COGENERATION SYSTEM DESIGN: ANALYSIS AND SYNTHESIS

A REVIEW OF SOME RELEVANT PROCEDURES AND PROGRAMS

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> *"Note that all these principles lead to cost effectiveness, IF AND ONLY IF ALL COSTS ARE RECOGNIZED."*
>
> Wayne C. Turner [26]

ABSTRACT

Typical approaches to design and evaluate cogeneration systems are studied. Needs and issues in current design and evaluation methods are identified. A balanced approach between design analysis and design synthesis is proposed. Further research and development is suggested.

BACKGROUND

A combined heat and power (CHP) plant is also called a cogeneration system. In general, we consider a cogeneration system an integrated process/facility and generating plant [1] where:

1. Mechanical or electrical power which is generated by
   - a thermodynamic cycle (e.g., steam turbine or diesel engine) or,
   - a direct energy conversion device (e.g., fuel cell or thermionic converter).

2. One or more forms of thermal energy are utilized (e.g., steam for heating or for cooling as in absorption cycles, process hot water, hot gas for drying, etc.).

Recently, some authors are using the term "trigeneration" to refer to systems that, besides power generation, convert/utilize more than one form of useful thermal energy (i.e. district heating and cooling plants). See for example Emho [2]. Note such distinction is not made here.

Also, most cogeneration systems constitute "on-site generation" or "distributed generation" plants. But not all on-site and distributed generation plants are cogeneration systems, unless a significant amount of heat is recovered and utilized, making them "topping cycles." As opposed to traditional utility power plants, most of the output of on-site/distributed generation is utilized in adjacent or nearby processes or facilities. Hence, the integration of the on-site cogeneration system to the host process and facility is paramount.

PURPOSE AND OVERVIEW

The intent is to propose a balanced approach between design analysis (break down of a problem/solution into many parts or components) and design synthesis (integration of the relevant problem/solution into a concise and cohesive whole). First, cogeneration system requirements and evaluation factors are discussed. Next, we review some representative design/evaluation methods to identify issues and needs. Then, we propose a balanced analysis-synthesis approach to achieve a robust design methodology. To conclude we make several recommendations for further research and development.

COGENERATION SYSTEM REQUIREMENTS AND MAIN EVALUATION FACTORS

In his "Cogeneration" sourcebook, Charles Butler [3] defined a highly profitable—but hypothetical—cogeneration project having the following system requirements:

Thus, a critical task in cogeneration design and evaluation is the effective translation of (1) facility/process needs and (2) financial objectives into (3) systems requirements. Often, these three subjects are treated as being separate and independent. Hence, we should constantly ask:

- *To what extent do the system requirements support the host facility/process operating needs and the cogeneration investor financial goal?*

- *To what extent do the design specifications and predicted/tested capabilities of the selected equipment meet the system requirements?*

The system requirements listed on Table 1 represent the most desirable state of ownership and operation. Several other factors constrain the viability of a real cogeneration plant. Six (6) significant evaluation factors are considered here, see Figure 1. Because such factors are so intertwined, they have been likened to the game of "Rubik's Cube," [4]. If one of the cube's face or factors is changed, it is likely to affect the other faces or factors.

COGENERATION DESIGN AND EVALUATION APPROACHES

The immediate objective of the design and evaluation process is to determine technical and economical feasibilities. Clearly, such feasibilities must be evaluated in terms of meeting the customer's operating needs and the investor's financial goals. Also, a good design and evaluation process should guide the designer and the investor to make wise technical and business decisions.

Design involves specifying the technology, size, operating characteristics and engineering specifications/documentation. For example, for

Table 1. Cogeneration System Requirements

1. The least complexity
2. The highest reliability
3. Simplicity of operation and interconnection with process or building systems
4. Minimum maintenance
5. Redundancy or backup features (to address reliability and availability concerns)
6. Low capital installed cost
7. Ease of construction
8. Sustainable performance (consistent system capacity and efficiency over time)
9. Secure fuel(s)

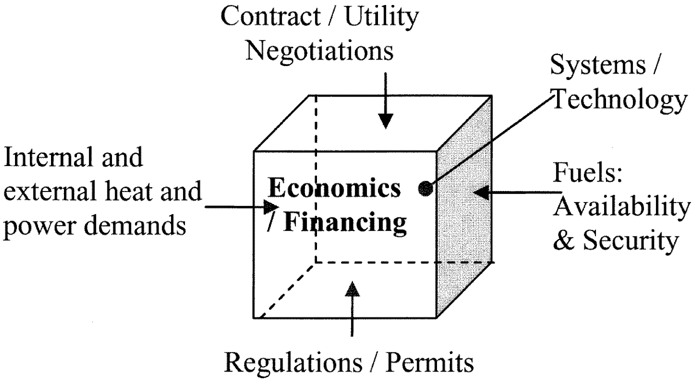

Figure 1. The main six design/evaluation factors of cogeneration.

a brewery we specified a 4.5 MW gas turbine and a heat recovery boiler to generate 30,000 lb/hr of saturated steam at 35 psig. Design includes screening for technical feasibility. Once a design concept is shown to be technically feasible, one evaluates its economic feasibility. Evaluation is predicting the cost of the system over its economic service life. Figure 2 is an overview of the cogeneration life cycle process. Note the overall quality of CHP system—designed in Phase I and implemented in Phase II—will impact in many ways its operation during Phase III.

System Type, Size and Mode of Operation

For a particular project there are often several potential system candidates (e.g., boiler-steam turbines, combustion turbines-waste heat boiler, diesel or gas engines with heat recovery, etc.). Hay [9] shows that cogeneration systems can be sized according to four basic modes of operation:

1. Isolated Cogeneration, to meet all heat and power needs of a process or facility.

2. Thermally Base Loaded, to meet the base thermal load; excess power is sold.

3. Electrically Base Loaded, to meet the base electrical load; power deficit is bought.

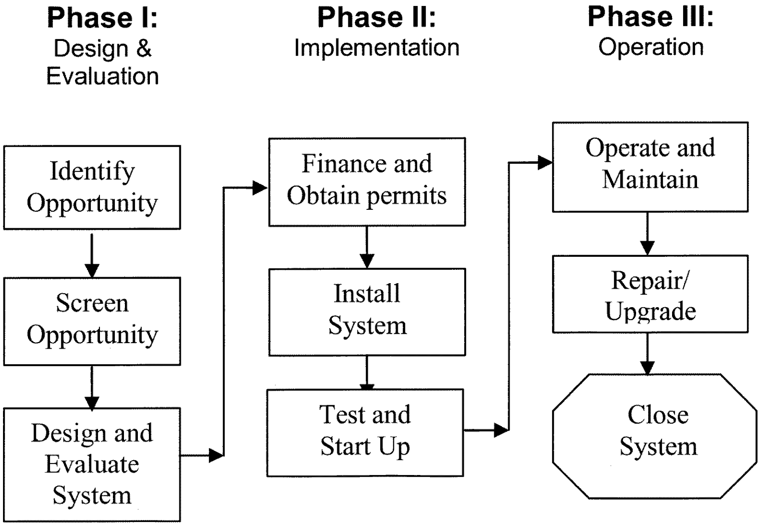

Figure 2. Cogeneration System, Life Cycle.

4. Maximum System, system sized to maximize power generation; excess power is sold.

Considering the four (4) operating scenarios listed above and N possible alternative technologies or systems, then 4N cogeneration alternatives are possible. In reality, the number of possible size alternatives is not only limited to the four operating modes listed above. For instance, one can size a plant to meet the average steam load (which is none of the four listed above). In this instance, the project would get the difference steam from auxiliary boilers and buy (sell) the power deficit (excess) to the utility grid.

Thus, *system size options are only limited by commercial type/size available equipment, internal and external CHP demands and what regulations allow. But only a few options tend to be truly superior investments.* Note that understanding the system requirements in terms of process, utility and investor objectives, is the key to narrow down many possible candidates to a short-list of profitable alternatives.

Analytical Procedures

There are "step-by-step" methods that break down the design and evaluation problem into a series of analyses. We call these procedures analytical because they break the whole project or problem in parts and pieces and then approach each sub-problem in a sequential fashion. Table 2 lists a sample of analytical procedures used or proposed by different authors and consultants. Such procedures usually focus on Phase I of the CHP system life cycle, as depicted in Figure 2. The evaluation and design steps are carried out using an iterative approach—further steps require more data to do a more detailed analysis. Hence, an iterative approach with successive approximations (design, evaluate, design, evaluate, etc.) is used to manage risks.

Computer Packages

Carrying out any procedure listed in Table 1 (or similar) through to completion is very time consuming. Consequently, to be time and cost effective, most cogeneration professionals use some computer aided design or evaluation. But most computer packages are data intensive. So, before one can use any cogeneration software effectively, relevant data must be collected and organized as input data suitable to the software. Typical input data include:

- Site characteristics and process needs
- Historic and forecast energy demand and consumption (heat and power)
- Applicable utility rates
- Cogeneration fuel(s) availability and security
- Interconnection infrastructure and access
- System equipment performance, reliability and costs
- Applicable cogeneration and environmental regulation
- Economic and financial hurdle expectations/metrics

We next examine two types of computer packages. First, we briefly describe a sample of "comprehensive" computer packages that actually focus more on preliminary evaluation than on detailed equipment design. These are CELCAP, Cogenmaster and Cogen Ready Reckoner. Next, some of the more detailed "technical" programs for equipment system design are listed.

Table 2. Some Cogeneration Design and Evaluation Procedures

PROCEDURES [Sources]			
A [5]	*B [6]*	*C [7]*	*D [8]*
Opportunity identification and site visit	Walkthrough analysis -technical compatibility -economic potential	Data collection	Pre-evaluation: -Identify customer present needs and mode of operation -Predict future needs and operation
Data collection	System type and size selection	Walkthrough analysis	
System configuration selection	Engineering and economic screening	Feasibility analysis, including equipment selection	Do feasibility study: Preliminary design modeling and economic analysis
Thermodynamic system analysis	Energy analysis	Preliminary design	Define client energy purchase options
Economic valuation	Cost analysis	Detailed design	Select a system
	Project budget		Detailed design
	Cash flow analysis		Implementation
	Economic analysis		
	Sensitivity analysis		

CELCAP

The Naval Civil Engineering Laboratory developed a cogeneration analysis computer program (CELCAP). Dr. R.T.Y. Lee [10] states this program was "for the purpose of evaluating the performance of cogeneration systems on a life cycle cost basis." Lee admits that "selection of a cogeneration energy system for a specific application is a complex task." He recognized that in a project there exists multiple system alternatives (gas-turbine, diesel engine, steam turbine, etc.), as well as multiple modes of operation/sizes, as described above. So the maximum number of

$$\text{Design options} = [\#\text{ of alternative systems}] \times [\#\text{ of operation modes or sizes}] \qquad \text{eqn (1)}$$

CELCAP does not specify systems (equipment) alternatives. These must be selected by the analyst. Next, to simplify the wide diversity of actual load profiles, data are input as "monthly averages" for "working and non-working days." The "best representative" profile is chosen for the "typical working day" of the month. A similar procedure is done for non-working days.

Once a number of candidate systems have been specified, equipment performance data and load profiles are fed into the program. The output can be obtained in a brief or detailed form. In brief form, the output consists of a summary of input data and life cycle cost analysis including fuel, operation, maintenance and purchased power costs. The detailed output includes all the data in the brief output plus hourly performance data for two days in each month of the year. It also includes the maximum hourly CHP output and fuel consumption. For both electricity and steam, the hourly demands and supplies are plotted for each month of the year.

Cogenmaster

This is a menu driven cogeneration program developed by Limaye and Balakrishnan [11] of Synergic Resources Corporation. It is intended to model the technical as well as financial aspects of cogeneration. This program extends the concept of project option to include finance and ownership arrangements. Thus, the maximum number of

$$\text{Project options} = [\#\text{ of systems}] \times [\#\text{ of op. modes or sizes}] \times [\#\text{ of finance \& ownership arrangements}] \qquad \text{eqn (2)}$$

To handle all these options, COGENMASTER has two sections: a Technology section with five modules and a Finance section with three modules. See Table 3 below.

Table 3. COGENMASTER Program Architecture

Technology Section	*Finance Section*
Database Module	Financing Module
Rates Module	Cash Flow Module
Load Module	Pricing Module
Sizing Module	
Operating Module	

Facility energy simulation programs output hour-by-hour heating and cooling energy needs for up to 8760 hours in a year. However, handling too many hourly data is time consuming and cumbersome for evaluation purposes. So, in Cogenmaster, electric and thermal loads may be entered in one of three ways, depending on available data and the detail required for evaluation:

- A constant average load for every hour of the year
- Hourly data for three typical days of the year
- Hourly data for three typical days of each month

Besides the data used by each module in Table 3, Cogenmaster outputs simple payback and net present value estimates for each one of the predefined project options or investment alternatives.

Cogen Ready Reconer

(Cogen R_R) This is a program to conduct "first-pass" technical and financial analysis of on-site cogeneration. Cogen R_R is distributed by the Australian Department of Industry, Tourism and Resources (DITR). [12]. It allows either Metric (SI) or Imperial (US) units, for the Australian or US scenarios, respectively. The program is a joint development of the

Commonwealth of Australia, Australian EcoGeneration Association [13] and Sinclair Knight Merz Pty Ltd (the providers). According to the providers:

- "The program is not intended to be a final or authoritative assessment but rather a preliminary assessment of potential cogeneration opportunities."
- "The software is not intended to be a tool for basing final investment decisions upon, and in all cases the user must conduct sufficient additional analyses and obtain appropriate professional advice before proceeding with any investment decision."

After the user has collected and organized the typical CHP input data, the user must select one "Cogen configuration," from the following options:

- Gas Turbine with heat recovery steam generation (HRSG)
- Gas Turbine with heat recovery steam generation and steam turbine (Combined Cycle)
- Reciprocating engine with (a) jacket water and (b) exhaust heat recovery options
- Topping cycle (boiler, non-condensing steam turbine and exhaust of process steam)
- Chilled water generation from either motor-driven or absorption-cycle chillers

The user can adjust and maintain the default values of the system performances. To this aim, the program contains a Tools section of the gas turbine and reciprocating engines database.

Cogen R_R evaluation approach is to estimate the difference in operation and maintenance cost between the non-cogen base case the selected cogen configuration. The program can output:

- Hourly and annual flows in each case
- Annual cash flows in each case

- Annual cash flow for the differential case (Cogen cash flows—benchmark cash flows)
- Financial summary parameters such as net-present value (NPV), internal rate-of-return (IRR), etc.
- Sensitivity graphs for the variation in import electricity cost, export electricity value, cogen case fuel cost, capital cost and discount rate.

Detailed Cogeneration Component Design Packages

The following is a sample list of programs intended to do detailed analysis or simulation of cogeneration components (steam turbines, heat recovery steam generators, heat exchangers, etc.). Also, many companies and consultants have proprietary ad-hoc design and analysis packages.

- The Energy Analyst: "Twenty programs* to calculate the performance of turbines, shell and tube exchangers, steam heaters, steam condensers, cooling towers, boiler efficiency, cogeneration economics, insulation thickness, liquid and gas flow, pipe network flow, pumps and tanks. Programs are rigorous and fully interactive (menu driven)."

- GTPRO: An advanced gas turbine and CHP system simulation and analysis program.

- Aspen: An advanced chemical process plant (unit processes and unit operations) modeling and simulation program.

- ProSteam: A spreadsheet based program to model steam system networks, steam turbines, heat exchangers, gas turbines, thermodynamic properties and emissions. It will optimize the design, operation and management of site utility systems. The program includes drawing tools, steam/water properties and a library of utility equipment models." [14]

- SuperTarget® 6 and PinchExpress6: Are pinch point technology programs to identify and evaluate improvement opportunities in

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*These programs are vintage MS DOS and may not be currently available. Thermal Analysis Systems, 1985.

heat exchanger networks. "It uses a simple interface to enter data about the steam system and improvement opportunity areas. It prints out energy, cost, and emission savings for the evaluated opportunities." [15]

Synthetic Approaches

Synthetic approaches attempt to encapsulate cogeneration evaluation in a compact model, equation, graph or method. Such approaches or metrics evaluate the overall performance of a design concept quickly and concisely. For instance, a close-form equation derived by this author has been demonstrated to be quite effective in optimizing generator sets for peak-demand shaving [29]. We examine next some of these approaches, including the fuel chargeable to power ratio, the cogeneration energy profitability and sensitivity graphs.

Fuel Chargeable to Power

Fuel Chargeable to Power (FCP) is the incremental fuel consumption caused by cogeneration, with respect to the non-cogeneration base case, divided by the gross generation minus the difference in cogeneration powerhouse auxiliaries. The idea is to quantify the incremental cost of cogenerated power (FCP) to compare it with the incremental electrical utility rate (Δe).

FCP = [Fuel assigned to power generation]/[Net power output]

$$FCP = \frac{(fuel)_2 \pm (fuel)_1}{kW \pm (PHaux)_2 + (PHaux)_1} = \frac{Fuel_r \pm Fuel_p}{kW \pm \Delta PHaux} \quad \text{Btu / kWh} \qquad \text{eqn (3)}$$

or

$$FCP = \frac{(fuel)_2\, p_2 \pm (fuel)_1\, p_1}{kW \pm (PHaux)_2 + (PHaux)_1} \bullet \frac{1}{\mathrm{T}} \qquad \$/\text{kWh} \qquad \text{eqn (4)}$$

Where:

FCP = fuel chargeable to power in Btu/hr per kW or Btu/kWh

$(fuel)_1$ = fuel consumption rate for the non-cogeneration base case (Btu/hr)

$(fuel)_2$ = fuel consumption rate for the cogeneration system (Btu/hr)

kW = average cogenerated power (kW)
$(PHaux)_1$ = power demand by base case auxiliary equipment (kW)
$(PHaux)_2$ = power demand by cogeneration plan (kW)

Cogeneration Energy Profitability (CEP)

The concept of "cogeneration energy profitability" was first proposed by D.R. Limaye [16] in 1987. The CEP index attempts to assess the goodness of cogeneration as a function of various efficiencies and energy cost factors in a closed form equation. The CEP index predicted the system size growth towards "PURPA machines" and the greater sensitivity of project feasibility to electrical rates. CEP extends the concept of FCP to the difference of fuel input between non-cogen base case and a cogen alternative:

$$CEP = \frac{C_{fe}\,Q_{fe} + C_{fb}\,Q_{fb} \pm C_{fe}\,Q_{fc}}{C_{fc}\,Q_{fc}} \quad \text{\$ CHP benefits/\$ CHP fuel} \qquad \text{eqn (5)}$$

Where:
C_{fe} and Q_{fe} = unit cost and quantity of fuel to generate electricity in a utility station
C_{fb} and Q_{fb} = unit cost and quantity of fuel to generate steam in an industrial boiler
C_{fc} and Q_{fc} = unit cost and quantity of fuel to generate CHP.

If the cost of all (primary) fuels is the same, as in larger firm contracts, i.e., $C_{fe}= C_{fb} = C_{fc}$, it can be shown that equation (5) can be expressed in terms of pure efficiencies, as follows

$$CEP = \frac{\eta_{ec}}{\eta_{eu}} + \frac{\eta_t \pm \eta_{ec}}{\eta_b} \pm 1 \quad \text{\$ CHP benefits/\$ CHP fuel} \qquad \text{eqn (6)}$$

Where:

η_{ec} = fuel-to-electricity conversion efficiency of CHP system (cogen case)
η_{eu} = fuel-to-electricity efficiency conversion of utility plant (base case)
η_b = fuel-to-steam efficiency of conventional boiler (base case)

These and other derived CEP equations have been used to do parametric evaluations of alternative CHP systems and technologies (with different hec efficiencies). In a future paper, we will show how to use the CEP index to handle economies of scale (i.e., the better efficiencies of larger turbines and engines) when optimizing CHP system size or output capacity.

Sensitivity Graphs

A different way to express the economic feasibility of cogeneration in a simple and effective way is through sensitivity graphs or utility curves. To generate such graphs, a given measure of merit such as a three-year payback period (a ROI hurdle = 33%) is defined as a parametric equation (simple payback = installed cost/annual savings). These graphs have been used by Steve Parker et al. to evaluate small cogeneration systems [17]. The graphs show that for various small cogeneration systems (100-300 kW), the economic feasibility is very sensitive to changes in energy charges ($/kWh) but rather insensitive to changes in demand charge ($/kW/month). In most cases, the 5- to 8-cent/kWh range is the zone of economic indifference, above which small cogeneration projects will become economically attractive.

ISSUES AND NEEDS

From the previously reviewed material and from references listed at the end of this paper, we have identified the following issues that can be the subject of further research and development.

1. **We Need Standards**. Speaking the same language is a necessary condition for effective communication. This is critical during design, evaluation, and negotiation. However, there is not an internationally accepted way of defining, quantifying and reporting *system requirements* (Table 1) nor *design-evaluation factors* (Figure 1) in cogeneration projects. While glossaries do exist, they seldom agree on key terminology. Moreover, there is not an industry standard, or generally accepted professional-society terminology, establishing operational definitions for the fundamental technical and economical variables in cogeneration system design and evaluation. Consequently, there is a need for an international industry standard for

the basic terminology and methods used during the whole life cycle of a cogeneration system (Figure 2). *It is axiomatic that speaking a common language is one of the pillars of solid cogeneration building.*

2. **System Interdependence**. Most *system requirements* are interdependent or conflict with other desirable requirements. For example, while redundancy can improve reliability and availability through back-up units, the installed cost and the operation and maintenance (O&M) expenses of multiple units is usually higher than that of a single prime mover. Many cogeneration professionals have often encountered a "chicken or egg" situation in industrial cogeneration projects. Hence, the Rubik's cube analogy mentioned earlier (Figure 1). Several cogeneration professionals have confirmed this peculiar situation [4, 16, 18, 19]. Thus, the complexity and interdependence of system requirements should not be ignored in the analysis and treated as an after thought. The issue—as it applies to Heat Recovery Steam Generator (HRSG) design and operation—has been recently reported by Power magazine as follows: *"Engineers representing HRSG manufacturers, meanwhile, expressed frustration at the owner/operator's obsession with low cost, which they said is preventing them from implementing even the most essential improvement to boost HRSG durability."[20]* On the other hand, Robert Anderson, president of the US HRSG Users' Group reports about the first HRSG users' group meeting in the UK (Fall 2002): *"Unlike at the US HRSG Users' meeting, there was widespread agreement in Birmingham about the importance of effectively and quantitatively dealing with low cycle fatigue (a structural reliability issue). The manufacturers in attendance all agreed that robust transient analysis throughout the HRSG, and such design features as full-penetration welds of superheater and reheater tube-to-header connections, are mandatory for cyclical HRSGs. The European users also seemed to have a better grasp of these issues than many operators…"* The fact is, HRSG reliability and down time problems are real. RAM is so critical for HRSGs, an unreliable HRSG will impact all relevant cash flows: asset value, cost of capital, back-up rates, revenues, penalties and O&M costs (see the reports or attend the conferences by the US HRSG Users' Group [23]). Therefore, improved methods should be established to design and evaluate cogeneration components and systems (including HRSGs). While we don't advocate mandatory command and control approaches, it

should be a distinct market advantage to design CHP using RAM standards (e.g., a car with air bags and antilock brakes). Going to the root-cause of the problems will help us make more profitable both existing and new plants.

3. **Design-for-Reliability**. Ignoring the reliability, capital cost and O&M interdependence issue doesn't make it go away. In fact, showing the way, the Australian "Cogen Ready Reconer" program deals with the system reliability-availability-maintainability (RAM) requirements, as related to system capacity and redundancy (using the "N+1 units" strategy) within the design and evaluation process. But integration or trade-off models between cogeneration system performance, costs and RAM are not available yet. To accomplish sound projects, this or similar approaches should become more commonplace in design and evaluation. The collection of relevant and significant field experiences by knowledgeable users, such as the HRSG Users' group, is key to provide corrective actions about existing systems and designs and helpful in improving design methods and standards. But there is even a higher and deeper RAM challenge. Not all prime movers are created with equal RAM capabilities. For instance, the RAM capabilities of aero-derivative gas turbines don't always have the robustness of heavy frame industrial gas turbines. How should we incorporate such a difference in design and evaluation? Again, only a life-cycle cost analysis can be the rational approach (Figure 2). Thus, cogeneration professionals need within their tool box the effective methods to define and evaluate (technically, operationally and financially) the RAM requirements and risks, and their interdependence with equipment performance and all the relevant costs. But note the feedback and learning process should never end.

4. **The "Key Issues."** We have dwelled on the RAM issue because there are several practical business needs that stem from it. Many of the issues (and associated costs!) about interconnection barriers, stand-by connection chargers and back-up power rates originate from real or perceived RAM problems. Figure 3 lists such "Key Issues" as expressed by the US CHP Association. Having a more proactive approach to RAM (i.e., start dealing with RAM at the screening and design concept stage) will help most CHP projects

WHAT ARE THE KEY ISSUES?

Interconnection policy—There are no consistent standards for interconnecting CHP units; each jurisdiction and in some cases each utility has its own. Often they are used as a barrier to entry. Interconnection approval is slow and expensive, often requiring the same processes and studies applying to 500 Megawatt power plant for a 5 MW CHP unit. Interconnection should be fast and streamlined, especially for smaller units, allowing mass-production of distributed generators that can operate in any state.

Credit for environmental benefits—Although CHP is widely recognized as the only means by which to increase fossil-fired generation to support economic growth while decreasing overall emissions, CHP units have trouble obtaining emissions permits. They run into hidebound standards, which fail to credit CHP on the basis of its greater efficiency, or do not allow credits for displacing emissions from grid generated power.

Equitable treatment in utility rates—CHP and other distributed generators are often abused by unfair rates if they seek to remain connected to the utility grid, including unreasonable stand-by connection charges and back-up power rates designed to cost as much as if they generated none of their own power. Some are threatened with exit charges if they leave the grid.

Equitable tax treatment—CHP machines are often subject to slower depreciation than the same machine used in other purposes because the tax code sees them as "utility" equipment. Their energy and environmental merits should instead entitle them to tax benefits.

Figure 3. "Key Issues" by the US CHP Association [19]
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become more profitable, less risky and more "connectable." With RAM as an integral part of system life-cycle evaluation, engineers and designers can better articulate the case for (1) more reliable systems, and (2) the removal of excessive stand-by connection and back-up utility charges. In short, it will enable us to make better business propositions through: (a) consistent standards, (b) integrated modeling with testing validation, (c) balanced synthetic-analytic methods and (d) improved CHP education.

5. **System Life-Cycle/Balanced Approach**. Recall Figure 2. While the CHP design and evaluation process appears to be an orderly "step-by-step" method, every cogeneration professional knows it is iterative in practice. Complex problem solving often requires several attempts from various angles. This also helps with learning. But we'd rather not make the same mistake twice. Thus, we are willing to invest money to learn from others' critical mistakes. In this context, we consider the need for a balance between: (a) the data intensive and time consuming analytical approach, usually implemented using computer programs, and (b) the concise and quick—but at times simplistic—synthetic approaches. To reconcile these two extremes, we recommend that both methods be integrated, starting with the synthetic approaches, as early as possible in the screening phase, and to keep them as "permanent dashboard indicators" as we progress towards more detail designs and get better predictions of the system life-cycle costs. Thus, if the "acid tests" of energy profitability index (say CEP >0.3) or a reasonable payback period does not pass muster, the business risk will still be there, regardless of how many advanced technology or financial schemes we incorporate into the project. Keep in mind that leasing and other off-balance-sheet options help us manage risk but do not eliminate it. Past research at Oklahoma State University [27, 28] and current development are underway to enhance synthetic methods to handle RAM, variable/cycling/random loads, and size optimization within a system life cycle approach. Recall that very complex systems and phenomena are often represented through compact models. Thus, $E= mc^2$.

6. **Integrated Design**. This is not a new concept, but the need is latent. In 1987, Cook and McCue or C&M [21] described *"an approach wherein technical and economic criteria are applied to size and select candidate power/process cogeneration systems, in an early stage when financial ownership negotiations may affect, and be affected by, such sizing and selection."* Notice again, the chicken-and-egg situation in their words: "may affect, and be affected by." They go on stating: *"The integrated approach is intended to avoid the waste of financial resources*

which has typically resulted from downstream collapse of large (and small) cogeneration projects, for which detailed design efforts have been initiated in a volatile financial/ownership environment." To emphasize the need for system design and industrial process integration, C&M conclude: "*…the integrated approach here described refers to the degree to which the (combined heat and) power producing system is integrated with the process system yielding the commercial product (or service).* ***This is the essence of cogeneration***."

7. **Facts versus Speculation**. What C&M were preaching is common sense but rare practice. "An ounce of prevention is better than a pound of cure, and much better than a ton of project failure." But a precautionary approach is not always popular in a highly speculative and "bias-for-action" environment. Nevertheless, those who don't heed this advice are fair game for the con artist. In fact, those who dive too quickly to the project development pool, without the lifesaver of due process, often drown their projects. Recall Dr. Turner's advice below the title of this article. A fact-based process always makes more dollars and better sense. So, it is critical for the cogeneration professional to do sufficient fact finding and data gathering on site (i.e., human intelligence). If at all possible, one must verify (a) the raw data and (b) the measurement system, instruments, bills, etc., used to get the data. From this depends the quality of information to be entered into the computer program. This way, we can prevent the garbage-in/garbage-out or GIGO syndrome.

8. **Tactics Follow Strategy**. We can win battles and still lose the war. Good tactics and techniques win battles. But only a good strategy wins the war. Here we mean strategic policy. Notice the "invisible hand" of a very imperfect deregulated market can not handle it all. It begs for help from another hand: For what is common sense in any ball game. That is the help from the visible hand to steer the system with "clear game rules" and "effective referees" in the regulatory, technical and economical arenas. That means—I beg your pardon-, we need a strategically minded US Energy Policy. Wayne Turner's call for government-agency consistency in his editorial "Letter to Congress, DOE and EPA" was an eloquent call for such strategic policy [24]. Until today, there was no response to Dr.

> Turner's call. But, now it appears President G.W. Bush is going to do it, as expressed in his State of the Union Address [25].

CONCLUDING REMARKS

While this study is by no means exhaustive, we trust the eight (8) points discussed above have been made. Thus, we sincerely call upon other cogeneration professionals and authors—hopefully with the illumination of a coherent US Energy Policy and the guidance of sound business strategy—to accompany us on the quest for consistent standards and integrated methods for cogeneration system design/evaluation. As Prof. Wayne Turner has advised, *to be cost effective we must account for all relevant costs*. Thus, more profitable CHP investments can result from a fact-based understanding of process/facility needs, opportunities and limitations, present and future. By using past and present research work, forthcoming articles in this Journal should model, quantify and integrate some of the previously discussed issues within the realm of cogeneration design and evaluation [30]. To conclude, we quote D. Steen, who reported at the 13th World Energy Engineering Congress on the performance of cogeneration units in the Detroit Edison's Service Territory. His advice we shall not ignore.

> *"I am of the opinion that (in cogeneration) to arrive at separate solutions for power reliability and quality problems independent of energy cost reduction efforts is to ignore optimal economics."* [22]

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