Design & Modeling for a Small Scale Cogeneration Plant Feasibility Study

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Overview:

With the increasing need for sustainability in the energy sector encouraging improvements in generation efficiency, the case for small scale cogeneration has become more compelling. Cogeneration—the simultaneous generation of electric power and heat, usually in the form of steam or hot water—has long been a stalwart option for installations in hospitals and university campuses. However, on-site small-scale cogeneration is becoming a viable option for both domestic and international industrial plants. Opportune industries include pulp and paper, breweries, bottling and canneries, manufacturing, agricultural mills (sugar, rice, wood, coconut, palm oil, fertilizer), steel, chemical, cement, and aluminum.

The increased viability is due to natural gas and electricity costs, which, unlike generation fuel prices, have remained consistently low. Moreover, gas prices are expected to remain at historic lows for some time to come in the U.S.; the country currently sits on ample reserves expected to last for the next 120 years (1), and there is a growing aversion to the importation of foreign energy sources. With traditional renewable energy technologies, such as photovoltaic and wind energy, proving financially or physically unfeasible on any reasonable scale, natural gas, the cleanest of all fossil fuels and more than twice as clean as coal (2), will continue to be the obvious choice for industrial on-site generation—with small scale cogeneration as an attractive long term option.

This paper describes the principal results of a pre-engineering and modeling feasibility study for a small scale cogeneration power plant performed by Maven Power, LLC of Houston, TX. The study was based on an industrial plant requiring 5.3MW of electrical power and two steam conditions for the plant processes. The objective of the study was to determine the techno-economic feasibility of on-site self generation of power and steam using a turbine-based cogeneration plant vs. the purchase of utility electric power and steam generation using traditional on-site boilers.

The cogeneration power plant was based on a single Solar Taurus™60 gas turbine generator and accompanying HRSG (Heat Recovery Steam Generator). The gas turbine was modeled using the manufacturer's SoLoNOx™ DLE technology; however, SCR (Selective Calalytic Reduction, NO_x reduction only, no CO catalyst reduction included) equipment was included in the modeling to ensure that the plant would qualify as a minor source of emissions as defined by some regulating authorities. Modeling calculations were performed using the GT Pro software by Thermoflow, Inc.

Objectives of the study included the determination of:

1) Gas turbine, HRSG and net overall plant performance;
2) Site considerations for water usage, fuel consumption, emissions, and site spacing requirements;
3) Commercial feasibility considerations;
4) Financial implications of a future carbon cap and trade program in the U.S.

The turbine model used for the study was the Solar Taurus™60 T7900S, rated at 5.7MW ISO and operating on pipeline quality natural gas.

Baseline site conditions (annual averages) used for the study included:

$T_{amb} = 75°F$

ALT =150 ft ASL

RH = 75%

$\Delta P_{inlet} = 3$ *in.* H_2O

$\Delta P_{exhaust+HRSG+SCR} = 11.55$ *in.* H_2O

Plant Electrical Requirement: 5.3MWe continuous

Plant Heat Requirement: 2 separate streams of saturated steam at 750 and 100 psig.

Turbine air inlet fogging was included at 85% effectiveness with a fine mean droplet size. The SCR equipment was included internal to the HRSG and was included in the model at an 80% NO_x reduction effectiveness.

Plant Performance:

The study yielded the following performance results[1]:

1) Net Plant Elec. Output:	5306 kW
2) Net Electrical Efficiency:	29.49%
3) Net Heat Rate:	11,569 Btu/kWh
4) CHP (Total) Efficiency:	81.93%

HRSG Performance:

The HRSG design determined from the study delivered a total of 26,000 pph of steam with two steam flows (baseline case) at the required saturated steam conditions:

1) HP (High Pressure) Steam Condition:
    a. $P_{HP} = 750$ *psig,*
    b. $T_{HP} = 513°F,$
    c. HRSG design at 90°F pinch
    d. HP flow: $\dot{m}_{HP\ Steam} = 22.9\ kpph$
2) IP (Intermediate Pressure) Steam Condition:
    a. $P_{IP} = 100$ *psig ,*
    b. $T_{IP} = 338°F,$
    c. HRSG design at 99.5°F pinch
    d. IP flow: $\dot{m}_{IP\ Steam} = 3.1\ kpph$

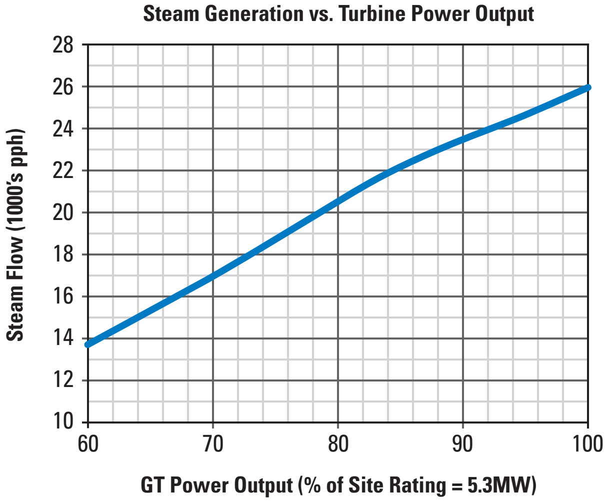

Figure 1. Steam Generation Range

An optional case of HRSG steam generation was also analyzed. Figure 1 shows the range of steam generation expected for the case of a one-stage HRSG producing a single stream of saturated steam at 300 psig:

Site Considerations:

Maven Power's modeling yielded the following results as related to the base line green-field site considerations:

1) Expected water usage[2]: 3,186 gal/hr at 75°F
2) Fuel consumption: 2,982 lb/hr natural gas (59 MMBtu/hr)
3) Required Site Area[3]: 221 x 204 ft.
4) Emissions:
    a. NO_x= 4.85 tons/yr (as NO_2)
    b. CO = 29.5 tons/yr
    c. CO_2 = 31,338 tons/yr

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[1] Performance based on continuous power output at 92.5% capacity factor (8100 hr/yr).

[2] Makeup Water: all process steam consumed by customer's process with none returning as boiler feedwater.

[3] Required area is reduced by a factor of 2 or more if location is an existing facility and new builing/access infrastructure is not required.

5) Ammonia consumption (SCR):
  a. Pure (NH_3) = 7.2 tons/yr
  b. Aqueous = 24.7 tons/yr

Commercial Considerations:

Maven Power modeled the economic feasibility of this project using the following base assumptions about today's commercial climate[4]:

Baseline Case
Fuel Cost = 6.0 USD/MMBtu, natural gas
Tolling Energy Cost = 0.105 USD/kWh
Heat (Steam) Export Price = 6.0 USD/MMBtu
Water Cost = 1 USD/kgal
Capacity Factor = 92.5% (8100 hr/yr operation)
Variable Costs = 0.0075 USD/kWh
Escalation: 3-4%

Commercial results from the study for this case assuming a U.S. green-field installation with a 20 year project life yielded the following:

Installed Cost[5]:	2,311 USD/kW
Time to Payback:	3.02 years
Cum. Net Cash Flow:	37.8 MMUSD

Figure 2 below shows the baseline case for time to payback vs. electricity price based on $4-$14 natural gas prices.

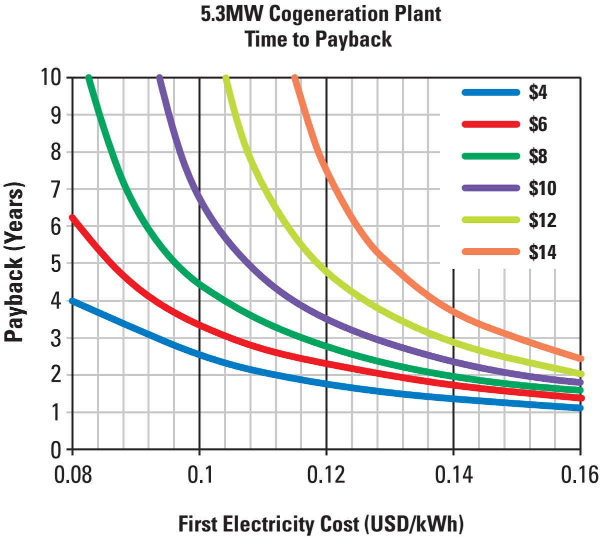

Figure 2. Project Payback vs. Electricity Price

Cap and Trade Considerations:

What are the possible implications of a federal cap and trade program on carbon dioxide emissions from a small scale cogeneration plant? At this point, several bills have been presented by the U.S. Congress, but the recently published American Power Act (APA) in June 2010 serves as a basis for estimating the impact on an industrial generating facility.

Starting in 2013, the APA would apply emissions allowances to covered entities based on the amount of CO_2 emitted by the entity in a given year. Noncompliance would be defined on a per ton basis in which the emissions of CO_2 of a covered entity in a given year exceeded those of the previous year.

For the purposes of Maven Power's model, an industrial covered entity was used, which exceeded its prior year's emissions of CO_2 by 10% of the previous year's allowance. The penalty for noncompliance as stated by the APA is effectively double the current auction price of carbon credits at the time of the violation (3), but with a limit of $25 starting in 2013 and a fixed increase of 5% year on year thereafter (4).

In this cogeneration study, the baseline CO_2 emissions of the plant for the previous year were assumed at (31,338 tons/yr)/1.1 = 28,489, resulting in an excess of 31,338 – 28,489 = 2,849 tons. Hence, the penalty under the APA with credits trading at a maximum value of $25/ton, would be:

Carbon Penalty (1 year, 10% over allowance):
($25/ton) x 2 x (2,849 tons) = $142,450.

Cleary, compliance on even a small scale is highly incentivized.

Conclusion:

In the current market, given the reasonably large "spark gap" between electricity and fuel costs and the expectation for natural gas prices to remain suppressed in the foreseeable future, small scale cogeneration in industrial applications is increasingly attractive. Moreover, even with longer term fuel price volatility as an uncertainty, with short break-even payback periods as demonstrated in the Maven Power study, risk is significantly reduced to the owner or end user. Further arguing the case is the presented study's focus on a near worst case scenario in terms of scaling—a single turbine/HRSG configuration generating relatively small amounts of power and steam. The economics and overall risk are significantly improved by the addition of another gas turbine (2 CGT x 1 HRSG configuration) or an additional turbine with HRSG (2 CGT x 2 HRSG configuration).

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[4] In addition to the given commercial assuptions, factors accounting for debt term and interest rate, taxes, and depreciation were included in the commercial analysis.

[5] Installed cost and payback vary depending on site specifics, but are significantly reduced if location is an existing facility and new building/access infrastructure is not required.

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1. **Smead, Richard G.** *North American Natural Gas Supply Assessment.* Chicago : Navigant Consulting, Inc., 2008.

2. **U.S. Energy Information Administration.** 2008.

3. **Kerry, John and Lieberman, Joseph.** *American Power Act, 111th Congress 2D Session.* Washington, D.C. : US Congress, 2010.

4. **U.S. Environmental Protection Agency, Office of Atmoshperic Programs.** *EPA Analysis of the American Power Act in the 111th Congress.* s.l. : EPA, 2010.