Miscellaneous Materials		Specify miscellaneous materials	
Engineering and Fees			
Feasibility Studies	200000		
Interconnection Studies			
Conceptual Design			
Final Design and Engineering	159700		
Regulatory and Building Code Approvals			
Air Permit	5000		
Emissions Testing	1500		
Miscellaneous Inspections/Approvals		Specify misc inspections/approvals	Utility interconnect approval and witness test.
Miscellaneous Subcontracts		Specify misc subcontracts	
Project Financing		Specify interest during construction	
Start Up and Commissioning	90000		
Contingency			
Grants, Gov't Incentive Programs	65000	Specify if state or federal programs	NYSERDA

Fuel Cell Installed Costs
250 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	1017000		
Mechanical Balance of Plant			
Power Electronic Balance of Plant			
Heat Recovery Unit	41200	Specify steam/hot water conditions, and if integrated into packages system	150 deg F hot water, separate
Heat Recovery Ducting/Valves			
Controls and Monitoring (incremental to generator set package standard controls)	11800		
Electrical Interconnection and Switchgear Systems			
Utility Tie-In		Specify generator type, and blackstart capability	250 kW fuel cell
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)			
Miscellaneous Equipment (e.g. safety controls and monitoring, cabinet ventilation fans, and other misc components)			
Miscellaneous Warranties		Specify miscellaneous warranties	
		Specify site conditions and physical constraints	open grassy area
Installation Labor/Materials			
Civil Installation	129510		
Electrical Installation	143000		
Mechanical Installation	102200		
Site Restoration			
Miscellaneous Materials	18000	Specify miscellaneous materials	delivery & rigging
Engineering and Fees			
Feasibility Studies	10000		
Interconnection Studies			
Conceptual Design	10000		
Final Design and Engineering	19000		
Regulatory and Building Code Approvals			
Air Permit (if applicable)	0		
Miscellaneous Inspections/Approvals	4000	Specify misc inspections/approvals	electrical, building
Miscellaneous Subcontracts		Specify misc subcontracts	
Project Financing	45000	Specify interest during construction	yes
Start Up and Commissioning	12000		
Contingency			
Grants, Gov't Incentive Programs	1110000	Specify if state or federal programs	state + federal

Fuel Cell Installed Costs
250 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	1017000		
Mechanical Balance of Plant			
Power Electronic Balance of Plant			
Heat Recovery Unit	41200	Specify steam/hot water conditions, and if integrated into packages system	150 deg F hot water, separate
Heat Recovery Ducting/Valves			
Controls and Monitoring (incremental to generator set package standard controls)	11800		
Electrical Interconnection and Switchgear Systems			
Utility Tie-In		Specify generator type, and blackstart capability	250 kW fuel cell
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)			
Miscellaneous Equipment (e.g. safety controls and monitoring, cabinet ventilation fans, and other misc components)			
Miscellaneous Warranties		Specify miscellaneous warranties	
		Specify site conditions and physical constraints	open grassy area
Installation Labor/Materials			
Civil Installation	55000		
Electrical Installation	96500		
Mechanical Installation	54300		
Site Restoration			
Miscellaneous Materials	18000	Specify miscellaneous materials	delivery & rigging
Engineering and Fees			
Feasibility Studies	10000		
Interconnection Studies			
Conceptual Design	10000		
Final Design and Engineering	19000		
Regulatory and Building Code Approvals			
Air Permit (if applicable)	0		
Miscellaneous Inspections/Approvals	4000	Specify misc inspections/approvals	electrical, building
Miscellaneous Subcontracts		Specify misc subcontracts	
Project Financing	45000	Specify interest during construction	yes
Start Up and Commissioning	12000		
Contingency			
Grants, Gov't Incentive Programs	860000	Specify if state or federal programs	state
	2253800		

Microturbine Installed Costs
60 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	$49,430		
Fuel Gas Compressor	$6,375	Specify suction side and pressure side pressures	
Heat Recovery Unit	$7,518	Specify steam/hot water conditions, and if integrated into packages system	Never Used
Heat Recovery Ducting/Valves			
Controls and Monitoring (incremental to generator set package standard controls)	$225		
Electrical Interconnection and Switchgear Systems			
Utility Tie-In		Specify generator type, and blackstart capability	Capstone C60 Grid Connected Microturbine System
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)	$525		
Miscellaneous Equipment (e.g. safety controls and monitoring, cabinet ventilation fans, and other misc components)	$1,760	Remote operating software	
Miscellaneous Warranties		Specify miscellaneous warranties	NA
Total Equipment cost	$65,833		
		Specify site conditions and physical constraints	Installed inside boiler room, limited space
Installation Labor/Materials			
Civil Installation			
Electrical Installation			
Mechanical Installation			
Site Restoration			
Miscellaneous Materials		Specify miscellaneous materials	
Total Installation Cost	$31,882		
Engineering and Fees			
Feasibility Studies			
Interconnection Studies			
Conceptual Design			
Final Design and Engineering	$15,000		
Regulatory and Building Code Approvals			
Air Permit (if applicable)			
Miscellaneous Inspections/Approvals		Specify misc inspections/approvals	
Miscellaneous Subcontracts		Specify misc subcontracts	NA
Project Financing		Specify interest during construction	NA
Start Up and Commissioning			
Contingency			
Grants, Gov't Incentive Programs		Specify if state or federal programs	NA
	$112,715		

Microturbine Installed Costs

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	$114,704		
Fuel Gas Compressor	$22,000	Specify suction side and pressure side pressures	5 psig
Heat Recovery Unit		Specify steam/hot water conditions, and if integrated into packages system	Waste heat recovery integrated into engines
Heat Recovery Ducting/Valves			
Controls and Monitoring (incremental to generator set package standard controls)			
Electrical Interconnection and Switchgear Systems			
Utility Tie-In		Specify generator type, and blackstart capability	
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)			
Miscellaneous Equipment (e.g. safety controls and monitoring, cabinet ventilation fans, and other misc components)	$30,000		Absorption Chiller+Installation
Miscellaneous Warranties	$38,000	Specify miscellaneous warraties	3 yr maintenance agreement
		Specify site conditions and physical constraints	
Installation Labor/Materials			
Civil Installation	$84,445		
Electrical Installation	$33,210		
Mechanical Installation	$7,900		
Site Restoration			
Miscellaneous Materials		Specify miscellaneous materials	
Engineering and Fees			
Feasibility Studies	$5,500		
Interconnection Studies			
Conceptual Design			
Final Design and Engineering	$9,765		
Regulatory and Building Code Approvals			
Air Permit (if applicable)			
Miscellaneous Inspections/Approvals	$3,800	Specify misc inspections/approvals	Building Permit
Miscellaneous Subcontracts		Specify misc subcontracts	
Project Financing		Specify interest during construction	
Start Up and Commissioning			
Contingency			
Grants, Gov't Incentive Programs		Specify if state or federal programs	
Sales Tax	$7,852		

Steam Turbine Installed Costs
3000 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Steam Turbine/Generator	801520		
Mechanical Balance of Plant		Specify steam conditions	450psi/650F
Steam Ducting/Valves	343000		
Controls and Monitoring (incremental to generator package	Inclu in below		
Electrical Interconnection and Switchgear Systems	457637		
Utility Tie-In	91367		
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)	36000		
Miscellaneous Equipment (e.g. safety controls and monitoring, and other misc components)	15000		
Miscellaneous Warranties		Specify miscellaneous warranties	1yr parts on the Turbine
		Specify site conditions and physical constraints	Winter conditions during cons
Installation Labor/Materials			
Civil Installation			
Electrical Installation			
Mechanical Installation			
Site Restoration			
Total CM cost incl 17,18,19	1136600	Specify miscellaneous materials	
Engineering and Fees			
Feasibility Studies			
Interconnection Studies	9500		
Conceptual Design			
Final Design and Engineering	350000		
Regulatory and Building Code Approvals			
Air Permit (if applicable)	500		
Miscellaneous Inspections/Approvals		Specify misc inspections/approvals	Building Inspection Town
Miscellaneous Subcontracts		Specify misc subcontracts	
Project Financing		Specify interest during construction	
Start Up and Commissioning	10000		
Contingency			
Grants, Gov't Incentive Programs		Specify if state or federal programs	

Fuel Cell Installed Costs
250 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	2,200,000		
Mechanical Balance of Plant			
Power Electronic Balance of Plant			
Heat Recovery Unit	60,649	Specify steam/hot water conditions, and if integrated into packages system	Heat recovery units at fuel cells recover heat from fuel cell exhaust. Heat transfer by glycol solution in underground hydronic piping to heat exchanger in company headquarters building basement that preheats boiler supply water.
Heat Recovery Ducting/Valves	59,653		
Controls and Monitoring (incremental to generator set package standard controls)	3,780		
Electrical Interconnection and Switchgear Systems	236,222		
Utility Tie-In	16,949	Specify generator type, and blackstart capability	
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)			
Miscellaneous Equipment (e.g. safety controls and monitoring, cabinet ventilation fans, and other misc components)	2,962		
Miscellaneous Warranties		Specify miscellaneous warranties	
		Specify site conditions and physical constraints	No physical constraints. Constructed on level ground next to company headquarters building.
Installation Labor/Materials			
Civil Installation	12,144		
Electrical Installation	97,517		
Mechanical Installation	40,286		
Site Restoration			
Miscellaneous Materials	11,456	Specify miscellaneous materials	insulation, hardware
Engineering and Fees			
Feasibility Studies			
Interconnection Studies	2,100		
Conceptual Design			
Final Design and Engineering	63,365		
Regulatory and Building Code Approvals			
Air Permit (if applicable)			
Miscellaneous Inspections/Approvals	200	Specify misc inspections/approvals	Montana State building permit for service gear building
Miscellaneous Subcontracts	118,131	Specify misc subcontracts	service gear building & fenced enclosure;rigging & transport;installation oversight
Project Financing	1,164,000	Specify interest during construction	
Start Up and Commissioning	35,000		
Contingency			
Grants, Gov't Incentive Programs	1,410,000	Specify if state or federal programs	DOE

Microturbine Installed Costs
120 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	101832		
Fuel Gas Compressor	13950	Specify suction side and pressure side pressures	10 psi / 75 psi
Heat Recovery Unit	18390	Specify steam/hot water conditions, and if integrated into packages system	Hot water
Heat Recovery Ducting/Valves	13977		
Controls and Monitoring (incremental to generator set package standard controls)	19699		
Electrical Interconnection and Switchgear Systems	7000		
Utility Tie-In	1800	Specify generator type, and blackstart capability	Capstone C60 GC/SA
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)	7000		
Miscellaneous Equipment (e.g. safety controls and monitoring, cabinet ventilation fans, and other misc components)	15854		
Miscellaneous Warranties	1 year	Specify miscellaneous warranties	1 year
Installation Labor/Materials		Specify site conditions and physical constraints	Building erection
Civil Installation	14636		
Electrical Installation	40124		
Mechanical Installation	40124		
Site Restoration	0		
Miscellaneous Materials	333	Specify miscellaneous materials	misc. electrical
Engineering and Fees			
Feasibility Studies	8000		
Interconnection Studies	2000		
Conceptual Design	2233		
Final Design and Engineering	8000		
Regulatory and Building Code Approvals			
Air Permit (if applicable)	n/a		
Miscellaneous Inspections/Approvals	2000	Specify misc inspections/approvals	REMC consultant inspection
Miscellaneous Subcontracts	11101	Specify misc subcontracts	Photographers
Project Financing	n/a	Specify interest during construction	n/a
Start Up and Commissioning	6250		
Contingency			
Grants, Gov't Incentive Programs	100000	Specify if state or federal programs	State

Microturbine Installed Costs
100 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	$44,000		
Fuel Gas Compressor	included	Specify suction side and pressure side pressures	14 in wc, 15 psi
Heat Recovery Unit	included	Specify steam/hot water conditions, and if integrated into packages system	Hot Water
Heat Recovery Ducting/Valves	included		
Controls and Monitoring (incremental to generator set package standard controls)	included		
Electrical Interconnection and Switchgear Systems	$4,040		
Utility Tie-In	included	Specify generator type, and blackstart capability	Induction, no black start
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)	included		
Miscellaneous Equipment (e.g. safety controls and monitoring, cabinet ventilation fans, and other misc components)	included		
Miscellaneous Warranties	1 year	Specify miscellaneous warranties	none
		Specify site conditions and physical constraints	Large warehouse, no constraints
Installation Labor/Materials			
Civil Installation	1,000		
Electrical Installation	$7,000		
Mechanical Installation	$5,600		
Site Restoration	n/a		
Miscellaneous Materials	$83.80	Specify miscellaneous materials	relief valve
Engineering and Fees			
Feasibility Studies	$500		
Interconnection Studies	$500		
Conceptual Design	$500		
Final Design and Engineering	$500		
Regulatory and Building Code Approvals			
Air Permit (if applicable)	n/a		
Miscellaneous Inspections/Approvals	n/a	Specify misc inspections/approvals	n/a
Miscellaneous Subcontracts	n/a	Specify misc subcontracts	n/a
Project Financing	n/a	Specify interest during construction	n/a
Start Up and Commissioning	included		
Contingency	n/a		
Grants, Gov't Incentive Programs	0	Specify if state or federal programs	n/a

MictroTurbine Installed Costs
750 kW

	Actual Cost ($)	Additional Data Requested	Site Information
Equipment			
Generator Set Package	635,800.00		
Fuel Gas Compressor	42,000.00	Specify suction side and pressure side pressures	
Absorption Chiller	92,000.00	Specify cooling or filtration etc	
Heat Recovery Unit	46,700.00	Specify steam/hot water conditions, and if HRSG is fired or unfired	
Heat Recovery Ducting/Valves	21,500.00		
Controls and Monitoring (incremental to generator set package standard controls)	58,900.00		
Electrical Interconnection and Switchgear Systems	65,100.00		
Utility Tie-In	16,000.00	Specify generator type, and blackstart capability	
Fuel Systems (e.g. enhancements to gas service, additional metering, fuel cleanup)			
Emissions Controls and Monitoring		Specify control technology and level of emissions required	
Water Treatment Equipment	12,600.00	Specify requirement and type of equipment used	
Miscellaneous Equipment			
Miscellaneous Warranties		Specify miscellaneous warranties	
total	990,600.00		
		Specify site conditions and physical constraints	
Installation Labor/Materials			
Civil Installation	9,900.00		
Electrical Installation	21,000.00		
Mechanical Installation	120,000.00		
Site Restoration	10,000.00		
Miscellaneous Materials	6,000.00	Specify miscellaneous materials	
total	166,900.00		
Engineering and Fees			
Feasibility Studies	18,000.00		
Interconnection Studies	17,900.00		
Conceptual Design			
Final Design and Engineering	21,000.00		
total	56,900.00		
Regulatory and Building Code Approvals			
Air Permit			
Emissions Testing			
Miscellaneous Inspections/Approvals		Specify misc inspections/approvals	
total	0		
Miscellaneous Subcontracts		Specify misc subcontracts	
Project Financing		Specify interest during construction	
Start Up and Commissioning			
Contingency			
Grants, Gov't Incentive Programs		Specify if state or federal programs	
total	0		