Part Two of a Two-part Series

Don't Even *Say* Energy Conservation— It's "Energy Productivity"

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ABSTRACT

The strategic energy related opportunities in manufacturing which sharply reduce production costs are often never identified. Even when identified, these low-risk investments, which provide very compelling financial returns, are often rejected when non-energy related investments, which have a higher risk and less compelling financial results, are implemented.

In part one of this article, we explained why the energy opportunities which will radically improve business results must be built upon manufacturing initiatives, not conservation. Energy productivity is the focus.

It's not about energy savings. It is about optimizing energy as a factor of production, leading to an energy epiphany. The best opportunities will improve the production rate, which may increase or decrease energy use.

With the conventional, less effective, energy conservation methods, the "energy auditor" (a word we shouldn't use) looks for which of the usual energy saving technologies "fit" at a plant. This is like a solution seeking a problem, and often leads only to superficial improvements. It is far more effective to find the root opportunities first.

In part two of this series, "energy productivity," a unique analysis methodology will be presented. It is effective in discovering the energy productivity opportunity within the manufacturing initiatives-based strategy. With the energy productivity approach, we aren't looking for

anything in particular; **the manner in which we gather unbiased facts about the plant energy processes will simply show us the fundamentally valuable opportunities**. It is backwards from the conventional methods.

Opening up to this broader view seeking to optimize energy productivity, the opportunity shows itself through a three-step process:

- Each production process is evaluated to define how energy adds value in direct relation to the process parameters. This is summarized in a value-added energy inventory.

- The aggregate plant energy use is measured during normal production, during a production-ready (but no production) condition, and during a typical no-production day. Some simple comparisons provide a top-down value-added energy assessment. This is used to cross check the value-added energy inventory and identify the aggregate non-value-added energy waste. The aggregate energy use patterns may characterize the major causes of the non-value-added energy waste.

- Each major non-value-added energy waste is characterized by engineering estimates or measurements, and summarized in a non-value-added energy inventory in an effort to break down the losses in relation to the total plant energy use.

THE VALUE-ADDED ENERGY INVENTORY

In prospecting for energy productivity, we first must understand how each energy application adds value in the manufacturing process. For these purposes, value-added energy processes would include thermal processes which directly affect the product(s) or are essential to the process environment, such as the following processes when in direct contact with the product:

- Heating
- Cooling
- Washing
- Rinsing
- Process sanitation
- Evaporation
- Freezing
- Thawing
- Thermal storage

The energy parameters (heat rates, temperatures, flows, etc.) are analyzed in relation to the process parameters (product time and temperature conditions, run rates, cycle times, etc.). The energy use is best determined by engineering calculations based on what is accomplished with the product itself, since this is all that really matters (such as a temperature rise or fall over a time duration) or the changes to the medium the product is in (such as inlet and outlet conditions in an air drying stream or water wash flow). This is based on the combined knowledge of operations, engineering, and maintenance personnel. It should not be based on engineering process definitions only, as there are likely to be some very important nuances which must be taken into account. Each value-added use of energy is defined, in a thermal/mass balance, so an accurate and reliable understanding of the energy requirements is obtained. Include all mass/energy flows entering and leaving the process for the average (steady state) condition (not start up).

Do not be distracted by ideas which will arise during this step. Just put these aside until later. Such distractions will take the initiative off course and result in little improvements with little returns. These may not even be relevant to the energy epiphany, which may show itself later. The purpose here is to understand the energy fundamentals of the processes, individually and in relationship to each other.

Early in an analysis at a textiles plant, the application of a direct-fired process water heater seemed to be a great opportunity. With the poor efficiency of the old boilers, and no condensate return, this would reduce fuel use by over 30 percent. However, we later saw how to use hot waste water heat recovery to reduce the water heating by 70 percent. The new water heater was a distraction; it would have been a comparatively small improvement with a longer payback.

This analysis provides several results:

- The process requirements for energy are clearly defined. This knowledge is essential to ground any energy productivity proposal in the process itself and assure that any proposal will (at least) not have any detrimental effect on production. (It should be clarified that changes in the process specifically are *not* being recommended as an energy strategy, as this is rarely (or never) worth the risk. Rather, the focus is to assure that the required energy flows (i.e.

200GPM of water at 185°F) are provided within any suggested alternative).

- Synergistic opportunities for energy productivity are exposed, such as pre-heating process hot water by heat recovery cooling of a process refrigeration system.

- Opportunities to accelerate energy delivery or improve energy control may be discovered, which will enhance production rates or reduce process variation. For example, faster response removal of non-condensables from process steam is often easily accomplished, accelerating heat-up cycle times.

This analysis need not involve a great expense to provide metering. The best measurements would be based on the product flow itself (such as a pasteurization process) or the product medium (such as a wash line flow), which is probably already monitored in detail. Otherwise, there are often rather easy methods to approximate the thermodynamic properties and mass flows. This is particularly true of heating and cooling which involves water (or any liquid), where it's much easier to observe the flow rates and temperatures with reasonable accuracy than to attempt to measure steam flows or refrigeration loads. When necessary, steam can be measured as condensate by counting condensate pump cycles of known volume, or just collecting the condensate in a barrel half filled with cold water.

In most plants, the true relationships of energy use to the production processes are not clearly known. Energy use characteristics are known only in aggregate terms. Through this analysis process, a better understanding of the production process itself will result, which often leads to large and simple energy productivity enhancements. Typical results have included:

- Heat recovery from hot waste water from a fabric washing process to pre-heat water for the same process at a textiles plant, which cut energy and related operating costs by $530,000 (over 70 percent) and sharply reduced capital cost to replace a 70-year-old steam plant.

- The use of hot water from food processing product cooling as water feedstock to the same process (in lieu of cold water make). This eliminated the cycle time and energy needed for pre-heating the blended raw product mix and the need for a large boiler replacement. The energy savings were over $400,000; the project cost was less than the averted boiler replacement.

- Heat recovery cooling of air compressors providing hot process water up to 175°F.

THE TOP-DOWN VALUE-ADDED ENERGY ASSESSMENT

The energy inventory is then integrated within a top-down (big picture) analysis of the energy use characteristics during normal production in comparison to a production-ready condition, and during no production downtime. These are compared in some simple ratios to find the easiest and most lucrative opportunities.

Energy use during downtime is measured, which provides the baseline non-value-added use. If space heating is involved, the measurement should be taken during the non-space heating season. Except for any product thermal storage, this is *all waste*.

Energy use during normal production is measured. As a ratio of downtime use/production use, several cases over 90 percent waste on this basis have been noted; 50 percent waste is not uncommon. A high percentage compels site analysis to find the root cause of such problems as:

- Steam trap leaks or other distribution piping losses.
- Sub-optimum boiler operation practices or related control problems.
- Sub-optimum process shutdown practices.

Energy use during a typical production-ready (but no production) condition is measured. The production-ready use, less the downtime use provides the aggregate of non-value-added process loads, which relates to losses in the process itself such as:

- Sub-optimum process controls.
- Leaks or other types of energy losses directly related to processes.

The energy use during normal production, less production-ready energy use, roughly indicates the value-added energy use, which serves to cross check the value-added energy inventory described previously. This usually leads to some further scrutiny of the production processes to assure that a reasonably accurate relationship of energy use to the process has been developed.

A logical review of existing data, such as the daily boiler logs charted in Figure 1, will usually show an informative picture of the overall top-down energy characteristics. In this example, the steam base load doesn't change during the downtime period over a few weeks in the summer. The system waste in the summer is about 20,000 PPH; the typical value-added use is the 'noise' on the summer curve of 5,000 PPH. Hence, waste is about 80 percent of input in the summer. The irregularly occurring 20,000 PPH summer load spikes were caused by the EMCS irrationally activating space heating. Warm periods during the space heating season show very high steam loads (see around April 1), which indicates a winter waste of 40,000 to 60,000 PPH. The energy inventory in this case, including steam generation losses, indicated over 90 percent waste.

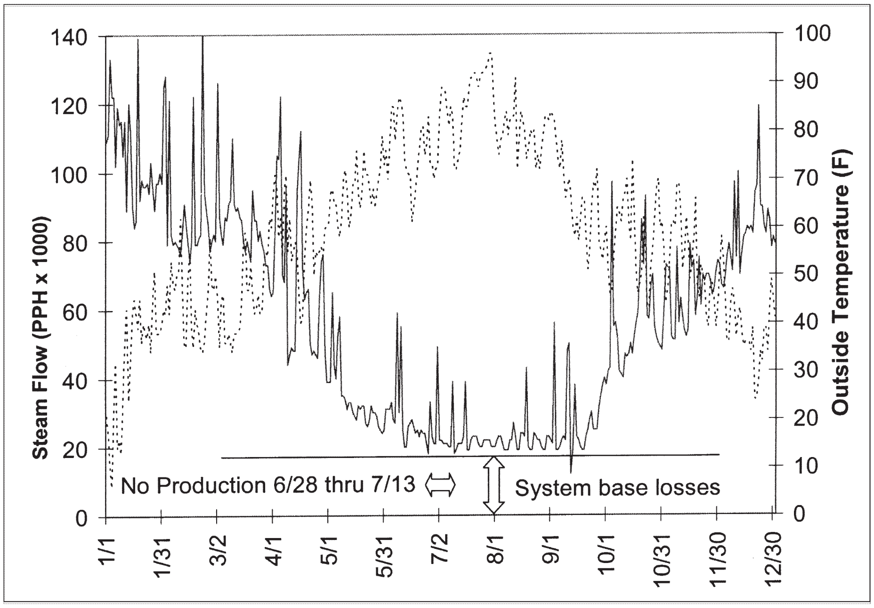


Figure 1

THE NON-VALUE-ADDED ENERGY INVENTORY

As stated earlier, the energy supply systems are not the first focus, they are last. Now is the time to identify these supply side losses with a more comprehensive technique.

The energy parameters (temperatures, flow rates, and physical conditions) of each major non-value-added energy waste are characterized to determine the average rate of energy waste for each, which is summarized in a non-value-added energy inventory. These non-value-added energy processes would be all other energy processes, including losses related to supply systems and any discarded flow streams, such as the following processes which are not in direct contact with the product:

- Steam generation
- Steam distribution
- Steam traps
- Condensate losses
- Hot waste water (after washing or rinsing)
- Facility heating or cooling
- Air compressor cooling
- Compressed air after coolers & dryers
- Refrigeration condensers
- Exhaust stacks

If the process uses hot water, the cooling processes which are not directly associated with the manufacturing processes should be included in the research, such as air compressor cooling systems and any sizable air conditioning condensers. The equipment whereby energy is thrown away (steam vents, condensers, cooling towers, once-thru cooling water) is of special interest. If there is reasonable proximity, these systems may provide a good opportunity for free process heat.

THE ASSEMBLED ENERGY INVENTORY

The value- and non-value-added energy inventories are combined, totaled, and compared to the top-down total plant use (again, during steady state, not start up, conditions). A close balance is not expected since the total metered use will include start-up loads. The intent is to drive the analysis process until all process heat requirements and the major non-value-added waste are identified.

The results of the study should be accumulated in a data table showing the relationship of value-added and non-value-added energy loads in relation to the top-down energy use measurement. The data table should also summarize each concurrent cooling process in relation to the associated manufacturing processes, or the plant in general. All should include the supporting process parameters, relevant supporting basis data, and typical operating schedules for each energy use.

This analysis often needs to be assembled for the space heating and non-space heating seasons separately in order to correlate to top-down metering data.

The supporting basis data are provided for a simplified (production, non-space heating season) example energy inventory in Table 1A. The energy usage and annualized extrapolation for each use is provided in Table 1B. In this example, further research is needed to find a significant amount of unaccounted for fuel usage. From this preliminary information, the value-added process parameters would be verified in detail to confirm that all process steam has been accurately addressed. Then the plant must be reviewed again for non-value-added losses. A close balance is not expected; the drive is to characterize all production needs and identify all uses which have an appreciable impact.

The top-down energy value-added energy assessment should be summarized and charted with interpretations. Data summaries should be prepared indicating the proportion of non-value-added energy waste. Charts to assist in seeing the overall picture should be developed as needed (similar to the steam chart provided earlier).

See that all major uses are accounted for and that the data make sense top-down and bottom-up. Further verification or additional information is likely to be necessary, several times.

This often shows that well over 50 percent of usage provides no value, which inspires scrutiny on the definitive causes and corrective measures to reduce this waste. With a comprehensive understanding of the plant value-added energy processes, and some good creative thinking, the focus is clarified as to where the major opportunities will be found. Time wasted researching dead ends or chasing rainbows is avoided. Radical improvements in supply system efficiency may be possible at very little or no cost.

In some cases, a major opportunity, which others have missed, is discovered after many attempts. Some examples of supply side cost reductions include:

- Operational changes to steam distribution—annual savings $100,000/Cost $0.

- Improvements to steam distribution piping to allow large-scale shut down of space heating and most of the plant steam supply piping in the summer—several cases in the 1- to 3-year payback range reducing summer loads by 20 percent or more.

- Proactive annual steam trap maintenance reducing steam loads by 20 percent or more, with payback in a few months.

- The 'typical' boiler operations improvements such as automatic blow down TDS control; blow down heat recovery, economizers, and combustion control, though fewer boilers will warrant these investments if the base load is reduced.

ENERGY PRODUCTIVITY MODELING

Regular discussion in which the preliminary findings are reviewed and people share ideas and questions among those directly involved in the analysis is suggested. This may result in some additional gathering and/or verification of information. Put together a rough list of ideas, without judgments.

There may be several ideas on the table which look attractive:

- Some are mutually exclusive;

- Some value-added side ideas may be affected by whether or not efficiency improvements on the supply side are implemented;

- And vice versa, some supply side opportunities may only be possible if certain ideas on the value-added side are implemented;

- Some are independent ideas which stand alone.

Maybe an energy epiphany has surfaced, or at least you think it has. Make no decisions at this point on what to recommend or not recommend.

Table 1A. Example Energy Inventory

EXISTING Normal production, summer conditions

VALUE ADDED - Processes which directly effect the product(s) manufactured or are essential to the process environment

AVERAGE (NOT DESIGN OR START UP) PER UNIT OPERATING CONDITIONS

				FLUID TEMP RISE METHOD								STEAM ESTIMATE METHOD			
PROCESS HEAT	# of units	Fuel Conversion %η	Steam Pressure (PSIG)	Fluid	Volume / Batch	Batches / Hour	Flow (units / min)	density #/unit	Btu/#°F	Entering (°F)	Leaving (°F)	KPPH	Enthalpy Baseline (Btu/#)	Steam Enthalpy (Btu/#)	Pump &/or fan kW
Product pre mix water blending	10	100%	100	water (Gal)			40	8.33	1.0	59	210				
Product raw material	10	100%	100	concentrate (Gal)			20	7.900	0.9	65	210				50

		HOT SIDE							COLD SIDE							
NON CONDENSING COOLING SYSTEMS	# of units	Fluid	Flow (units / min)	density #/unit	Btu/#°F	Entering (°F)	Leaving (°F)	Pump &/or fan kW	Fluid	Flow (units / min)	density #/unit	Btu/#°F	Entering (°F)	Leaving (°F)	Heat Recovery (%)	Pump &/or fan kW
Finished product cooling	10	water (Gal)	58	7.95	0.93	190	80	45.0	water (Gal)	51	8.33	1	59	170		

NON VALUE ADDED LOSSES - All other energy processes (supply systems, discarded flow streams)

		HOT SIDE							COLD SIDE							
NON CONDENSING COOLING SYSTEMS	# of units	Fluid	Flow (units / min)	density #/unit	Btu/#°F	Entering (°F)	Leaving (°F)	Pump &/or fan kW	Fluid	Flow (units / min)	density #/unit	Btu/#°F	Entering (°F)	Leaving (°F)	Heat Recovery (%)	Pump &/or fan kW
2000CFM oil flooded screw air compressor oil cooler	1	oil (Gal)	80	8.19	0.5	180	135		water (Gal)	177	8.33	1.0	85	95		16.2

DISTRIBUTION LOSSES	# of units	Fuel Conversion %η	Steam Pressure (PSIG)	Pipe OD (inches)	OS Temp °F	Steam Temp °F	Dist. (ft.)	Insul (inches)	Insul Type	Insul Btu/in/(hr ft2 d°F)
Main	1	100%	100	8.0	70	337	900	2.0	F	0.55
Sub mains	5	100%	100	4.5	70	337	200	1.5	F	0.55

OTHER STEAM LOSSES	# of units	Fuel Conversion %η	Steam Pressure (PSIG)	Loss each (PPH)	Enthalpy Baseline (Btu/#)	Steam Enthalpy (Btu/#)	
Steam Trap Leaks	71	100%	100	40	308	880	See Steam Trap Testing Summary. The sampling of 46 traps tested showed 34% to be leaking an estimated 40PPH average (210 estimated total traps).

INTERNAL BOILER ROOM LOADS:	% of fuel input	Loss percentages obtained from boiler testing, flow & temperature measurements which is provided in the Boiler Analysis.
Stack Loss	18.0%	Determined from stack excess oxygen & temperature testing.
Heating Unidentified Condensate Lost	5.2%	Total facility condensate loss (including flash loss) less any specific condensate losses identified above.
Heating for Blow down Lost	0.6%	Determined from raw feed water TDS in relation to average actual boiler drum TDS.
Returned Condensate Heating	2.4%	Heat from returned condensate temperature to feedwater temperature
Turbine Exhaust Wasted	0.0%	Turbine exhaust not useable for beneficial heating
TOTAL IDENTIFIED THERMAL INVENTORY		
METERED FUEL INPUT DURING THESE OPERATING CONDITIONS (From Top Down Analysis)		
UNACCOUNTED FOR FUEL USAGE (= Metered Fuel Use - Value Added Usage - NON Value Added Losses)		

Table 1B. Example Energy Inventory

EXISTING **Normal production, summer conditions**

VALUE ADDED - Processes which directly effect the product(s) manufactured or are essential to the process environment

		TOTAL USAGE / HOUR (ALL UNITS)				UTILIZATION			ANNUAL USAGE (ALL UNITS)			
		FUEL	OTHER						FUEL	OTHER		
PROCESS HEAT	Utility	FUEL KBtu / H	Electric Power (kW)			Hours / Week	Utilization Factor	Weeks / Year	FUEL MMBtu / Year	Electric Power kWH		
Product pre mix water blending	STEAM	30,187.9	0.0			120	80%	28	81,145	0		
Product raw material	STEAM	12,371.4	500.0			120	80%	28	33,254	1,344,000		
				COLD SIDE								
NON CONDENSING COOLING SYSTEMS	Utility	FUEL KBtu / H	Electric Power (kW)	HEAT REJECTED KBtu / H	WATER. GPM	Hours / Week	Utilization Factor	Weeks / Year	FUEL MMBtu / Year	Electric Power kWH	HEAT REJECTED, MMBtu / Year	COOLING WATER KGal / Year
Finished product cooling	WATER	0.0	450.0	28,302.3	510	120	80%	28	0	1,209,600	76,076.6	82,277.9
	Σ VALUE	**42,559 58%**	**950**	**28,302**	**510**				**114,399 49%**	**2,553,600**	**76,077**	**82,278**
	NON VALUE ADDED LOSSES - All other energy processes (supply systems, discarded flow streams)											
				COLD SIDE								
NON CONDENSING COOLING SYSTEMS		FUEL KBtu / H	Electric Power (kW)	HEAT REJECTED KBtu / H	WATER. GPM	Hours / Week	Utilization Factor	Weeks / Year	FUEL MMBtu / Year	Electric Power kWH	HEAT REJECTED, MMBtu / Year	COOLING WATER KGal / Year
2000CFM oil flooded screw air compressor oil cooler	CTW	0.0	16.2	884.0	0	120	65%	28	0	35,419	1,930.6	0.0
DISTRIBUTION LOSSES		FUEL KBtu / H				Hours / Week	Utilization Factor	Weeks / Year	FUEL MMBtu / Year			
Main	STEAM	113.8				120	100%	28	382			
Sub mains	STEAM	90.3				120	100%	28	1,517			
OTHER STEAM LOSSES		FUEL KBtu / H				Hours / Week	Utilization Factor	Weeks / Year	FUEL MMBtu / Year			
Steam Trap Leaks	STEAM	1,633.6				120	100%	28	5,489			

INTERNAL BOILER ROOM LOADS:		FUEL KBtu / H								FUEL MMBtu / Year				
Stack Loss	NG	13,230.0					168	100%	28	62,234				
Heating Unidentified Condensate Lost	NG	3,792.3					168	100%	28	17,839				
Heating for Blow down Lost	NG	404.5					168	100%	28	1,903				
Returned Condensate Heating	NG	1,764.5					168	100%	28	8,300				
Turbine Exhaust Wasted	NG	0.0					168	100%	28	0				
		FUEL KBtu / H		Electric Power (kW)	HEAT REJECTED KBtu / H	WATER. GPM				FUEL MMBtu / Year		Electric Power kWH	HEAT REJECTED, MMBtu / Year	WATER KGal / Year
	Σ NON VALUE	**21,029**	**29%**	**16**	**884**	**0**				**97,665**	**42%**	**35,419**	**1,931**	**0**
TOTAL IDENTIFIED THERMAL INVENTORY		**63,588**	**87%**	**966**	**29,186**	**510**				**212,064**	**90%**	**2,589,019**	**78,007**	**82,278**
METERED FUEL INPUT DURING THESE OPERATING CONDITIONS (From Top Down Analysis)		**73,500**	**100%**							**235,000**	**100%**			
UNACCOUNTED FOR FUEL USAGE (= Metered Fuel Use - Value Added Usage - NON Value Added Losses)		**9,912**	**13%**							**22,936**	**10%**			

Give it some time. If there is a strategic opportunity, it will show itself in the comprehensive energy assessment which has now been assembled with patient review of the fundamentals in the energy inventory. Don't be distracted by some of the usual suspects who are also present. Deal with them later if they aren't swallowed by the strategic opportunity.

Create a separate file of the energy inventory, copied from the initial inventory, to develop an energy productivity model incorporating the improvements which are under consideration. Different sets of ideas which are mutually exclusive will need to be assembled in separate models. In each model, start with improvements in value-added loads first, then modify the supply side (non-value-added) impacts proportionately, then model improvements to the supply side last. This approach eliminates errors in overstating the impact from related improvements, such as over-estimating a boiler efficiency savings on the basis of the existing higher steam loads which will be sharply reduced by other measures.

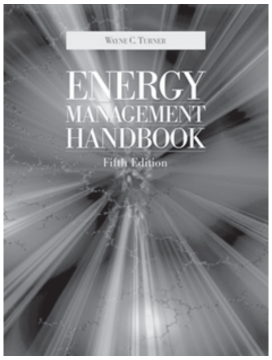
After considerations to optimize energy productivity at the process level first and then reducing the non-value-added waste, the total requirement for energy supply is redefined, often at a substantially lower level. Only at this point can the optimization of the energy supply system be effectively considered. In this order, investment in supply capacity or efficiency for energy services which are actually not needed is avoided. For example, where prior planning showed one of the boilers needed to be replaced or substantially upgraded, the need for that boiler was eliminated.

The bottom line impact of a set of improvements is simply determined by subtracting the energy productivity model total use from the existing systems energy inventory.

CONCLUSION

In about one of every five plants, this energy productivity strategy and the supporting value-added analysis methods focused the plant's energy processes from an entirely new perspective, leading to improvements of 40 percent or more, which sometimes also increased manufacturing output.

For example, an energy epiphany is lurking in the simplified case provided in Tables 1A & 1B. These tables show a simple, single change



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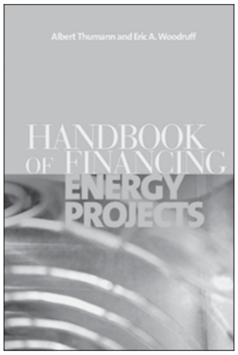

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that will reduce process energy use by over 50 percent and increase plant output. It had been obscured for over 40 years of operation and missed in recent detailed analysis by three site "energy audit" teams.

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ABOUT THE AUTHOR

Oliver L. Clarke, CEM, is president of Synergy America, Inc., an engineering consulting firm specializing in the development of innovative energy productivity opportunities in manufacturing. Clients include both manufacturing companies and large energy service companies who are serving manufacturing clients. Core capabilities include steam systems optimization, heat recovery, compressed air, and refrigeration.

The foundation of Oliver's capabilities is 20 years of experience in mid- to top-level engineering, utilities, and maintenance management at two massive manufacturing plants. He knows the manufacturing client's heart and conscience, because he lived there, holding the line responsibility for their same concerns. This common experience builds the strong relationship and trust at the project site, which is essential to developing the optimum solutions.

Oliver is a graduate of Georgia Institute of Technology with a degree in mechanical engineering, and has completed post-graduate education in business administration, finance, risk management, business law, total quality management (TQM), predictive maintenance, and innumerable energy subjects.

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