Status of Waste Heat to Power Projects on Natural Gas Pipelines

November 2009

Prepared for:

Interstate Natural Gas Association of America

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1. INTRODUCTION

This report reviews the status of waste heat recovery to power projects on pipeline compressor drives in North America as of September 2009, and represents a follow-on analysis to the February 2008 report entitled "Waste Energy Recovery Opportunities for Interstate Natural Gas Pipelines" prepared for the Interstate Natural Gas Association of America (INGAA). INGAA requested this analysis to determine if any significant changes have occurred in the market for waste heat recovery projects since the release of the initial report, specifically in terms of new project development activities, the entry of new market players or technologies, and changes in market conditions that would impact the economic thresholds outlined in the original report. This follow-on review was conducted by interviewing waste heat recovery developers and equipment suppliers and by reviewing publicly-available information on project activity. This status report includes:

- A summary of existing and announced waste heat recovery to power projects on North American pipeline compressor stations.
- A review of current market drivers and incentives, and a discussion of recent market activity.
- A review of current and potential project participants, including pipelines, technology suppliers, and developers/operators.

Background

The 2008 report verified that waste heat recovery to power systems are economically viable in areas where power purchase prices include some incentive for clean energy (e.g., states where heat recovery qualifies as an option under a renewable portfolio standard), and where compressor capacity and load factor both are above certain minimums. The report concluded that near-term applications are and will remain for the foreseeable future limited to gas turbine drives that have higher exhaust temperatures and flows, and typically are larger than internal combustion engine drives.

The report concluded that economic feasibility of these projects can be evaluated with more certainty as a retrofit on existing compressor stations that have available operating histories. Based on current technologies and prevailing power prices, the report proposed that minimum hurdles for economic waste heat recovery projects are a (1) total gas turbine compressor station capacity of at least 15,000 hp and (2) stations which operate at or more than 5,250 hours per year over the previous 12 months (an annual load factor at or above 60 percent). The report estimated that 90 to 100 compressor stations in the United States meet these hurdles, representing approximately 500 to 600 megawatts (MW) of potential power generation capacity.

The report concluded that project feasibility is determined primarily by the price paid for the power generated. Project financial margins are narrow and systems were installed only in states or provinces where waste heat recovery qualified for some level of incentive in a renewable portfolio standard (RPS) or as a green power resource. Further, the report concluded that deployment of waste heat recovery could be enhanced best by a market-based approach to power purchases that recognizes the value of and rewards clean energy production, such as power produced from pipeline waste heat recovery. The report also noted that the market development of compressor heat recovery to power projects could be further promoted by providing modest incentives to pipelines. To this end, the report called for the FERC's affirmation that a pipeline's shareholders retain the revenues from the sale of waste heat to project developers as an incentive for pipelines to expend time and resources to work with such developers. The report also called for FERC to: (1) expressly exclude waste heat pipeline affiliates from the definition of the term "Marketing Affiliate" under the Commission's regulations; (2) confirm that gas turbine compressor exhaust, a waste product, is owned by the pipeline and not subject to recompense for the shippers' account; and (3) confirm that waste heat power generation assets and business are non-jurisdictional for ratemaking and certificate purposes.

Based on the information in the 2008 report and recognizing the need to promote increased energy efficiency, the pipelines established a voluntary program to help expedite the development process for compressor heat recovery projects. The program included the following elements:

- Pipelines will identify on their EBB websites *gas turbine* compressors on their systems that:
    - Have a total gas turbine station capacity of at least 15,000 hp; and
    - Operated at or more than 5,250 hours per year (60 percent load factor) over the previous 12 months.

- Pipelines that elect to outsource waste heat recovery opportunities will make specific information available to third-party waste heat developers about gas turbine compressor stations (including existing compressors, modifications to existing compressors, and new compressors) that meet the minimum thresholds stated above.

- Pipelines will provide this specific information to third-party waste heat developers (or an affiliate developer) upon request and subject to the developer signing a confidentiality agreement.

It is important to note that the minimum levels for inclusion in the program (*total gas turbine station capacity of at least 15,000 hp and station operation at or more than 5,250 hours per year over the previous 12 months*) were developed through discussions with both compressor station operators and heat recovery system developers. These levels were intended to represent a reasonable economic floor based on current technology performance and prevailing purchased power prices. The posted information available to developers includes data that the developers specified as necessary to allow them to proceed with a preliminary project feasibility analysis.

2. MARKET UPDATE

The interest in waste heat recovery to power for all applications (industrial applications as well as pipeline compression) has increased since issuance of the 2008 report. This interest has increased further since establishment of a number of federal and state incentives to promote the deployment of combined heat and power (CHP), including waste heat recovery to power projects, and the growing likelihood of greenhouse gas legislation in the United States.

Potential Federal and State Incentives

Specific federal and state incentives (some already established and others under consideration) that could apply to waste heat recovery to power projects include:

- *Energy Independence and Security Act of 2007 (EISA)* – Title IV, Section D contained new provisions designed to improve energy efficiency by promoting combined heat and power, waste energy recovery and district energy systems. Specifically, EISA called for the Environmental Protection Agency to establish a Waste Energy Recovery Registry that would include a list of economically feasible waste energy recovery opportunities, and to conduct an ongoing survey of major industrial and commercial sources to quantify the quantity and quality of recovery potential and to populate the Registry. The Registry also serves as the basis for potential waste energy recovery projects to qualify for financial and regulatory incentives including a "Waste Energy Recovery Incentive Grant Program" under Section 451. The grant program calls for incentive grants to owners and operators of projects at the rate of $10 per MWh during the first three calendar years of operation. While the grant program has been authorized, funding has not yet been appropriated by the Congress.

- *Energy Improvement and Extension Act of 2008 (EIEA)* – Title I, Section 103 established a 10 percent investment tax credit (ITC) for the costs of the first 15 MW of CHP property under Section 48(a)(3)(A)(v) of the Internal Revenue Code of 1986.[1] To qualify for the tax credit, the CHP system specifically must:
    - Produce at least 20 percent of its useful energy as electricity and 20 percent in the form of useful thermal energy;
    - Be 60 percent efficient on a lower heating value basis;
    - Be smaller than 50 MW; and
    - Be placed in service before January 1, 2017.

  The definition of CHP systems as "energy property" under EIEA might also qualify CHP for a five-year accelerated depreciation schedule under Section 168 of the Internal Revenue Code. Section 168 provides a Modified Accelerated Cost Recovery System through which "energy property" qualifies for a five-year depreciation method.

- *American Recovery and Reinvestment Act of 2009 (ARRA)* – ARRA provides a number of potential funding opportunities for "shovel-ready" CHP and waste heat recovery to power projects depending on how agencies and states implement specific programs. As an example, DOE's Industrial Technology Program within the Office of Energy Efficiency and Renewable Energy released a Funding Opportunity Announcement (FOA) in late spring to provide $156 million to co-fund the installation of CHP, waste energy recovery and district energy systems.[2,3] The ARRA also includes a number of enhancements to existing

[1] While the intent of the EIEA clearly was to include waste heat to power systems under the CHP ITC, the actual language is ambiguous. Efforts are underway either to clarify the language in pending tax legislation or alternatively to provide specific guidance to the IRS.

[2] https://ecenter.doe.gov/doebiz.nsf/d76fbc294818822885256d98006c63b6/62887be24440643085257553006cdd44?OpenDocument

incentives such as providing "refundability" to investment and production energy tax credits through a grant program within the Department of Treasury, and extending bonus depreciation through 2010 (including CHP), thereby allowing 50 percent of the depreciation value to be taken in the first year and the rest over the following four years.

- *Renewable Portfolio Standards (RPS)* – Eight states – Colorado, Connecticut, Nevada, North Dakota, Ohio, Pennsylvania, South Dakota, and Utah – specifically identify waste heat recovery or recycled energy as eligible in their RPS programs.[4] Five other states – Hawaii, Michigan, Massachusetts, North Carolina, and Washington – specifically include CHP, which could include waste heat recovery to power projects, as an eligible resource in their RPS programs. Pending federal legislation introduced in both the House and Senate includes CHP/waste heat recovery in proposed RPS and Energy Efficiency Resource Standards.

Operating and Planned Systems

While the incentives listed above are driving a variety of developers and equipment suppliers to evaluate the compressor waste heat recovery to power market, the market is still served by a limited number of technology and developer options. A review of operating and planned systems indicates clearly that current project activity still is based on organic rankine cycle (ORC) systems produced by Ormat Technologies in Reno, Nevada. As shown in Table 1, since 1999, fifteen waste heat recovery to power systems (all based on Ormat ORCs) have been installed on pipeline gas turbine compressor drives in North America, representing 75.5 MW of electric generating capacity.[5] Nine of these, representing 47 MW of generating capacity, have been commissioned since the release of the original report. Table 2 shows that ten systems are under construction, under contract or in advanced planning stages, representing an additional 62 MW of generating capacity.

Project activity has accelerated since release of the 2008 report, but market development is still constrained by current economic uncertainties and limited access to capital, the continued low wholesale price for power in most of the regions where compressor opportunities are located, the limited number of viable commercial waste heat recovery products and experienced project developers, and the 18 to 24 month lead time necessary for project implementation. It is also likely that some project plans may be on hold as project participants (developers, pipelines and utilities) await the outcome of pending climate change legislation.

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[3] The awards for FOA44 were announced on November 3, 2009. Although there were several compressor station waste heat to power projects proposed, none were selected for funding.

[4] While not included in an RPS, New Mexico provides state tax incentives for "recycled energy."

[5] For completeness, it should be noted that there are five steam-based compressor heat recovery systems installed on TransCanada Pipeline in Ontario (see Appendix A). All were installed between 1992 and 2000 and are a unique design in which steam generated from gas turbine compressor drive exhaust is used to enhance the output of adjacent combined cycle merchant power plants. The systems were installed to address a specific need for power in the region driven by growing demand for lumber products in the 1990s. All are based on long-term, fixed price power purchase agreements with Ontario Hydro. The systems were developed by TransCanada Power and are currently owned and operated by Epcor Canada. Epcor does not consider these types of systems as viable project options under current economic conditions or beyond the unique requirements of these specific installations. See Epcor Power LP website (www.epcorpowerlp.ca).

Table 1. Waste Heat to Power Systems Applied to Pipeline Gas Turbine Drives – Operating Systems

Project	Gas Turbine	Turbine Horsepower	Recovered Power	Power Purchaser	Developer/ Operator	Equipment	Commissioning Date
TransCanada Pipeline, Gold Creek, Alberta, Canada	Rolls Royce, RB211	38,000 hp	6.5 MW	Alberta Power Pool	Maxim Energy	Ormat	1999
Northern Border Pipeline, St. Anthony, North Dakota	Rolls Royce, RB211	38,000 hp	5.5 MW	Basin Electric Cooperative	Ormat	Ormat	2006
Northern Border Pipeline, Wetonka, South Dakota	Rolls Royce, RB211	38,000 hp	5.5 MW	Basin Electric Cooperative	Ormat	Ormat	2007
Northern Border Pipeline, Clark, South Dakota	Rolls Royce, RB211	38,000 hp	5.5 MW	Basin Electric Cooperative	Ormat	Ormat	2007
Northern Border Pipeline, Estelline, South Dakota	Rolls Royce, RB211	38,000 hp	5.5 MW	Basin Electric Cooperative	Ormat	Ormat	2007
Alliance Pipeline, Kerrobert, Saskatchewan, Canada	GE LM2500	33,000 hp	5.5 MW	SaskPower	NRGreen	Ormat	5/2007
Alliance Pipeline, Loreburn, Saskatchewan, Canada	GE LM2500	33,000 hp	5.5 MW	SaskPower	NRGreen	Ormat	5/2008
Alliance Pipeline, Estlin, Saskatchewan, Canada	GE LM2500	33,000 hp	5.5 MW	SaskPower	NRGreen	Ormat	6/2008
Alliance Pipeline, Alameda, Saskatchewan, Canada	GE LM2500	33,000 hp	5.5 MW	SaskPower	NRGreen	Ormat	8/2008
Spectra Pipeline, 150 Milehouse, BC, Canada	GE PGT20	24,000 hp	5 MW	BC Hydro	EnPower	Ormat	8/2008
Spectra Pipeline, Savona, BC, Canada	GE PGT20	24,000 hp	5 MW	BC Hydro	EnPower	Ormat	9/2008
Northern Border Pipeline, Manning, North Dakota	Rolls Royce, RB211	38,000 hp	5.5 MW	Basin Electric Cooperative	Ormat	Ormat	12/2008
Northern Border Pipeline, Zeeland, North Dakota	Rolls Royce, RB211	38,000 hp	5.5 MW	Basin Electric Cooperative	Ormat	Ormat	1/2009
Trailblazer Pipeline, Peetz, Colorado	Solar Mars 100 (2 units)	10,000 hp* (each)	4 MW	Highline Electric Coop	Ormat	Ormat	3/2009
Northern Border Pipeline, CS 6, North Dakota	Rolls Royce, RB211	38,000 hp	5.5 MW	Montana-Dakota Utilities	MDU/Ormat	Ormat	7/2009

*Turbine capacity derated due to high altitude

Table 2. Waste Heat to Power Systems Applied to Pipeline Gas Turbine Drives – Planned Systems**

Project	Gas Turbine	Turbine Horsepower	Recovered Power	Power Purchaser	Developer/ Operator	Equipment	Expected Commissioning Date
Northern Border Pipeline, Culbertson, Montana	Rolls Royce, RB211	38,000 hp	5.5 MW	Basin Electric	Ormat	Ormat	2009
Northern Border Pipeline, Garvin, Minnesota	Rolls Royce, RB211	38,000 hp	5.5 MW	Basin Electric	Ormat	Ormat	2009
Northern Border Pipeline, CS 13, Minnesota	Rolls Royce, RB211	38,000 hp	5.5 MW	Great River Energy	Ormat	Ormat	2010
Kern River Pipeline, Goodsprings, Nevada	Solar Mars 100 (3 units)	3X15,000 hp	6 MW	NV Energies	NV Energies	Ormat	2010
Alliance Pipeline, Windfall, Alberta, Canada			2X 7 MW	AltaLink	NRGreen	Ormat	2009
Alliance Pipeline, Morinville, Alberta, Canada			5.5 MW	Alberta Energy	NRGreen	Ormat	2009
Alliance Pipeline, Irma, Alberta, Canada	GE PGT25+	42,000 hp	5.5 MW	Alberta Energy	NRGreen	Ormat	2009
Spectra Pipeline, Summit Lake, BC, Canada	GE PGT25	31,000 hp	5 MW	BC Hydro	EnPower	Ormat	2010
Spectra Pipeline, Hixon, BC, Canada	GE PGT25	31,000 hp	5 MW	BC Hydro	EnPower	Ormat	2010
Spectra Pipeline, Australian, BC, Canada	GE PGT25+	42,000 hp	5 MW	BC Hydro	EnPower	Ormat	2010

** This table only identifies publicly-announced projects. There are additional projects in the evaluation/negotiation process.

Summary of Current Market Activity

As described above, most existing and all planned systems are based on organic rankine cycle (ORC) technology. Further, all systems are in states or provinces with RPS programs that include waste heat recovery to power, or where the power output qualifies under some sort of green power program. Key characteristics of the operating and planned systems include:

- **Third-party developers own and operate waste heat recovery projects -** The business model for pipeline compressor waste heat projects in North America continues to be projects developed, owned and operated by third-party entities. The third-party developer owns and operates the waste heat recovery equipment, has a long-term power purchase contract with a local utility or power wholesaler, and pays the compressor station owner/operator for the waste heat and land use. Ormat has been the developer, owner and operator on seven of the existing 15 ORC installations. While all existing ORC projects are based on Ormat technology and have been developed by a small number of third-party developers, a variety of developers and equipment suppliers are testing the market. Still, there remain only a small number of developers with actual demonstrated project experience and technical capabilities. Besides Ormat, experienced third-party developers include NRGreen, an unregulated pipeline affiliate of Alliance pipeline, and EnPower, an independent power producer (IPP) owned by Pristine Power (an independent IPP) and Enmax Corp (an energy distribution, supply and service company wholly owned by the City of Calgary). Two electric utilities, Montana Dakota Utilities and NV Energies, are also participating as project developers in ORC projects within their service areas.

- **Projects are in states with RPS programs or other incentive programs that include waste heat recovery -** "Green Power" value continues to drive existing projects. Most of the installations have been in states or provinces where waste heat recovery qualifies for some level of incentive in an existing RPS or where waste heat recovery to power is a qualified green power resource. For example, the power purchased by SaskPower from the Alliance pipeline installations qualifies under the "Environmentally Preferred Power" program; Basin Electric Cooperative retained green credits as part of the power purchase agreement (PPA) for the Northern Border Pipeline installations; the Spectra Energy systems in British Columbia have long-term PPAs with BC Hydro as part of BC Hydro's "Clean Energy Program;" and the Trailblazer system generates Green Credits as qualified under the Colorado RPS.

- **Existing and planned pipeline systems are all on gas turbine compressor drives –** All existing and planned pipeline compressor heat recovery to power systems are on gas turbine drives.[6] Organic rankine cycles technically can be applied to reciprocating engines, and there are examples of where this is done (primarily in Europe and on power generation applications that are running continuously for long periods). However, the reduced amount of thermal energy in the exhaust of even large reciprocating engines (compared to gas

[6] Ormat installed and operates an ORC heat recovery system on a gas turbine compressor drive in a gas processing plant in Louisiana in addition to the pipeline compressor systems listed in Table 1.

turbines) and the generally lower load factor of these engines in pipeline service make the economics for compressor applications very marginal.

- **Existing systems are all on compressor stations with gas turbine capacity above 15,000 hp –** All operating and planned systems are at stations with gas turbine drives well above the 15,000 hp minimum capacity established by the pipeline voluntary program. The smallest compressor station with an existing or planned waste heat recovery to power installation is on a station with two Solar Mars turbines with a combined capacity of 20,000 hp. Only three waste heat to power installations are on stations with capacities below 30,000 hp. Ormat indicated that currently they are considering, primarily, compressor stations with total gas turbine capacity above 20,000 hp.

- **Existing projects are retrofit systems –** All existing projects are retrofit systems on existing compressor stations. The economic feasibility of a waste heat recovery project depends heavily on the amount of heat available for electric generation. As a practical matter, this is a product of both the compressor turbine's ability to produce waste heat (exhaust temperature and flow) and the amount of time that the compressor actually operates. Third-party developers and pipelines can use the operating history of the compressor engine or station to determine with greater certainty the economic feasibility of waste heat power generation as a retrofit. It should be noted that any financial evaluation of a project will include considerations of both the historical performance of the station and projected long-term future operating performance of the pipeline.

- **Economics continue to be driven by the price paid for power generated –** Project economics are marginal, and the economics depend on a number of variables. Total installed costs of waste heat recovery systems are a function of capacity and are in the range of $2,500 to $3,500 per kW. System capacity is a function of the temperature and flow of the gas turbine exhaust stream (which are functions of turbine model and turbine capacity). Installation costs are affected further by site conditions such as the number of exhaust streams (one turbine or multiple units that need exhaust streams to be combined), site work, interconnection requirements, local subcontractor rates, taxes and transportation. Lack of accessible power transmission capacity close to the station can have a significant impact on project costs. The waste heat developer's overall costs and required return on investment need to be covered by the purchase price of power produced. Compressor load factor and ambient conditions impact the amount of saleable power generated on an annual basis. Ormat indicates that power purchase prices in the low $50/MWh could make project economics acceptable at high load factors.

3. CONCLUSIONS

Interest in the compressor drive waste heat recovery market has increased since release of the INGAA sponsored 2008 report, "Waste Energy Recovery Opportunities for Interstate Natural Gas Pipelines," due to the establishment of federal and state incentives for CHP and waste heat recovery, and the growing likelihood of greenhouse gas legislation in the United States. However, there are currently a limited number of proven commercial technologies and experienced project developers operating in North America. In addition, waste heat recovery project economics remain marginal and very site-specific. Generally, projects are economically viable only in areas where power purchase prices include some incentive for clean energy (e.g., states where heat recovery qualifies as an option under a renewable portfolio standard). Successful applications continue to be limited to gas turbine drives that have higher exhaust temperatures and flows and are typically larger than internal combustion engine drives. Project economics are affected by gas turbine size and load factor – the bulk of existing systems are on turbine drives of 30,000 hp or greater and on long haul trunk lines with a history of high load factors. All systems have been retrofits on existing compressor stations, because the economic feasibility of these projects can be evaluated with more certainty on stations that have available operating histories.

The 2008 report estimated that there are 90 to 100 compressor stations in the United States that meet the 15,000 hp and 5,250 hours per year (60 percent annual) load factor hurdles of the pipeline voluntary program. Currently, eight ORC heat recovery systems are operational and four are under development in the United States. Seven ORC systems in Canada are operational and six more are in the planning stages. All systems to date are based on the Ormat Technologies ORC system, and have been installed by a limited number of developers. The pace of current project activity is significant given the current economic uncertainties and limited access to capital, the continued low wholesale price for power in most of the regions where compressor opportunities are located, the limited number of viable commercial waste heat recovery products and experienced project developers, and the 18 to 24 month lead time for project implementation.

Finally, the overall conclusions of the 2008 report remain valid. Compressor heat recovery projects are being developed where and when siting is feasible and where there is a compelling business case for investing in such projects. The existing thresholds of 15,000 hp gas turbine capacity and 60 percent load factor continue to be appropriate initial screens for determining which compressor stations might be appropriate candidates for heat recovery given that there have been no fundamental changes in either technology, market players or market conditions. While the ability to site waste heat recovery for power projects and make an economic business case is affected by a variety of site-specific considerations, the primary determinant of project feasibility is the price paid for the power generated. Project margins remain narrow and could be enhanced by a market-based approach to power purchases that recognizes the value of and rewards clean energy production such as power produced from pipeline waste heat recovery.

APPENDIX A

These five steam-based compressor heat recovery systems installed on TransCanada Pipeline in Ontario. All were installed between 1992 and 2000 and are a unique design in which steam generated from gas turbine compressor drive exhaust is used to enhance the output of adjacent combined cycle merchant power plants. The systems were installed to address a specific need for power in the region driven by growing demand for lumber products in the 1990s. All are based on long term, fixed price power purchase agreements with Ontario Hydro. The systems were developed by TransCanada Power and are currently owned and operated by Epcor Canada. Epcor does not consider these types of systems as viable project options under current economic conditions or beyond the unique requirements of these specific installations. See Epcor Power LP website (www.epcorpowerlp.ca).

Project	Gas Turbine	Turbine Horsepower	Recovered Power	Power Purchaser	Developer/ Operator	Equipment	Commissioning Date
TransCanada Pipeline, Nipigon, Ontario	Rolls Royce, RB211 (x2)	72,922 hp	40 MW(1)	Ontario Hydro	Epcor Power	Steam	1992
TransCanada Pipeline, Hearst Ontario	Rolls Royce, RB211; Rolls Royce Avon, GE LM1600	76,810 hp	35 MW(2)	Ontario Hydro	Epcor Power	Steam	2000
TransCanada Pipeline, Kapuskasing, Ontario	Rolls Royce, RB211 (x2)	71,180 hp	40 MW(1)	Ontario Hydro	Epcor Power	Steam	1997
TransCanada Pipeline, Tunis, Ontario	Rolls Royce, RB211; Solar Mars; Rolls Royce Avon	71,980 hp	43 MW(1)	Ontario Hydro	Epcor Power	Steam	1995
TransCanada Pipeline, North Bay, Ontario	Rolls Royce, RB211; Solar Mars	48,930 hp	40 MW(1)	Ontario Hydro	Epcor Power	Steam	1997

(1) Includes output from gas turbine/steam turbine combined cycle system
(2) Includes output from integrated waste wood boiler system

APPENDIX B

Waste Heat to Power Equipment Suppliers and Project Developers

ORC Equipment Suppliers

Ormat Technologies, Reno, NV. Ormat has over 1,000 MW of ORC generation deployed worldwide, the vast majority of this capacity in geothermal power applications. Ormat recovered energy generation systems are based on a pre-packaged Ormat Energy Converter (OEC) that consists of a vaporizer/preheater, turbine generator, air-cooled condenser and feed pump. Ormat participates in the compressor heat recovery market as an equipment supplier, turn-key EPC, and third party build/own/operate developer. Currently, Ormat technology is the only ORC equipment installed on North American compressor stations.

GE Oil and Gas, Houston, TX. GE Oil and Gas announced the introduction of the ORegen waste heat recovery system in January 2009. The ORegen system appears to be designed specifically to match with GE gas turbines including PGT25, PGT25+, PGT25+G4, MS5001, MS50002C, MS5002D and MS6001B models. Expected power generation output ranges from 6.9 MW to 15.6 MW across the gas turbine models. The ORegen ORC system was developed by Nuovo Pignone SpA business unit, mostly likely using Rotoflow (another GE business unit) expanders. There is no evidence of GE actively marketing the ORegen system in the United States at this time. The U.S. Department of Energy announced a research project with GE in December 2008 to optimize the ORC system by eliminating the secondary heat exchanger loop (i.e., incorporating a direct evaporator design). DOE's justification of the project indicated that "current waste heat recovery technologies, including organic rankine cycles….are technically feasible but economically unattractive. This limits their current use to a small number of niche applications." It is unknown if GE has installed any ORegen units in commercial duty.

Turbine Air Systems, Houston, TX. TAS is a designer and manufacturer of pre-engineered, pre-packaged, modular chilled water and CHP systems. They supply chiller packages from 200 to 8,000 tons and CHP systems from 1 to 10 MW. TAS is currently developing a series of pre-engineered, modular waste heat ORC systems in the 1, 3 and 7 MW size range. TAS's initial market focus appears to be geothermal and industrial waste heat applications, but they are searching for developer partners to pursue the compressor drive market. The TAS ORC design has the potential to deliver more power per gas turbine hp than the current Ormat systems. TAS is working with Ridgewood Power on an initial commercial demonstration of their technology in an industrial waste heat application.

UTC Power, South Windsor, CT. UTC has commercialized a 250 kW ORC system named the PureCycle. Market focus has been on geothermal applications exclusively. The current design is not compatible with the higher temperatures of gas turbine compressor drives. They have announced plans to develop a 1 MW system, but status of this development is unknown.

WOW Energies, Houston, TX. WOW is developing the WOWGen ORC power unit. WOW's unique cascading heat recovery design has the potential for increased efficiency and power output compared to conventional ORC systems on the market. There are no WOWGen systems in commercial operation at this time.

Turboden, Italy. Turboden manufactures and sells a broad range of ORC units ranging in size from 500 kW to 2 MW. They have over 90 systems in operation in Europe, primarily in biomass recovery systems. They have no systems operating on reciprocating engines or gas turbines. They do not appear to be active in North America or in the compressor drive market.

Barber-Nichols, Inc., Arvada, CO. Barber-Nichols is a broad-based turbomachinery manufacturer that produces a line of ORC units for waste heat recovery and geothermal applications. They have commercial units as large as 2 MW producing geothermal power. They do not appear to be actively pursuing the compressor heat recovery market at this time.

GMK, Germany. GMK produces modular ORCs in the 0.5 to 5 MW size range for geothermal and biomass applications. They are developing the INDUCAL unit for industrial and engine waste heat recovery. No commercial INDUCAL units are in operation at this time.

TransPacific Energy, Carlsbad, CA. TransPacific is developing a multi-refrigerant ORC that has the potential for greater efficiency and power output than commercially available systems. They do not appear to have any systems in commercial operation.

Infinity Turbine, LLC, Madison, WI. Infinity markets a 225 kW modular ORC package. They do not appear to have any systems in commercial operation.

Turbo Thermal Corp., Austin, TX. Turbo Thermal markets ORC packages in the 100 kW to 5 MW size range. Information on their web page suggests the system needs a $0.10/kWh power price for sufficient project economics. They do not appear to have any systems in commercial operation.

Project Developers:

Ormat Technologies, Reno, NV. Ormat serves as a third-party build, own, and operate developer. Ormat currently owns and operates seven systems on compressor stations. They also operate an eighth system for a third-party developer, MDU.

NRGreen Power, Albertat, Canada. NRGreen Power Limited Partnership, an entity related to Alliance Pipeline Limited Partnership (Alliance Pipeline), was established in 2002 to pursue the commercial development of electrical generation opportunities associated with the Alliance Pipeline system. They have four operating systems on pipeline compressors in Saskatchewan under long-term (20 year) power agreements with SaskPower. They have plans to construct three additional units on the Alberta portion of the pipeline.

EnPower Green Energy Generation, Inc., British Columbia, Canada. EnPower is an independent power producer (IPP) owned by Pristine Power (an independent IPP) and Enmax Corp (an energy distribution, supply and service company wholly owned by the City of Calgary).

They currently have two compressor ORC systems in operation, one under construction and two under contract and in advanced planning.

Recycled Energy Development (RED), Westmont, IL. RED designs, builds and operates industrial heat recovery power projects. They have no ORC installations or systems installed on pipeline compressor drives at this time.

Ridgewood Renewable Power, LLC., Ridgewood, NJ. Ridgewood is an owner/operator of renewable energy projects including landfill gas and biomass. They have expressed interest in pursuing the compressor drive market with ORC technologies but to date have no installations in place. Ridgewood is working with TAS to on a commercial demonstration of the TAS ORC in an industrial waste heat application.