HOW TO SUCCESSFULLY INCREASE THE REVENUE OF WASTE-TO-ENERGY FOR THE LONG TERM

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Abstract
The objective of the paper is to outline a new business-oriented methodology based on the principle of diagnosing before improving and with the aim to produce long-term results that mutually benefit the owner and the operator of a Waste-to-Energy or biomass plant.

The scope covers (1) the determination of correction curves and coefficients for various operating conditions to compare actual equipment performance with design one (with illustration for a steam turbine); (2) the mapping of the yearly plant operation schedule into different operating modes, for a better evaluation of dollar benefits of improvement solutions; (3) the use of a computerized plant simulator model that performs heat and mass balances and translates available monitoring data into dollar value.

When benchmarking the illustrated plant case study with industry standards, we found out that reducing the Deaerator pressure by 40 psi (by 2.7 bar) would translate into an expected additional $850k of total benefits a year.

1. Introduction
This paper presents a result oriented methodology aimed at improving the performance of waste-to-energy and biomass power plants. Despite being a top performer in its industry (see Fig. 1), SERRF (South East Resource Recovery Facility, the city of Long Beach-owned waste-to-energy facility) chose to launch in late 2003 a performance improvement program based on this new methodology. For information, an historical review of key performance data of the SERRF plant is given in Table 1.

The goal of this program is to generate long-term benefits. So far, the methodology has proven to be very efficient and has led to the identification of numerous performance improvement solutions for SERRF. Illustrations from the SERRF case will be used throughout the article.

![Fig. 1 Energy Performance vs. WTE Facility Size](image-url)

Source: Deltaway Energy Best Practices [1]

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refuse received (Metric tons)</td>
<td>433,819</td>
<td>450,845</td>
<td>456,441</td>
<td>451,917</td>
</tr>
<tr>
<td>Exported Power (Mwh)</td>
<td>230,994</td>
<td>229,795</td>
<td>236,081</td>
<td>233,568</td>
</tr>
<tr>
<td>Plant availability</td>
<td>89%</td>
<td>89%</td>
<td>89%</td>
<td>89%</td>
</tr>
<tr>
<td>Ash (Metric tons)</td>
<td>156,402</td>
<td>166,718</td>
<td>159,733</td>
<td>157,992</td>
</tr>
</tbody>
</table>

Table 1 Historical review of SERRF Performance Data
The different steps of this methodology are:
(1) Diagnosis,
(2) Solution implementation,
(3) Performance Monitoring.
Also parts of this methodology, constant key-factors ensure long-term results from the improvement process: a mutual benefit approach between all parties involved, the use of a plant performance model that computes technical data in dollar value, and the balance of expertise between plant design, operation and financials.
Although all steps are important to achieve performance improvement, this paper emphasizes the diagnosis phase, which is the most replicable to any other case studies. Two most valued items of the diagnosis phase will be illustrated through examples: (2.2) the use of correction algorithms to compare actual performance of main equipments with design performance, and (2.4) the importance of the dollar value estimation of the improvement opportunities in the diagnosis phase.

2. Diagnosis
We will describe in the following paragraphs the main steps of the Diagnosis approach. Throughout these steps, frequent reference is made to a key computerized tool: the "Plant Performance Model" that performs a heat and mass balance of WTE and biomass plants and that can be used as a "plant simulator" once it has been customized to a specific plant. The model serves as a tool to track the Btu's throughout the complex processes of such plants.

2.1 Step 1: measure actual performance
Data collection and plant visits are the first step of the diagnosis work. In the case study, the availability of DCS data in an electronic format greatly facilitated the work at SERRF.

2.2 Step 2: compare actual performance with design data and with actual operating conditions
It is challenging to evaluate in a practical context if a piece of equipment is operating well or if its performance is downgraded compared to its original specifications. Very often, too many parameters are different from design specifications and from the guaranteed performance conditions.
In order to overcome this challenge, the methodology calls for:
(1) Comparing design operating conditions with actual operating conditions,
(2) Establishing correction algorithms to convert actual performance to design conditions. Equipment manufacturer specifications [2], literature research, practical experimentations or industry best practices [1] are used in establishing the correction algorithm.

Analysis of SERRF steam turbine performance
As numerous parameters have an impact on a Turbine Generator final output, evaluating steam turbine performance cannot usually be done by analysing standard operation data. Direct comparison of turbine actual output with constructor rated performance is meaningless because actual operating conditions always differ from design operating conditions. Short tests with specific instrumentations are usually used by plant operator to assess turbine performance. The following case study illustration will show how the methodology proposes to assess the turbine performance level without having to perform specific testing, on the sole basis of readily available operating data.
SERRF steam cycle is presented in Fig. 2, with the design operating conditions. SERRF 37.5MW rated turbine has 4 extraction ports, which supply the deaerator (DA), two feedwater heaters, and the boilers air pre-heaters.

Identifying the operating conditions which have an impact on the turbine output and choosing which available instrumentation would accurately measure these operating conditions were the first steps (See Table 2).

![Fig. 2 SERRF Steam Cycle](image-url)
Operating condition  | Data                          
---------------------|-------------------------------
Inlet steam conditions | Directly available in the DCS historian  
- flow                |                               
- temperature         |                               
- pressure             |                               
Condenser vacuum       | Directly available in the DCS historian  
Extraction usage       |                               
- DA                  | DCS DA temperature           
- Feedwater heating    | DCS DA condensate inlet temperature  
- Air pre-heating      | DCS Pre-heated air temperature  

Table 2 SERRF turbine operating conditions

Correction factors
In order to evaluate the degradation of the turbine performance over the years, the difference between (1) the actual turbine performance and (2) the design turbine performance corrected to the actual operating conditions was calculated:

\[ D = kW_{\text{actual}} - kW_{\text{design}} \times K_{\text{actual operating conditions}} \]

where:

- \( D \) is the difference in turbine performance (in kW). A negative value of \( D \) means that the turbine is performing below design, a positive value of \( D \) means the turbine is performing above design.
- \( K \) is the correction factor for operating conditions, with:

\[
K = K_{f} \times K_{p} \times K_{v} \times K_{DA} \times K_{FWH} \times K_{APH}
\]

- \( K_{f} \) is the correction factor for the inlet steam flow
- \( K_{p} \) is the correction factor for the inlet steam temperature
- \( K_{v} \) is the correction factor for the inlet steam pressure
- \( K_{DA} \) is the correction factor for the DA extraction usage
- \( K_{FWH} \) is the correction factor for the feedwater heater extraction usage
- \( K_{APH} \) is the correction factor for the air pre-heating extraction usage

\( kW_{\text{actual}} \) is the gross T/G output measured by calibrated plant instrumentation.

\( kW_{\text{design}} \) is the gross design T/G output at design operating conditions: 37,550 kW (see Fig.2).

Vendor correction curves
Turbine vendor correction curves were available for inlet pressure, inlet temperature [3] and vacuum [4] (see Fig.3).

Self-generated correction curves
Correction curves for inlet steam flow and extraction usage were calculated with the help of the Plant Performance Model (see Fig. 4 to 6 and Tables 3a and 3b). The DA pressure/temperature correction curve is presented Fig. 4.

The correction curves are calculated by plotting values of turbine output for different values of the input parameter, all other parameters remaining constant. For example, for the DA pressure correction curve (Fig. 4), the turbine generator output is calculated for different values of DA pressure/temperature. Table 3a shows that for plotting point #6, the only input parameter change is the DA temperature (from 162°C to 145°C), all other parameters remain constant.

<table>
<thead>
<tr>
<th></th>
<th>Standard design conditions</th>
<th>Data used for point #6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet steam conditions</td>
<td>159.3 t/h</td>
<td>159.3 t/h</td>
</tr>
<tr>
<td></td>
<td>42.4 bar</td>
<td>42.4 bar</td>
</tr>
<tr>
<td></td>
<td>399°C</td>
<td>399°C</td>
</tr>
<tr>
<td>Vacuum</td>
<td>69 mbar</td>
<td>69 mbar</td>
</tr>
</tbody>
</table>
The thermodynamics calculations show that there is a lower extraction #2 flow for a DA temperature of 145°C (See Table 3b: 10.0 t/h vs. 15.0 t/h), which translates into a higher flow through the T/G turbine (see Table 3b: 147.9 t/h vs. 142.9 t/h), which in turn increases the T/G output (See Table 3b: 38,346 MW vs. 37,518 MW).

Table 3a Input data - DA correction curve calculation

<table>
<thead>
<tr>
<th></th>
<th>70°C</th>
<th>70°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>70°C</td>
<td>70°C</td>
</tr>
<tr>
<td>DA condensate inlet temperature</td>
<td>104°C</td>
<td>104°C</td>
</tr>
<tr>
<td>DA temperature</td>
<td>162°C - 6.5 bar</td>
<td>145°C - 4.2 bar</td>
</tr>
</tbody>
</table>

Table 3b Output data - DA correction curve calculation

<table>
<thead>
<tr>
<th></th>
<th>Data calculated for the standard design conditions</th>
<th>Data calculated for point #6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction flow #2</td>
<td>15.0 t/h</td>
<td>10.0 t/h</td>
</tr>
<tr>
<td>Turbine flow into 3rd section</td>
<td>142.9 t/h</td>
<td>147.9 t/h</td>
</tr>
<tr>
<td>T/G gross output</td>
<td>37,518 MW</td>
<td>38,346 MW</td>
</tr>
</tbody>
</table>

The correction factor for point #6 is consequently: 38,346/37,518 = 1.022.

Once we had plotted the entire curve, we checked that the curve did not change when other operating conditions change. For example, as we generated the curve with a 69 mbar vacuum value, we made sure that the curve was similar for different vacuum values, by plotting the curves for 50 mbar, 100 mbar and 120 mbar.

Nota: we used the DA temperature measurement to establish Fig. 4 correction curve, but the graph units have been translated into pressure to make it more readily understandable.

Correlation curves for air pre-heating and for inlet steam flow are presented in Fig. 5 and 6.

Nota: design called for pre-heating 100% of the primary air from extraction #3. The plant has since been modified to pre-heat only 2/3 of the primary air flow, and extraction #2 is now used instead of

Fig.6 SERRF Turbine inlet steam flow correction curve [5]

The feedwater heating correction curve changes depending on the steam flow value. Two of these curves are presented in Fig. 7.

Fig.5 SERRF Turbine air temperature correction curve [5]

Nota: inlet steam pressure correction is considered to be negligible.

Table 4 SERRF turbine performance calculation

Nota: design called for pre-heating 100% of the primary air from extraction #3. The correction curve has been plotted simulating the current operating pattern.
The global correction factor, calculated by multiplying all of the above correction factors is 1.0324. It means that the expected design performance of the turbine in these conditions is: 37,550*1.0324=38,768 MW.

The related Jan. 30 actual DCS gross output was 36,950 MW, showing that the turbine was performing 38,768-36,950 = 1,818 kW below design (D=−1,818 kW). If no correction had been made, the turbine would have "appeared" to be only 600kW below design.

Fig. 8 shows the value of D for the June 03 – December 03 period. This graph has been calculated with available historic DCS data, but no information on the calibration of instruments during that period were available. The graph shows that the turbine seems to be performing around 2.5MW below design, but the interpretation of this graph is subject to caution (see the sensitivity analysis below).

### Sensitivity analysis

In order to direct the calibration effort to be undertaken before a "turbine performance monitoring phase" and to evaluate if the calculation of turbine performance with past DCS data would make sense, the sensitivity of the different DCS data was evaluated. The results are shown in Table 5.

<table>
<thead>
<tr>
<th>Input data</th>
<th>Inlet parameter change</th>
<th>Corrected design performance sensitivity (average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet steam flow</td>
<td>+7 kpph (+3.2 t/h)</td>
<td>+1.7%</td>
</tr>
<tr>
<td>Inlet Steam Temperature</td>
<td>+10°F (+5.5°C)</td>
<td>+0.9%</td>
</tr>
<tr>
<td>Inlet Steam Pressure</td>
<td>+25 psi (+1.7 bar)</td>
<td>+0.1%</td>
</tr>
<tr>
<td>Condenser vacuum</td>
<td>+0.15 psi (+10.3 mbar)</td>
<td>Between -1% and -3% (variable)</td>
</tr>
<tr>
<td>DA temperature</td>
<td>+10°F (+5.5°C)</td>
<td>-0.7%</td>
</tr>
<tr>
<td>DA condensate inlet temperature</td>
<td>+10°F (+5.5°C)</td>
<td>-0.2%</td>
</tr>
<tr>
<td>Pre-heated air</td>
<td>+10°F (+5.5°C)</td>
<td>-0.3%</td>
</tr>
</tbody>
</table>

Following this analysis, recommendation was made to perform a comprehensive calibration of the inlet steam flow, inlet steam temperature, vacuum, gross wattmeter and DA temperature instrumentation, so the turbine performance could be estimated with a high confidence level during a future monitoring period. The results of this monitoring are not available yet.

### Benefits of the turbine performance assessment

With a major outage approaching, the level of health of the steam turbine is an important topic for SERRF in the first semester of 2005. The assessment of the turbine overall performance by the above mentioned method will be one of the main tools used by the plant to evaluate the turbine upgrade opportunities for the 2005 major outage.

### Step 3: Understanding plant economics

Understanding the plant economic drivers is an important step in the diagnosis process in order to evaluate the economical benefits of improvement opportunities, and later on on the return on investment of the possible solutions. The mutual benefit approach at this stage is key: taking into account each of the plant actors' economics is important to ensure a fair balance between the benefits and to help with the solution decision making process. This step won't be illustrated here as SERRF economics situation is not transposable to other plants.

### Step 4: Estimation of dollar value of improvement opportunities

Once the plant economics are understood, it is an efficient process to calculate the dollar value of each improvement opportunity area as soon as possible in the performance improvement process, for the following reasons:

1. It allows to identify upfront the high impact solutions, helping the prioritization process and avoiding spending time and money in the heavy process of "solution evaluation and design" for all solutions (vendor quotes gathering, identifying best suited design...)
2. It gives a maximum level of capital investment above which the solution will not generate an acceptable financial return, helping to rule out upfront some solutions.

### Reference scenario and improvement scenario

For evaluating the dollar value of an improvement opportunity, we compare a baseline scenario reflecting the plant actual performance with an "improvement
scenario" representing the improvement opportunity that is assessed.

**Operating modes**

It is important to take into account different operating modes, because an average plant does not run even all year long. The yearly plant operation schedule is mapped into different operating modes such as "3 boilers-full load", "3 boilers-reduced load", "wet fuel", etc., and for each of them a percentage of running time is calculated based on historical data. In the case of SERRF, we chose to use 6 different operating modes, based on the history of plant operations (see Fig. 9). It is interesting to note that a plant like SERRF, which has a good 89% availability factor, is only operating at full load half of the time.

**Fig. 9 SERRF Reference Scenario Operating Modes [5]**

The Plant Performance model, which addresses boiler and steam cycle operations, gives for each improvement opportunity the additional MW and the additional tons/hour processed by the plant in each operating mode compared to the reference situation. Other factors, such as water consumption, auxiliary fuel consumption or back-up power consumption can also be estimated.

In this step, the model is key to establish the dollar gain linked to a one-parameter change. The related dollar gain is usually impossible to measure practically, because too many parameters change at the same time and because validation of field data is often a challenge. To this matter, the model becomes an important tool for the decision-making process by eliminating all speculations, presuppositions or beliefs on plant expected reaction to any operating change.

Improvement opportunities that help reduce unavailability and/or partial load operations are evaluated with a different operating mode schedule in their "improvement scenario" than in their "reference scenario".

**Dollar benefits of SERRF DA operating pressure change**

When benchmarking SERRF with similar plants over the world, we found out that the DA operating pressure of SERRF was higher than industry standards. We studied the benefits that SERRF would get by lowering their DA operating pressure from 80 to 40 psi (from 6.5 bar to 3.8 bar). The difference in the plant operation would be threefold:

- Increase in net MW output due to lower turbine extraction.
- Increase in plant tonnage due to lower feedwater temperature (verification that the boilers could process that additional tonnage is to be made). This tonnage increase is somewhat offset by the efficiency increase of the economizer at the lower feedwater temperature (a 10°F (5.5°C) drop in flue gas exit temperature was taken into account, based on the study of past plant DCS data).
- Additional plant downtime due to risks of corroded economizer tubes replacement. The replacement of one economizer bank per boiler every 15 years was taken into account.

The impact of the change of operating pressure in the DA for the different operating modes is summarized in Table 6:

<table>
<thead>
<tr>
<th>Operating mode</th>
<th>3B-F</th>
<th>3B-R</th>
<th>2B-F</th>
<th>2B-R</th>
<th>1B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional T/G output</td>
<td>970 kW</td>
<td>848 kW</td>
<td>684 kW</td>
<td>614 kW</td>
<td>431 kW</td>
</tr>
<tr>
<td>Additional MSW tons processed</td>
<td>2,1 t/h</td>
<td>2,0 t/h</td>
<td>1,4 t/h</td>
<td>1,3 t/h</td>
<td>0,7 t/h</td>
</tr>
</tbody>
</table>

**Table 6 Benefits of a new DA operating pressure**

The translation of these "technical" results into "business" results is presented in Table 7. Additional yearly production of 7,400 MWh and 16,000 tons of MSW can be expected. This translates into total benefits of more than $850k/year. Table 7 shows how the benefits are calculated for the owner and for the operator of the plant, according to our mutual benefits approach.

<table>
<thead>
<tr>
<th>Owner</th>
<th>Additional energy sales</th>
<th>Not disclosed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Additional tipping fees</td>
<td>Not disclosed</td>
</tr>
<tr>
<td></td>
<td>Additional disposal costs</td>
<td>Not disclosed</td>
</tr>
<tr>
<td></td>
<td>Additional O&amp;M contracts payments</td>
<td>Not disclosed</td>
</tr>
<tr>
<td>Yearly total for the owner</td>
<td>669k</td>
<td></td>
</tr>
</tbody>
</table>
2.5 Solution identification

In order to identify the best solutions to transform the improvement opportunities into results, root cause analysis and worldwide industry best practices research are conducted.

2.6 Goal setting – Prioritization

Based on the above described work, an achievable performance goal is set for the plant. Frequent stage reviews must be held in order to keep the momentum of the improvement effort. The mutual benefit approach and the dollar value opportunities estimation are taken into account one more time at this stage to help in the process of prioritizing and screening the possible solutions. Once a consensus is reached by all parties, the solution implementation process can start.

3. Solution implementation

The methodology calls for estimating at this stage the financial return of the selected solutions, according to standard industry practices. During this process, the general specifications for each identified and prioritized solution are drafted and vendor quotes are gathered in order to estimate each solution capital cost. Based on operational and financial expertise from industry standards, the operation & maintenance costs impacts are evaluated for each solution. A comparison of the financial study and side benefits between the different solutions is done and leads to the final implementation decision. An implementation planning schedule is then defined, based on solution capital cost and budget factors. During this stage, the project management expertise is an important factor to stay within the financial returns indicated.

4. Monitoring

Follow-up sessions are hold to track actual improvement against the achievable performance goal. The methodology calls for an on-going business oriented performance monitoring that translates the technical monitored data into gained dollar value. For example, the monthly dollar gains of a 10°C increase in feedwaterheaters outlet temperature for the plant owner and the plant operator can be calculated. It is a very efficient help for the plant decision makers, and a good continuous improvement tool.

5. Conclusions

The above methodology shows the importance of the diagnosis phase with the understanding of the plant economic key driver and the early translation of technical results into dollar value in order to implement the best solution in an efficient manner.

The plant performance model used in this study obtained from mass and energy balances is key to estimate benefits of solutions, as it allows to isolate the impact of a one-parameter change, and to compute dollar gain of each solution in each operating mode.

The mutual benefit approach taken throughout the study is critical to the long-term success of the improvement effort. This approach gives its best results with the maximum transparency from all parties involved.

Simple and proven solutions like the change of DA operating pressure can easily be found by benchmarking the plant design with other plants from the industry.

References


