Pump Systems Performance Impacts Multiple Bottom Lines

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ABSTRACT

Given the volatile economic climate, organizations are increasingly adopting process improvements to gain competitive advantages. Finding ways to save money and enhance operations are more important than ever. In the United States industrial sector, electric motor systems consume over 679 billion kWh of electricity per year, with pumping systems accounting for about 25 percent of that total [DOE 1998]. A better system design and optimized pumping system can usually save 20% or more in energy costs annually [DOE 1998]. This represents approximately 29,000 GWh per year (the electrical output of the city of Los Angeles), which equals a reduction of carbon emissions by nearly 20 million tons per year.

With the pressure on industry to help protect the environment and positively affect global climate changes, efficiency remains an extremely cost effective option. Just as critical as energy reduction, improved pump system performance lowers maintenance costs and improves systems reliability for better asset management.

The process of identifying, understanding, and effectively eliminating unnecessary efficiency losses, while reducing energy consumption, improving reliability and minimizing the cost of ownership over the economic life of the pumping system is commonly referred to as systems optimization.

To assist pump users gain a more competitive business advantage through strategic, broad-based energy management and pump system performance optimization, the Hydraulic Institute developed Pump Systems Matter (PSM), an educational 501 (c) 3 organization.

This paper will highlight the financial benefits of system optimization practices and the use of variable speed drives. It will review case studies which will show specific ways to validate financial savings and payback periods.

Overview

System optimization best practices offer a new way of viewing pump systems as opposed to components. Currently, many companies are employing pump system optimization methods and evaluating existing pumping systems to affect multiple bottom-line cost savings, increase energy efficiency, address environmental issues, improve systems reliability and most importantly enhance organizational profitability.

This is because pumps are widely used by industry to supply water, process wastewater, transfer fluids for processing applications, provide cooling system fluid circulation and offer the motive force in hydraulic systems, among numerous other applications. In the commercial sector, pumps are primarily used in heating, ventilation, and air conditioning (HVAC) systems to provide water for heat transfer. Municipalities use pumps for water and wastewater transfer and treatment and for land drainage.

As a result of all of these applications, pumps are the second most widely used machine in the world after motors, with their purchase and operation entailing significant expenses for most facilities. However, it is common practice for pumping system design and procurement to be based primarily upon the initial purchase cost of the equipment. Often such decisions, particularly with new systems, are under the control of the engineering contractor – who has few incentives in the world of fixed price contracts to embrace energy efficient pump system designs.

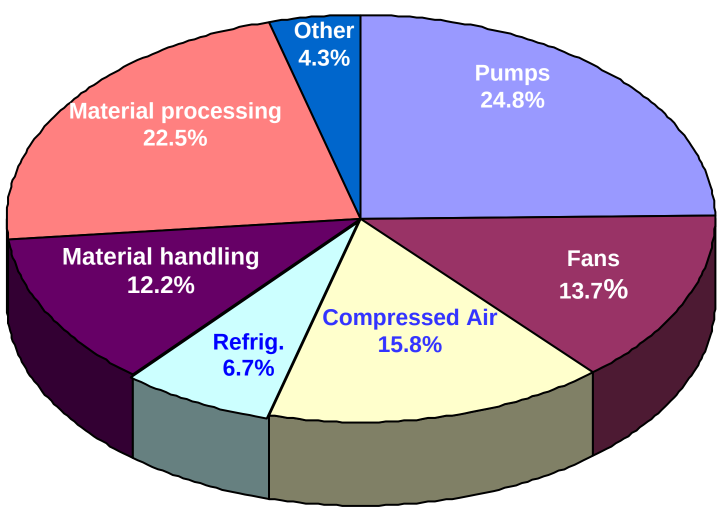
Depending on the application and operating environment, the initial pump purchase is small in relation to overall pumping systems costs. Energy, maintenance, and other operating costs far outweigh initial expenditures. Therefore, it makes economic sense to consider these lifetime costs in addition to original pump pricing when designing and procuring pumping systems. [LCC Guide]

Subsequently, each year the number of retrofit optimization opportunities greatly exceed the number of new system installations with the bulk of potential savings lying within the enhancement of existing control systems, pumps or both. As a result, the average energy savings potential through economically viable pump system optimization projects is approximately 20%, although certain installations can realize even greater savings ranging from 25% - 50%. This potential represents significant *cost* savings in addition to energy efficiency improvements that normally coincide with improved reliability, productivity, and reduced environmental costs.

However, the numerous benefits derived through the optimization of existing systems should also not be ignored. For a given *new* system, the potential savings in energy and life cycle costs are far greater than in a given *existing* system of similar size and application. One reason for this is the opportunity to optimize piping system designs. Other aspects of the pump system can also be better tailored to the system requirements in the design of new systems.

In 2007, the Department of Energy (DOE) "Save Energy Now" Program identified over $5 million dollars in costs savings with just 31 pumping system assessments looking at only 2 or 3 systems per plant. In addition, a recent industrial motor systems market opportunities assessment by the DOE also reviewed motor energy consumption and savings by numerous industry groups. Among the findings was the realization that pump system optimization practices could greatly increase organizational cost savings since pump systems make up 25% of the motor opportunities in these companies (see Figure 1).

Figure 1. Electric Motor System Energy Use by System



However, this process must begin with the proper assessment of pump system costs. For example, the average plant today, based on kWhr cost increases since 1998, spends over $1,400,000 per year on pump system energy. As a result, the average savings achieved from the optimization of pumping systems can potentially be valued at $350K per year. In larger facilities, these savings could even run into the millions of dollars. For example at Eastman Kodak's Kodak Park facility in Rochester, NY, pump system energy assessments were performed on 122 systems in which the pump was over 75 house power (HP). The energy savings identified were $2.3 Million per year with an implementation cost of approximately $1.1 Million. [Kodak]

A Pump "Systems Approach" to Energy Efficiency

Energy efficiency offers an extremely important way to address energy concerns since many of its methods are both cost effective and easy to implement. For instance, energy efficiency costs less than $400 dollars per KW, while new power plant building costs can reach $2500 dollars per KW. [EnergyBiz]

In United States industrial plants, more than 40 million electric motors convert electricity into useful work. These motors consume about 60 percent of the electricity used in the industry. Increasing the energy efficiency of these existing motor systems can lead to dramatic energy savings nationwide.

According to the DOE, since implementing "Six Sigma" energy management practices in 1990 to complete more than 75 projects, DuPont has saved $250,000 annually per project, while reducing greenhouse gas emissions by 68% — exceeding their 2010 target of 65%. In addition, the company's corporate-wide energy use has remained flat since 1990, despite a 35% increase in production.

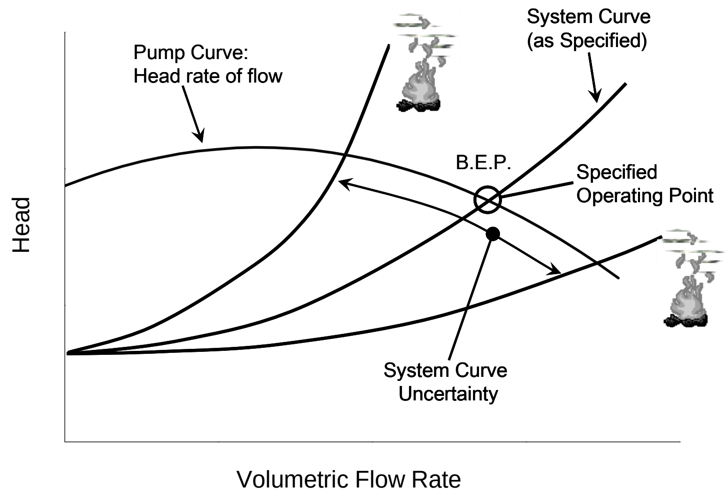
With the pressure on industry to help protect the environment and positively affect global climatic changes, especially considering the very possibility of legislation evoking a cap and trade system, increasing industrial efficiencies, including the optimization of pumping systems, is by far the most cost effective solution.

In addition, a systems approach, which analyzes both the supply and demand sides of a pumping system and how they interact, almost always produces greater energy and cost savings than the optimization of components alone. For example, a survey of only the components of a pumping system may reveal opportunities for an energy efficient motor, replacement of a leaking valve, and adjustment to the energy management system to precisely align the pump operation hours to the schedule of the end-use process. In comparison, analysis of the pumping system using a systems approach could identify a varying load profile that could best be met through a two-pump arrangement or adjustable speed drive, resulting in a 50-60% savings.

In fact, approximately 75% of the total life cycle cost of a typical pumping system is accounted for in energy and maintenance costs. (This will vary significantly by application.) To maximize pump system efficiency, the pump must be operated at its "Best Efficiency Point" (B.E.P). According to HI standards, "the B.E.P. is the rate of flow and head at which the pump efficiency is at maximum." [HI 1997, HI 2000]

A systems approach to new pumping system design is equally important, and often overlooked. A recent survey of seven pump manufacturers revealed a significant lack of understanding on the part of pump specifiers and purchasers regarding the proper application of pumps [Walters]. These pump manufacturers were asked "What percentage of the pumps your company sells are incorrectly specified by the contractor or owner/operator?" Of the five manufacturers that responded with a percentage, three indicated a value of 60% or greater, and one indicated that 30-40% were incorrectly specified. A follow-up question asked “Of the pumps that are incorrectly specified, what percentages is a result of inaccurate operating point specifications (i.e., rate of flow, required pressure, and net positive suction head)?” The answers varied between “most” to 90%. Even though this was a small survey, the responses indicate a severe lack of understanding of the proper application of pumps and properly matching their characteristics to the system. Misapplication of pumps has a direct affect on pumping system operating costs. A pump forced to operate away from its Best Efficiency Point (B.E.P.) increases energy and maintenance costs, and shortens the life expectancy of that pump. Figure 2 shows this graphically.

Figure 2. Pump System Curve Uncertainty



Pumping System Efficiency & Optimization

New solutions for increasing pumping system efficiencies can provide significant economic opportunities for reducing energy consumption. For instance, the over-sizing and under-sizing of pump systems during the purchasing and installation processes can create numerous issues. This is because centrifugal pumps alone:

- Consume 20% to 60% of plant motor energy
- Have the highest process equipment maintenance cost
- Remain a major source of process leaks & fugitive emissions

However, a recent paper by the ARC Advisory Group revealed that while American industry spent millions of dollars on information systems to review production management and asset management processes, major assets such as pumps, fans, blowers, etc. were disconnected from the process. Companies have little real time data on the performance of these assets and up to 60% percent of scheduled maintenance checks on valves and motors are unnecessary due to the lack of performance data. [ARC]

But, this can be easily remedied with low-cost Internet-based technologies as well as other methods, which can now provide an integrated view of pump system efficiencies that include a review of chips or variable speed drives, operational conditions and process parameters like flow and pressure. Among these technologies are low cost, wireless predictive condition monitoring systems that provide continuous online machine monitoring as well as intelligent flow systems that work with any pump using variable frequency drive (VFD) controller and control software to provide advanced process control, enhanced reliability through failure prevention, reduced life cycle costs and up to 65 percent lower energy costs. It is then through the use of products like these that facilities worldwide can greatly increase their ability to enhance process parameters and production assets, while simultaneously reducing energy costs and increasing corporate bottom lines.

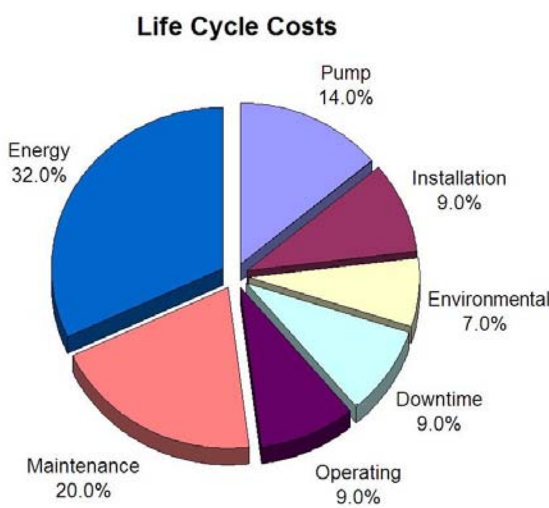
To further highlight the need for enhanced pump system optimization processes, in 1996 a Finnish Technical Research Center report, "Expert Systems for Diagnosis and Performance of Centrifugal Pumps," revealed that the average pumping efficiency, across the 20 plants and 1690 pumps studied, was less than 40%, with 10% of pumps operating below 10%. Pump oversizing and throttled valves were identified as the two major contributors to this sizeable efficiency loss. [Finnish]

Pump systems optimization is all about maximizing efficiency. This includes modifying pumps mechanically to achieve best efficiencies for the longest possible period of times.

Unfortunately for the past 150 years, industrial automation development practices have included the oversizing of pumps to accommodate increased production expectations or larger-than-needed safety margins. As a result, pumping systems that may have been purchased at exceptional prices could actually be operating with extremely high maintenance and energy costs since they were not because optimized initially to run at best efficiency.

After factoring these conditions along with rising inflation costs, a pump costing $100,000 to purchase and install could actually end up costing up to $435,000 a year, once you factor in the energy, maintenance and other costs involved when you analyze the life cycle costs of a pumping system (Figure 3).

Figure 3. Life Cycle Costs Analysis



Pump	**$**	**60,870**
Installation	**$**	**39,130**
Total Project Cost		**$100,000**
Environmental	**$**	**30,435**
Downtime	**$**	**39,130**
Operating	**$**	**39,130**
Maintenance	**$**	**86,957**
Energy	**$**	**139,130**
Life Op Cost	**$**	**334,783**
Total LCC	**$**	**434,783**

This is a considerable expense since the optimum pump and type diameter sizing as well as use of variable speed can provide significant pump savings. In addition, the proper pump system design choices on the front end could also reduce plant building and operation costs since the entire process includes the installation and maintenance of less equipment, valves, bypass lines.

As for existing facilities, many pump systems can be modified through control or mechanically re-engineered with paybacks periods that usually range from six to 24 months. Variable speed drives, whether electrical or mechanical, also account for only 4% of motor energy usage, while the potential exists to apply its use up to 25%. [DOE 1998]

Furthermore, anecdotal evidence indicates that about 75% of all pumping systems are oversized. This inefficient condition may result from conservative design, design for anticipated system capacity increases, or a decrease in the output demand. Other factors include the propensity of everyone involved in the design process to overestimate current and future needs with the inclusion of larger-than-necessary margins. For instance, a dramatic example of this process could begin with the system demand for a pump operating 2,500 gpm @100 ft. of head.

Not sure about piping losses, the junior engineer adds 15 percent to the head, while a senior project engineers adds another 10 percent to compensate for the demands of operations that would like to accommodate future demands for a system that operates at 3,600 gpm. After reviewing the specifications, the purchasing department then requests a pump with requirements of 3,600 gpm @ 126 ft. of head. As a result, even though the most efficient pump was specified at the outset, a pump is delivered that is oversized up to 44% on flow and 26% on head.

Typical indications of an oversized system include frequent on/off cycling, highly throttled valves, or heavy reliance on bypass lines. Possible improvements include trimming the existing pump impeller, installing a smaller impeller, removing stages of the pump (if a multi-stage pump), replacing the unit with a smaller pump, or reducing the pump speed. An engineering analysis can identify practical alternatives, and a life cycle analysis can then be employed to determine the most economical option. Proper sizing results not only improve energy efficiency, but also have a positive effect on other factors in the life cycle cost equation. A properly sized system operates close to its BEP, resulting in lower maintenance costs, longer equipment life (increased mean time between failure), and reduced downtime expenses.

End users frequently install variable frequency drives (VFDs) to control motors on pumping systems with variable loads. The VFDs often result in substantial energy and maintenance savings, but it is important to note that not all applications are appropriate for VFDs, particularly systems with substantial static head. [IETC 1999] A systems analysis will typically identify whether a VFD is appropriate for a particular application. Flow control alternatives such as impeller trimming and multiple pump arrangements may be more effective and economical. [OPS Guide 2008]

Overview of Life Cycle Costing

A greater understanding of all the components that make up the total cost of pumping system ownership will provide insights into opportunities for significantly reducing energy, maintenance, and other operational costs. LCC analysis management tools can help companies realize these opportunities. The analysis takes into consideration the costs to purchase, install, operate, maintain, and dispose of all components of the system. Determining the LCC of a system involves following a methodology to identify and quantify all of the components of the LCC equation. When used as a comparison tool between possible design or overhaul alternatives, the LCC process will identify the most cost effective solution within the limits of the available data.

In applying the evaluation process, or in selecting pumps and other equipment, the best information concerning the intended output and operation of the plant must be established. If bad or imprecise information is used then a bad or imprecise assessment will result. The LCC process offers a way to predict the most cost-effective solution; it does not guarantee a particular result but allows plant personnel to make reasonable comparisons between alternate solutions within the limits of the available data.

Pumping systems often have a lifespan of 15 to 20 years. Some cost elements will be incurred at the outset and others will be incurred at various times throughout the lives of the different solutions being evaluated. It is therefore necessary to calculate a *present* or *discounted* value of the LCC to accurately assess the different solutions.

To make the most of an LCC analysis, it is best to evaluate alternative system solutions. For a majority of facilities, the lifetime energy and/or maintenance costs will dominate the life cycle costs. Therefore, it is important to determine the current cost of energy and the expected annual energy price escalation for the estimated life, along with expected maintenance labor and material costs. Other factors, such as the life time costs of downtime, decommissioning, and environmental protection, can often be estimated based on historical data for the facility. In some processes, down time costs can be more significant than the energy or maintenance elements of the equation. Therefore, careful consideration should be given to productivity losses due to down time.

In 2001, The Hydraulic Institute, an association of US pump manufacturers, in cooperation with Europump, an association of national pump manufacturing associations in Europe, produced *Pump Life Cycle Costs: A Guide to Life Cycle Cost Analysis for Pumping Systems* to help facilities calculate in-depth life cycle costing for pumping systems as well as provide substantial technical guidance on new pumping system designs and assessments for existing system enhancements [LCC Guide]. The guide also includes examples of manual calculation of LCC and a software tool to assist in LCC calculation. The LCC equation, as defined in the HI/Europump Guide [LCC Guide], is:

$$LCC = C_{ic} + C_{in} + C_e + C_o + C_m + C_s + C_{env} + C_d$$

Where;

C_{ic} = initial cost, purchase price (pump, system, pipe, auxiliary)

C_{in} = installation and commissioning

C_e = energy costs

C_o = operating cost (labor cost of normal system supervision)

C_m = maintenance cost (parts, man-hours)

C_s = down time, loss of production

C_{env} = environmental costs

C_d = decommissioning

BestPractices suggests the following steps as a general guideline when analyzing an existing pumping system:

- Assemble a complete document inventory of the items in the pumping system;
- Determine the flow rates required for each load in the system;
- Look for heavily throttled valves;
- Look for frequent pump starting and stopping;
- Listen and feel for excessive vibration;

- Listen for excessive noise; and
- Identify pumps with high maintenance costs.

Taking Advantage of Opportunity/Case Studies

Many pump system inefficiencies are related to operation. Although it is challenging to downsize a pump or modify its operation while in production since the potential downtime involved in its optimization can directly and negatively impact output. This can be true even when the positive effects of system enhancements are clearly identified.

However, industry must realize that methods exist for creating a very efficient pumping system in a single unit or as an aggregate, while still meeting production levels. Limited resources need not be a constraint. All it takes is the commitment to develop and implement the proper polices procedures, strategies, skills and standards.

The Manitoba Hydro's Performance Optimization Program worked closely with a customer to examine a system's approach to identify the energy savings in an existing very simple cooling water circulation system that is very common across many industries, and similar to potable and process water systems.

In this system, there were two largely oversized pumps in place. One pump was running while the other was used as a back-up. The pump operated very inefficiently with much vibration. This caused numerous reliability issues as well as the ongoing operation of the back up pump. Every two years, one of the two pumps was completely overhauled, while the spare pump ran on its own.

After a technical analysis of the system, two business cases were proposed. The first involved no capital expenditures and operations that remained unchanged for the next 15 years. The facility measured and calculated power and energy costs, while reviewing maintenance records. The bottom line was that pump operations would cost this customer over $2 million over that period.

The next business case involved spending $250,000 to install two 60 hp pumps equipped with variable speed drives to replace the two original 400 hp pumps. The annual energy costs were estimated at about $9,675 per year. Over the next 15 years, the life cycle costs for this solution were estimated at $395,000. The savings were significant with an annual energy savings of $77,000 and annual maintenance savings of $55,000, with a less than 2 year simple payback and a savings of over 2,000 tons of CO_2 (Table 1). [Manitoba Hydro]

Table 1.

Capital Cost	= $ 250,000
Annual Energy Savings	= $ 77,064
Annual Maintenance Savings	= $ 55,000
IRR (15 years)	= 53%
NPV (d=12%)	= $ 558,341
NPV (d=8%)	= $ 776,636
CO_2 savings per yr.	= 2,048 tons

In addition, another prominent field that could benefit tremendously through the utilization of pump system optimization methodologies is the pulp and paper mill industry, where rapidly changing business conditions are forcing companies to accelerate cost cutting measures, increase process efficiencies and bolster productivity.

Yet, while mills are currently installing the latest IT tools to support their business systems, they continue to use aged and inefficient motor systems to operate the production process. Today, inefficient motor systems are a weak link in modern process management. Most rotating systems have little to no performance monitoring other than their on/off status at the operator console. More specifically, motor driven centrifugal pumps, which constitute about 30% of motor energy consumption in a typical mill, can play a critical role in optimizing the production process. Although often overlooked, there are significant opportunities to lower energy, maintenance, and material cost through the use of motor efficient technologies.

Overall plant performance has always been tied to the proper selection, sizing, installation, and maintenance of pumping systems. Standard industrial practice has been to oversize the pump in order to ensure an adequate supply if process demand was to increase in the future. In consideration of today's market realities, oversized, inefficient pumping systems must be viewed as long-term liabilities. The cost of oversizing, as an insurance policy to handle a future contingency that seldom materializes, is just too high.

Typically, the largest consumers of industrial motor energy are the pumps moving fluid throughout the pulp and paper process. Optimizing system efficiency has the potential to achieve 20% to 60% improvements in energy and maintenance costs, while improving pump and process reliability. Besides lowering overall energy efficiency, poor pump performance results in lower product quality, lost production time, collateral damage to process equipment and inordinate maintenance costs.

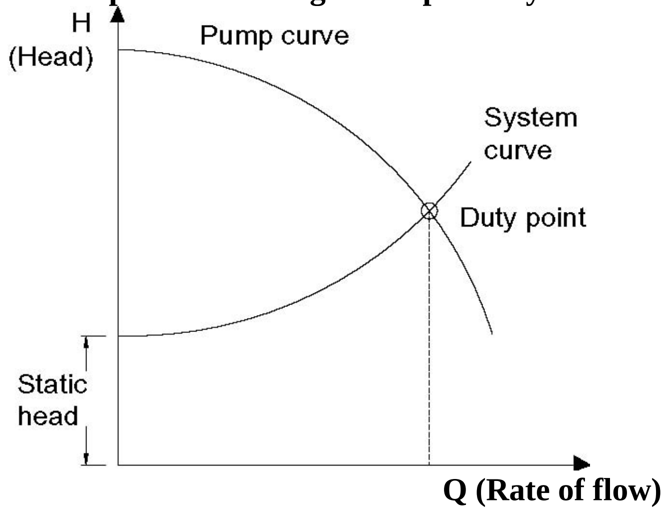
A millwide assessment offers the ideal method for helping pulp and paper companies to better understand the performance of pumping systems and quantifying the best opportunities for improving efficiencies. Modifications that often provide the most potential for efficiency improvements include:

- Motor efficiency via new replacement or upgrade
- Best match between component size and load requirement
- Reduced load on the motor through improved process and systems design
- Use of speed control instead of throttling or bypass mechanisms.

Also, when performing system assessments, the following pump symptoms are good indicators of potential opportunity—throttled valve; bypass line normally open; multiple parallel pump system with same number of pumps always operating; constant pump operation in a batch environment, and presence of cavitation noise.

The growing use of VFDs, particularly intelligent drives for pump control, is a major departure from the standard operating practice of using control valves as the final control element for fluid flow. Intelligent drives will allow the pump to operate near its best efficiency point (BEP) or duty point (Figure 4), assuming a low static head system, and will protect the pump from mechanical damage when it moves away from BEP. Recent studies reveal that pump operation near the BEP provides dramatic improvements in pump efficiency and operating reliability. Subsequently, when combined with lower energy and maintenance cost, the total LCC of a given pumping system can be significantly reduced when using VFD's and other cost saving measures such as slower speed motors, impeller trims and right-sized pumps.

Figure 4. Example of Centrifugal Pump and System Curve



Conclusion

In conclusion, pump optimization practices on a facility wide basis can increase plant profitability and asset reliability, while improving corporate citizenship through the implementation of energy and greenhouse gas emission reduction methodologies. The corporate benefits can also include an improved balance sheet in addition to an enhanced stock valuation. In addition, companies that utilize energy efficiency best practices are generally considered more environmentally friendly, responsible and reliable.

Commonly, opportunities exist when companies look beyond components and at a total systems approach to pump system optimization. Improper sizing, the failure to review whole system operations, inflexible process changes in a mechanical world and quick speed design fixes are all culprits of inefficient operations that waste both money and energy.

For many companies, the ability to increase energy savings and use can be as uncomplicated as designing adaptable bypass lines, which can be inexpensive in terms of re-circulating flow and consuming energy, or reviewing the operation of variable speed or multiple pumps. This can include the design of pump systems that shed load or slow down with variable speeds during low demand periods.

Pump Systems Matter™ (PSM) was specifically created by the Hydraulic Institute (HI) in 2005 to help process industries, utilities and municipalities, to decrease energy costs, optimize pumping systems and gain a more competitive business advantage through strategic, broad-based energy efficiency management tools.

An increasing number of PSM sponsors, as well as the U.S. DOE, now offer system assessments of plant operations to identify potential energy savings and areas for process and/or performance improvement. Further, PSM has created a free document, the "***Pump System Basic Assessment Guide",*** which outlines processes for identifying simple cost-effective system improvements. PSM also has enhanced its one day course ***"Pumping System Optimization: Opportunities for Life Cycle Performance."*** Students attending this course will better understand the pump/system interaction, learn how to identify and implement basic pump system performance improvement opportunities, learn when to use variable speed drive and understand how to position an action plan to their management. (See www.PumpSystemsMatter.org for more information).

The bottom line is that by 2015, PSM sponsors hope "end users will understand the value of – and the demand for – pump system optimization services, and that the supply chain will understand the value of offering these services on a competitive basis." PSM invites those who share this vision to participate with the organization to achieve this outcome.

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[Manitoba Hydro] Manitoba Hydro. Canadian utility in Winnipeg - 2008 Customer case study