Water Use in Vacuum Pump Systems
&
Viability for a Water Conservation Best Management Practice in California

An Investigation for the California Urban Water Conservation Council

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Table of Contents

Project Scope and Method

The California Urban Water Conservation Council has identified the replacement of liquid ring vacuum pumps with dry vacuum systems as a Potential Best Management Practice (PBMP). This investigation was undertaken to assess the potential viability of dry vacuum pump systems as a Best Management Practice (BMP) for urban water purveyors in California.

The assessment included:

- A literature review to ascertain the latest technology in the market, its costs, benefits, and water savings potential
- Interviews with representatives of relevant industry associations, and other regulatory bodies with jurisdiction with respect to this technology
- Interviews with key staff of water agencies that have or have had programs involving dry vacuum pump systems
- Evaluation of potential water savings and cost-effectiveness of different types of dry vacuum systems
- Development of recommendations on the advisability of upgrading from a PBMP to a BMP.

Summary of Key Findings

This section provides a summary of the most important findings covered in more detail in subsequent sections of the report.

Vacuum pumps and systems are presently used in a wide range of commercial and industrial sectors including:

- Dental
- Medical
- Food handling, processing, packaging
- Pharmaceutical
- Chemical
- Electronics manufacturing
- Light bulb manufacturing
- Scientific/laboratory
- Petroleum
- Groundwater Remediation
- Pulp and Paper Mills
- Sewage Treatment

Many of these vacuum pump applications are highly specialized - requiring process-specific and site-specific knowledge to properly engineer. However, dental and medical sectors have relatively homogenous needs, and are found in many water utility service areas.

Water Use in Vacuum Pumps

A broad range of vacuum pump technologies are presently available and viable for many of the applications listed above. These include water sealed liquid ring vacuum pumps, oil sealed liquid ring and rotary vane vacuum pumps, and a range of vacuum pump technologies that use no water for sealing. The liquid ring pump is the only one that uses water (and sometimes other liquids) to seal the vacuum chamber inside the pump housing. Some vacuum pumps that do not use water in the vacuum chamber do use water for cooling the pump housing. It is possible to have a partial or a full water recovery system for both the vacuum pump sealing water, and cooling water. But it is also possible to have once-thru systems for both sealing and/or cooling water. In cases where the vacuum is drying very wet materials, the pump sealing liquid may be a byproduct of the industrial process itself, for example, food processing. However, anecdotal evidence suggests the majority of water sealed liquid ring vacuum pumps use potable water. A large number of once-thru liquid ring systems likely exist in various dental, medical, and industrial applications.

This research found no industry surveys documenting the prevalence or saturation of specific types of vacuum pump technologies used in these various applications. Interviews with experts and industry marketing literature suggest that many types of vacuum pump technology are frequently utilized in the applications noted above. These are discussed in greater detail below. Evidence collected for this study suggests that liquid ring vacuum pumps, long a workhorse technology of the vacuum pump industry may be the most common. Some industry experts, however, recognize the water inefficiency of liquid ring vacuum pumps in many applications and are receptive to efficiency-enhancing alternatives where appropriate.

Of particular interest to this investigation, we found that dental facilities are common users of liquid ring pumps, as are medical facilities. Both types of facilities are widespread and numerous in California.

It appears vacuum pump technology may be ripe for significant water (and energy) efficiency enhancement in California. It also presents an excellent opportunity for water and energy utility collaboration to address common efficiency goals. However, it is a very complicated issue and substantial additional research and program development effort would be needed to assess the full potential.

Determining the best vacuum pump for a particular application can be a very complex, highly technical issue. In some applications, such as those requiring vacuum pumps capable of handling contamination, a liquid ring pump may have unique advantages. It is possible, and in many cases may be cost-effective to equip liquid ring vacuum pumps with a partial or full water recovery system that recycles the sealing and/or cooling water. In many applications, a completely waterless vacuum pump system may be viable and even have a number of advantages over liquid ring pump technology.

Furthermore, while outside the scope of this investigation, we found evidence that liquid ring compressor pumps may also be in widespread use. Liquid ring compressors may not represent as large a fraction of the existing compressor market as liquid ring vacuum pumps represent of the vacuum pump market. However, compressor pumps may also use water for cooling and may present a viable additional water conservation opportunity to be addressed along with liquid ring vacuum pumps.

Some California water agencies already have rebate programs for dry vacuum pumps, or mechanisms such as customized rebate programs for CII customers that can handle rebates for dry vacuum systems. However, it appears the activity level of existing programs for dry vacuum system is very low. A significant communications and marketing effort, along with partnerships with vacuum pump industry experts will probably be necessary for this conservation measure to reach full potential.

Recommendations

This investigation found that dry vacuum pumps generate cost-effective water savings in dental facilities, meriting an upgrade of this measure to a BMP. However, a CUWCC vacuum pump focus group would need to work out the details of this new BMP and determine an appropriate timetable for implementation. This focus group would also have to assess how best to promote this BMP, for example, by encouraging local retail agencies to adopt suitable local ordinances, or through financial incentives such as rebates, or by promoting state legislation requiring dry vacuum pumps in dental facilities.

Specific BMP recommendations:

1. In dental facilities, Council members should promote the use of partial recovery water recycling modules at a minimum for all new liquid ring vacuum pumps, or utilize full water recovery or dry

vacuum pump systems as an alternative. Council members could do this either by offering adequate financial incentives or by adopting an ordinance applicable to new dental offices and the retrofit of old vacuum pump systems.

2. For medical and industrial applications, require with an ordinance or provide adequate financial incentives for partial recovery water recycling systems on new liquid ring vacuum pumps, unless it can be demonstrated that site specific conditions would lead to impeller flushing and fouling problems, or utilize full water recovery or dry vacuum pump systems as an alternative.

Additional recommendations:

1. Water agencies should work to combine rebates with electric utilities for the new generation of dry vacuum pump systems with variable speed motors.

2. Establish a working group of experienced CII program agency representatives to further develop and establish partnerships with vacuum and compressor industry representatives and experts to advance the use of dry vacuum and compressor pump technologies in appropriate industrial applications

3. In a utility co-funded effort, engage an experienced medical facility engineer who is well known in the industry to better assess the potential market and effective retrofit mechanisms for dry vacuum pump technology in medical facilities.

4. Pursue a collaborative partnership with the UC Davis CIFAR program to address food industry vacuum pump use.

5. Collect data on other vacuum pump applications through industrial surveys/site audit programs for use in developing a targeted retrofit program with appropriate industries.

Vacuum Pump Technologies

Vacuum pumps are available in a wide range of designs including:

- Water sealed liquid ring
- Oil sealed liquid ring
- Oil bathed rotary vane
- Dry rotary vane
- Oil lubricated rotary piston
- Dry rotary screw
- Oil sealed rotary screw
- Dry rotary claw
- Scroll
- Regenerative blower
- Diaphragm
- Steam ejector/venturi

At a most basic level, vacuum pumps are typically rated in cubic feet per minute (CFM), inches mercury vacuum (Hg), and pump horsepower (hp). As noted by one manufacturing representative the vacuum pump rated horsepower to CFM relationship is about a 1:15 ratio.[1]

Different vacuum pump mechanisms have different but often overlapping operating parameters. These include the range of vacuum produced, the capacity or volume of gas the pump is able to move or evacuate

(CFM), the acceptable gas temperature range, and pump operating temperature, ability to handle contaminants that may enter the vacuum pump chamber, maintenance requirements, and others listed below. These all influence the suitability of a pump design with respect to a particular application. With the exception of very deep vacuum requirements (close to 30" Hg) for some laboratory and scientific uses, and very high temperature processes, more than one vacuum pump mechanism may be possible for a broad range of applications. This is reflected in the marketing of a broad range of pump mechanisms for a broad range of applications.

Pros & cons of different vacuum pump technologies:

- Energy use
- Cubic feet per minute capacity issues
- Depth of vacuum issues
- Maintenance issues
- Reliability issues
- Central vs. localized in a facility
- Integration with other technology in a facility
- Sound/noise level

For the purposes of this assessment, a thorough understanding of all the vacuum pump mechanisms and operating parameters is not essential. However, a basic understanding of liquid ring vacuum pumps is helpful in better understanding the potential of retrofitting to water saving technologies.

Liquid Ring Vacuum Pumps

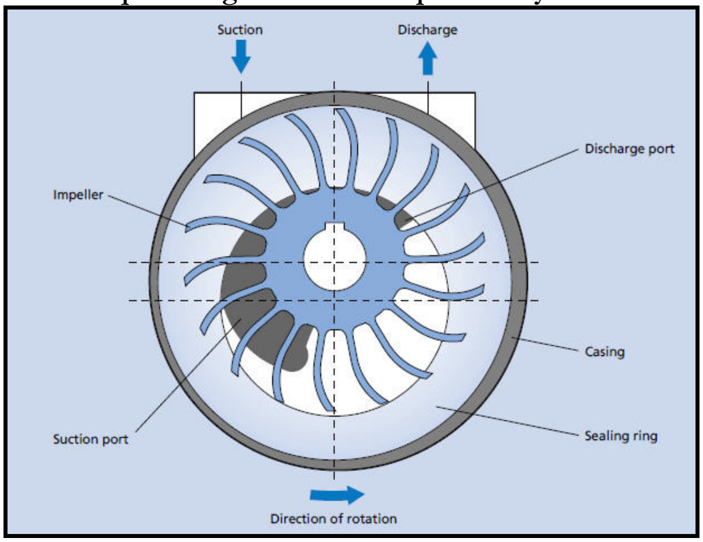
Liquid ring pumps operate with a rotary vane mechanism spinning inside a cylindrical chamber. As shown in Figure 1, the individual vanes are part of an impeller that is located off center of the pump casing. The individual vanes are not long enough to reach or contact the outer wall of the casing to create a seal. Instead, a liquid is introduced into the chamber, and as the rotary vane spins, centrifugal force creates a sealing ring of liquid around the inside perimeter of the vacuum pump chamber, and seals the rotating vanes. Liquid ring pumps frequently use water for the sealing ring liquid, but can also use oil or other liquids depending on the vacuum needs, pump and gas operating temperatures, and processes served by the vacuum. Note that liquid ring pumps can also be used as an air compressor, and are marketed by numerous manufactures for this purpose. Compressed air is widely used in many industries.

Liquid ring vacuum pumps have been a frequent workhouse for many industries. As noted by one industry expert, "liquid ring vacuum pumps have been in use for many years and are the most common vacuum pump out there; some recycle around 50% of the sealing liquid, most recycle very little."[2]

Liquid ring vacuum pumps have a reputation for reliability. Since the rotary vanes in the liquid ring vacuum pumps do not directly contact the pump chamber walls, liquid ring vacuum pumps can pass a considerable amount of contaminants and debris (within design limits) through the pump mechanism without harm to the pump.

An important operating parameter of liquid ring pumps is that they must be operated at a high enough speed to create the centrifugal force necessary for the liquid to seal the rotary vane. However, some other pump designs, including dry rotary vane and rotary screw, can operate effectively at a much broader range of speeds, including low speeds. Depending on the installation and process requirements, the ability to run at variable and low speeds can save considerable energy in addition to the water savings.

Figure 1
Liquid Ring Vacuum Pump Cutaway View



Source: Houston Vacuum Pump & Compressor[3]

Since liquid ring pumps are usually plumbed to pass most of the contaminants present in the suction line through the pumps, which will then mix with the sealing water, this can create water quality problems for recycling the water, and for the wastewater stream.

Liquid ring pumps have been in use for many years. Many facility design and maintenance engineers appear to have developed a fundamental comfort level with liquid ring pumps and consider their use in many applications as standard practice. The sense gained from interviews of a number of facility managers and industry representatives is that the adoption of new technologies may be received by many with some degree of skepticism and caution. This is consistent with the manner in which many other new water conservation technologies have been initially received. It may present an initial communication and marketing challenge for efforts to advance more efficient alternatives.

This investigation also found numerous vacuum pump industry representatives that were enthusiastic about dry pump technologies that are more water and energy efficient, and may also provide a longer service life with less maintenance. There is considerable potential to leverage this growing support for dry vacuum pump technology for conservation purposes.

Recycling Water Used in Liquid Ring Vacuum Pumps
Many vacuum pump manufacturers provide an option for a partial or full recovery water recycling system. Or they can be adapted to existing liquid ring pumps, but will require careful engineering to assure a reliably functioning system.

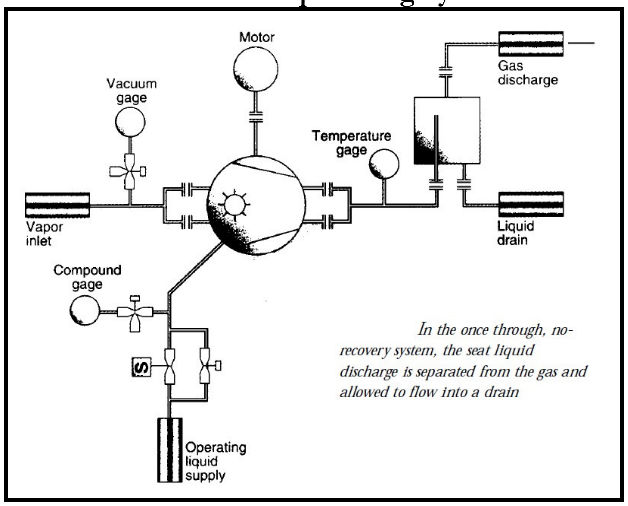
Engineering and installing a custom water recycling module to an existing vacuum pump system when the manufacturer does not offer a recycling module may be costly. This may be cost prohibitive in the case of existing small vacuum systems. Also, in some cases, a secondary water pump may be needed to circulate the cooling water through the heat exchanger system, which would increase energy use.

The NES Engineering website provides the follow description of water recycling options:[4]

> **1. Once-Thru Systems:** These systems are design with a water seal which is wasted to the drain line once it is exhausted from the vacuum pump. These systems are economical and require little

maintenance but especially with larger pumps can consume large quantities of water. All our close-coupled NCC series vacuum pumps can be fitted with our exclusive Water-Saver™ discharge separators which can recover between 40-50% of seal water.

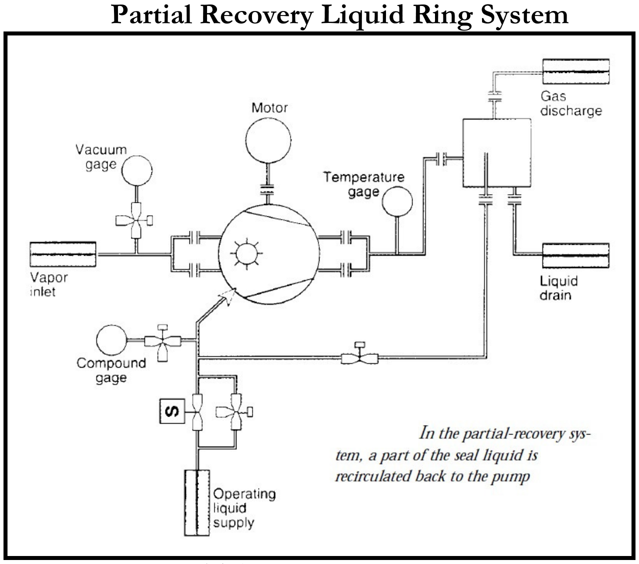
Figure 2
Once-Thru Liquid Ring System



Source: NES Company Website[5]

2. Partial Recovery Systems: These systems are designed to recover up to 50% of seal water and are only slightly more expensive than once-thru systems. When recovering seal water, care must be taken to avoid over heating the pump as process heat and heat from compression are captured in the seal fluid. Temperature of seal water should not exceed approximately 175F as a general rule. Higher temperatures are possible using alternative seal fluids but pump performance is inversely related to temperature as a general rule.

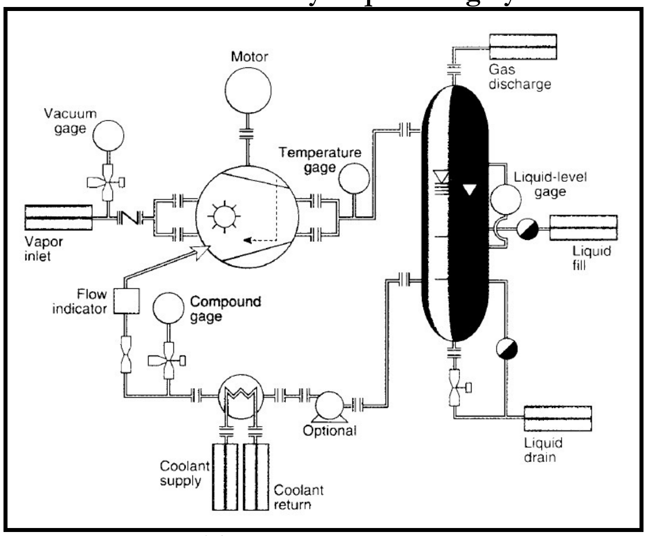
Figure 3
Partial Recovery Liquid Ring System



Source: NES Company Website[6]

3. Full Recovery Systems (Self-Contained): These systems are designed to be 100% self-contained by fully re-circulating the seal fluid. This is often desirable where water usage is limited or the process requires a closed system. As a result of constantly circulating the seal fluid, these systems require some method of heat extraction to remove excessive process heat and heat from compression. Heat extraction is typically accomplished by way of a centrally cooled or air-cooled heat exchanger. Self-contained systems require planned maintenance to ensure the seal fluid is free of debris and contamination.

Figure 4
Full Water Recovery Liquid Ring System



Source: NES Company Website[7]

Liquid ring vacuum pumps operating with potable water will require backflow prevention devices. This is an installation and ongoing inspection expense that can be avoided with dry vacuum pumps.

How Do Dry Vacuum Pumps Compare to Liquid Ring Pumps?
It should be noted that dry vacuum pumps are often louder, may run at higher temperatures, and are usually significantly more costly for the initial installation. For the dry vacuum pump mechanisms, filters and sumps are used to capture liquids and contaminants present in the suction line before they reach the vacuum pump. This can make it easier to separate out hazardous contaminants for proper disposal. However, failure of the necessary sumps and filters for dry vacuum pumps can cause catastrophic and very expensive pump failure.

One the plus side, dry vacuum pumps tend to be about 30% more energy efficient since they do not have to pump water along with air.[8] The horsepower requirement of a dry vacuum pump for any specific task can often be reduced compared to liquid ring pumps, thereby reducing initial costs and ongoing energy cost. But achieving energy savings, particularly for the smaller vacuum pumps systems, will be dependent on pump sizes available and use parameters at the site. A new generation of variable speed dry vacuum pumps equipped with sophisticated controllers is becoming available that can further reduce energy use compared to liquid ring pumps, which by design, must be run at relatively high speed when in use.

Which Type of Pump Goes Where?
A consistent comment received from numerous vacuum industry representatives interviewed for this project is that each specific application must be carefully considered for all of the site specific and process parameters to avoid installation and operational problems. Many of the vacuum pump manufacturers strongly encourage

customers to work directly with the manufacturer's in-house engineering staff to determine the best vacuum pump for any specific application. According to one expert, important questions to assess while selecting a specific pump for a specific purpose include:[9]

What ultimate pressure is required?
What gas loads will be present?
Are there process gas problems?
What cleanliness levels will be required?
Will the system be opened frequently?
Will the pump require valves and a backing pump?
Do the pumping speed vs. pressure curves match the process requirements?
Can the pump be installed easily on the system?
What maintenance requirements or problems are there?
What will the cost of ownership be?

In order to obtain or construct a reference chart comparing the various operating parameters of the available vacuum pump technologies, and suitability for different applications, we reviewed the literature and contacted numerous manufacturers and distributers. However, a comprehensive comparison chart was unavailable. Manufacturing representatives noted that different models of the same type of vacuum pump mechanisms can be designed for significantly different operating parameters. For both proprietary reasons and because manufacturers are concerned that a simplistic reference chart would lead to non-optimum pump selection, they do not provide this type of information. Wrong pump selection could lead to very short pump life or serious, ongoing problems with the manufacturing process reflecting badly on the manufacturer's brand.

A range of vacuum pump technologies may be utilized for any specific application. It largely depends on what was specified by the design engineers during the construction, or maintenance and rehabilitation of any specific facility. In addition, there may be cases where a combination of vacuum pump technologies in, multiple stages, is used for a specific industrial process in a single facility. However, liquid ring vacuum pumps are probably the most common, and most of them probably recycle little, if any, of the water they use.

Summary of Vacuum Pump Uses in the CII Sector

Industries that commonly use vacuum pumps include:

- Dental
- Medical
- Food handling/packing/drying
- Chemical
- Pharmaceutical
- Petroleum
- Electronics manufacturing
- Light bulb manufacturing
- Scientific/laboratory
- Groundwater remediation
- Sewage treatment
- Pulp and Paper mills

Dental & Medical Vacuum Pump Regulations

Vacuum pumps are widely used in dental and medical facilities. Vacuum pumps are plumbed to procedure rooms for removing fluids, and the collection of gases such as anesthetics.

The National Fire Protections Association Heath Care Facilities Code, Section 99 (NFPF 99), regulates medical facility vacuum pump and compressor use. NFPA 99 also addresses the use of liquid ring air compressors,[10] which may also be worthy of investigation for water conservation potential.

NFPA 99 language addressing vacuum pump systems starts on page 99-34. Regarding specific vacuum pump technology, the code provides few very restrictions. Section 5.1.3.7.2.1. states in its entirety, "Vacuum pumps shall be constructed of material deemed suitable by the manufacturer."[11] Section 5.1.3.7.2.3 states, "For liquid ring vacuum pumps, seal water shall be of a quality recommended by the vacuum pump manufacturer."[12]

NFPA 99 also addresses system and capacity requirements of vacuum pump systems. In medical facilities, a backup vacuum pump with a capacity capable of providing 100% of the overall system need is required.[13] In dental facilities, the backup pump requirement is 70% of overall system need.[14]

Vacuum Pumps in Dental Facilities

Interviews were conducted with numerous manufacturers and distributors of liquid ring and dry vacuum pumps. Many offer both types in their product line. Information synthesized from numerous sources suggests that liquid ring vacuum pumps are the most common in dental facilities with saturation between 80-90%.[15]

Several industry sources indicated the industry is in the early stages of shifting to dry pump technology for dental applications. Industry representatives generally recognize many advantages to dry vacuum pumps. These include water savings, energy savings, lower maintenance costs, longer service life, and an improved ability to separate out contaminants such as dental amalgams from the wastewater stream. One supplier noted that they recently began to offer a new variable speed dry vacuum pump that dramatically reduces the energy use compared to fixed speed dry vacuum pumps. Annual sales of the new variable speed dry vacuum pump introduced in 2011 were three times the supplier's expectation.[16]

Some water agencies in California presently offer rebates for replacing liquid ring vacuum pumps with dry pumps in dental facilities. A summary of agency programs, as reported to a brief questionnaire of CUWCC membership is provided in Section 6 of this report. Agency dry vacuum program activity in California to date appears to have been very low. A higher level of activity appears to have occurred in Texas, where hundreds, and potentially thousands of liquid ring pumps have been replaced with dry vacuum pumps.[17]

Of all the vacuum pump applications investigated, the dental market appears to be the most ripe for a BMP requirement. However, dry vacuum pumps have significantly higher capital costs. An effective financial incentive would likely require a larger rebate than is commonly offered by water agencies in California. Increased technical support and outreach would also be helpful. Mandatory requirements for water recirculating systems on liquid ring pumps could also be instituted. Section 7 provides greater detail about cost-effectiveness, water savings, and the economic viability of a BMP.

Medical Facilities

Vacuum pump technology is commonly used in medical facilities. But we were unable to find published information indicating the saturation of liquid ring and other types of vacuum pumps in medical facilities. One vacuum pump supplier commented that oil sealed screw vacuum pumps are common in medical facilities.[18] Further evidence of the use of oil sealed vacuum pumps was found in a brief questionnaire circulated to the board members of the California Society of Healthcare Engineers. This is further discussed below.

Anecdotal evidence suggests liquid ring vacuum pumps are used in medical facilities, but the saturation of liquid ring vacuum pumps in medical facilities is below the 80-90% level that probably exists in dental facilities. However, for many of the medical facilities, the vacuum pumps may be much larger and may be in operation 24 hours per day, seven days per week. Since dry vacuum pump alternatives exist, these may provide a significant additional opportunity for cost-effective water efficiency.

Norwood Hospital Case Study
In the early 1990s, the Massachusetts Water Resources Authority worked with Norwood Hospital to develop and implement a site specific water management plan for the facility. Norwood's website describes the facility as "a 264-bed acute care facility, conveniently located just outside of Boston… Our major clinical services include advanced surgical services, obstetrics, cardiology, neurology, orthopedics, gastroenterology, psychiatry, cancer care and pediatrics."[19]

One of the measures in the plan was addressing the liquid ring compressors and vacuum pumps. According to a case study bulletin on the project, providing "recirculating seal and cooling water for four vacuum pumps and one medical compressor as well as removing a vacuum pump that was not needed resulted in a net annual water savings of 8.5 million gallons. [20]

California Medical Facilities
Wikipedia lists 480 hospitals in California but notes that the list is probably incomplete.[21] The largest 11 in this list have over 1,000 beds each. Information on the number of procedure rooms and vacuum system connection points was not available.

To collect information on the types of vacuum pumps used in medical facilities, a number of large hospitals in Northern and Southern California were contacted repeatedly by phone and by email when email addresses were available.[22] Despite numerous attempts to interview the engineering staff of these facilities, it was not possible to obtain information for this project directly from facility staff. While it is likely these staff members are under substantial time pressures with other priorities, it appeared there was a consistent hesitance to communicate and provide information to this investigation.

In a further effort, the California Society of Healthcare Engineers (CSHE) was contacted for input. The CSHE response to inquiries was hesitant and guarded. Ultimately, a brief questionnaire was circulated to the 11-member board, all of whom are active healthcare facility engineers. The association insisted on anonymity for the responses. Two responses were received.

One response was from a 200-bed facility that had two Reitschle VC300 vacuum pumps and reported no problems with the vacuum pumps and system. These are oil flooded, air cooled rotary vane vacuum pumps.[23] No water is used for sealing or cooling these vacuum pumps.

The second response, verbatim and in its entirety, was as follows:

> Several years ago I added water conservation manifolds to our NASH water cooled vacuum pumps in an effort of reducing the water usage. At first it seemed to work fine but in less than a year our pumps starting having problems tripping and eventually seized up (fortunately we had 3 pumps). It was then found that the pumps have a very tight clearance between the housing and the impeller and the water solids/deposits left behind was the cause.
>
> Solution:
>
> Rebuilt the pumps at their expense and piped in soft water. To my knowledge they are still running. So, water conservation vs. soft water? This is just one example of the choices we have in front of us when considering any energy/utility savings…

Liquid ring vacuum pumps described in this response typically pass water along with extracted fluids and material *through* the vacuum pump impeller chamber. In some cases, a liquid ring recycling module may concentrate contaminants and exacerbate poor water quality problems. Dry vacuum pumps are designed to capture all the extracted fluids and materials in a sump/filter before the pump impellers. With proper filter maintenance, the pump has a longer service life, hazardous material can be more easily contained for proper disposal, and impeller fouling does not occur.

The saturation level of different vacuum pump technologies in medical facilities is unknown. One supplier suggested that a large portion of medical facilities use oil sealed vacuum pumps.[24] There is clear evidence of the use and likely widespread use of liquid ring vacuum pumps (and possibly liquid ring compressors) in medical facilities. There is also clear evidence that waterless alternatives exist. The regulatory framework does not restrict adoption of oil sealed or dry vacuum pumps and/or compressor technologies in medical facilities.

Based on the consistent reaction of medical facility engineers contacted in the course of this investigation, some initial medical industry skepticism and resistance to dry pump technology may occur. Furthermore, facility managers, who are not vacuum technology experts, may not be fully aware of more efficient alternatives, and the potential water and energy saving benefits. The help of an industry insider, who is well known and respected in the hospital engineering industry, may be necessary to establish good communication channels and develop facility engineering manager cooperation and support. A carefully crafted collaborative effort with recognized medical facility engineering experts to address the use of vacuum pump technologies in medical facilities could be effective and highly beneficial.

The new generation dry vacuum pumps are considerably more expensive than liquid ring vacuum pumps. In existing facilities already plumbed for liquid ring pumps, it may be more cost-effective to utilize a dry vacuum pump as the primary pump, and a liquid ring backup unit with a recycling module. This may also provide a transition period for facility managers to develop comfort with a new generation of technology.

Food Processing and Packaging

Liquid ring vacuum pumps are commonly used in food processing. According to information from a liquid ring pump manufacturer, "most of the applications in the food industry are geared toward the removal of water. Concentrating fruit juice, adjusting the boiling point (temperature) of water during cooking, and flash cooling after a food item has been cooked are all common processes where liquid ring vacuum pumps may be found."[25] For some of these applications, some or all of the liquid for sealing the pump vacuum chamber may be derived from the drying process; how much would vary case by case.

The assessment and development of retrofit recommendations for food processing facilities will be a complex issue typically beyond the expertise level of water agency staff. To effectively address the use of vacuum pump technology in food processing facilities, the development of partnerships with organizations active in this arena may be required. One suitable partner for such collaboration is the California Institute of Food and Agricultural Research (CIFAR).

CIFAR's ("see-far") mission statement is "To create opportunities for collaboration, multidisciplinary research and technology exchange between UC Davis and the food and agriculture industries."[26]

According to its website, "CIFAR, founded in 1991, serves as a portal and catalyst for collaborative discussion, research and technology exchange between UC Davis and the agricultural, food/beverage, health, and integrated bio-refining industries. The primary vision and guiding principal for CIFAR is to help create a clean, sustainable, recycling economy based on agriculture for the generation of food, fiber, chemicals and materials. With its focus on value-added processing and new product development, CIFAR is unique in its ability to integrate the diverse needs and interests of the business, academic and legislative communities to create value across the entire agri-food chain."[27]

In a project led by Ricardo Amón, CIFAR is working with the Department of Energy (DOE) on a project to conduct Energy System Assessments of food processing facilities and advance Best Practices for improving energy efficiency. Energy System Assessments are conducted by DOE Certified Specialists and calculate energy system performance, identify energy conservation opportunities and calculate cost effective resource efficiency investments. The assessments are prioritized for food industry companies ready to identify and adopt energy conservation and resource efficiency improvements.[28] CIFAR has engaged compressed air and vacuum system expert, and DOE certified inspector and trainer, Frank Moskowitz to assist in the project. In addition to energy efficiency, the project calls for full life cycle accounting of costs and benefits, including water impacts.[29]

Ricardo Amón provided helpful input into this investigation and expressed enthusiastic interest in the possibility of developing a partnership with CUWCC for the purpose of addressing energy and water inefficiency in food processing facilities. Frank Moskowitz is also an expert the use of liquid ring vacuum and compressor systems in applications beyond the food processing industry. Based on input received in this research, he appears highly supportive of replacing liquid ring vacuum pumps and compressors with more efficient alternatives where practical.

A partnership between CUWCC and CIFAR presents an excellent opportunity to engage with experts on vacuum pump systems and address liquid ring vacuum pumps and compressors in food industry, and to use that effort as an initial step in addressing other industrial applications.

Other Industrial Applications
Applications such as chemicals, petroleum refineries, pharmaceutical, and other manufacturing facilities, may be more limited in location and concentrated in industrialized areas in California. These applications may be more appropriate for a targeted approach, managed through a collaborative regional or statewide program. Other than vacuum pump marketing material, facility design guidelines, and comments obtained from interviews of knowledgeable industry personnel, we found no published evidence about the saturation of various vacuum pump technologies in different applications. However, much anecdotal evidence suggests that the use of liquid ring vacuum pumps is very widespread (as may be the case for liquid ring compressors). The liquid ring vacuum pumps used in some of these applications may be very large, as much as 300-400 hp or more.[30] In comparison, a large vacuum pump array in a dental facility may be 5-10 hp. Suitable dry vacuum pump technology probably exists for many of these applications, and if used to replace large liquid ring vacuum pumps could potentially generate large water savings for the individual site.

Identifying suitable vacuum pump technology for various industrial applications requires highly specialized expertise, and in many cases requires the engineering services of the vacuum pump manufacturers. As noted in discussions with many of the vacuum pump engineering representatives, a multitude of issues must be carefully considered to avoid costly breakdowns and system failures due to incorrect sizing, or selection of incorrect vacuum pump technology. Water agency programs that help advance the use of the most water efficient technology may often be helpful in these cases, but would need to be structured to provide flexibility for site specific conditions. Many of the pump manufacturer representatives expressed a willingness to work in a collaborative effort with water utilities and to provide presentations and representation to groups focused on this issue.

An engineering manager from one pump manufacturer noted that the chemical and pharmaceutical industry may provide particularly viable targets for vacuum pump water efficiency improvement, and that these industries are already beginning to move away from liquid ring vacuum pump technology.[31]

Summary of Water Agency Vacuum Pump Programs

Agency programs in California addressing vacuum pump technologies appear to be relatively limited and focused largely on dental facilities, although vacuum pumps in other facilities may be occasionally addressed in large CII audit programs.

To collect up-to-date information on agency programs, a brief survey was circulated to CUWCC membership in November 2011. The survey requested information about agency vacuum pump programs, and in particular programs that addressed vacuum pumps in non-dental facilities. Since the survey was focused on non-dental facility programs, the responses may not fully account for agency programs addressing dental facilities. Responses were received from the City of Roseville, Contra Costa Water District, and Upper San Gabriel Valley Municipal Water District. These responses, along with relevant information from other water agencies, are summarized below to provide a better sense of existing agency programs and the activity level in California and the Western states.

City of Roseville
Roseville indicated a site survey had determined that the Roseville Surgery Center utilizes dry vacuum pumps. Roseville offers rebates for dry vacuum systems through its CII Customized Rebate Program. Customers that replace liquid ring vacuum pumps with dry pumps could receive $0.50 per hundred cubic feet of saved water, and some potential retrofits sites have been identified, but thus far the rebate program has not generated any retrofit activity.[32]

Contra Costa Water District (CCSD)
Contra Costa Water District responded to the CUWCC dry vacuum survey and noted that vacuum pumps can be found in laboratories, hospitals and the food and beverage industry. CCWD provides rebates for dry vacuum pumps on a case by case basis, and depending on the amount of water savings, up to half of the dry vacuum pump cost. While the program has identified once-thru liquid ring pumps, CCSD staff report that few customers taking advantage of the rebate program.[33]

Upper San Gabriel Valley Municipal Water District (USGMWD)
USGMWD currently offers "rebates of $100 per 0.5 hp on top of MWD's $125 per 0.5 hp. Maximum rebate amount is $200."[34] The USGMWD representative was not aware of any dry vacuum pumps installed in non-dental facilities.

Metropolitan Water District of Southern California (MWD)
In 2008, MWD began offering rebates for dry vacuum pumps of $125 per 0.5 hp of pump rating capacity, with a maximum rebate of $500. This program is being matched by some member agencies such as USGMWD as noted above. Since 2008, a total of 5 rebates were issued under this program. Two of the rebates were in 2008, and three were in 2009. The program is open to non-medical facilities. However, MWD's records indicate that three of the rebates were for dental facilities and two were for "healthcare" facilities, but the specific type of healthcare facility was not noted in the records.[35] It is possible that some dry vacuum rebates were provided in a "Pay per Performance" incentive program, but the representative was not aware of any of these occurring.

MWD also noted that the marketing effort to push dry vacuum pumps slowed in mid-2008 due to budget constraints. MWD's program implementation contractor noted that many agencies may be ill-informed about liquid ring and alternative dry vacuum pump technologies, and that rebate amounts remain relatively small compared to the up-front cost of a dry vacuum pump, thus unlikely to trigger a significant customer response.[36]

East Bay Municipal Utilities District (EBMUD)
In 2008, EBMUD published a "Water Smart Guidebook" that recommends air cooled dry vacuum pumps be used in place of liquid ring vacuum pumps in dental, medical, and industrial facilities.[37] The guidebook notes that in many cases a lower horsepower dry vacuum pump can be used in place of a liquid ring pump since dry pumps tend to be more efficient, due to only pumping air, and not water. The report notes that in new facilities, the use of dry vacuum pumps will avoid the cost of installing plumbing to provide the pumps with water, installing backflow prevention devices, and providing annual inspections for backflow prevention devices.

The EBMUD "Water Smart Guidebook" includes a brief general discussion on the cost effectiveness of replacing liquid ring vacuum pumps with dry pumps alternatives. The guidebook notes that for the same horsepower rating, dry pumps are typically 2-3 times more expensive than liquid rings pumps, but in some installations the dry pumps can be downsized to help reduce installation cost. For new facilities, the dry pumps would not incur the cost of plumbing to provide the pump with water, nor backflow prevention. The guidebook also cites a medical installation for which a liquid ring pump was replaced with a 10 hp dry vacuum pump and resulted in annual water and energy saving of $40,000. However, the facility was not identified.[38]

EBMUD has a mechanism that allows rebates for dry vacuum systems in a wide range of applications through their WaterSmart Customized Rebate Program. EBMUD's website states, "rebate amounts are calculated for each proposed conservation measure based on estimated water savings and a current rate of $0.50 per billing unit (100 cubic feet or 748 gallons) of water saved. The payback period for each water conservation measure must be two years or more. The actual rebate amount may incorporate an estimated project/measure life expectancy. Rebates will not exceed half the installed cost of an approved measure."[39] EBMUD staff indicated that the WaterSmart Customized Rebates consider the value of water saved for the life of the measure, up to a 10-year limit. The rebates are designed to "buy down the customer payback period to a 2-year period," with a rebate limit of 50% of the cost of the measure.[40]

San Antonio Water Service (SAWS)
According to its conservation staff, SAWS has offered rebates for dry vacuum pumps systems since 2000. While an exact figure was not available, SAWS has provided a large number of rebates, probably hundreds possible thousands. The rebates are calculated on a site specific basis. The dry vacuum pumps are assumed to save 2/10 of a gallon of water per horsepower per hour of operation. Water savings is valued at $400/af saved over the pump life, with a 10-year maximum life.[41]

San Antonio Water Service also has an ordinance addressing the use of liquid ring vacuum pumps. The City of San Antonio oversees SAWS. City Code, Chapter 34 defines vacuum systems as "a system, often consisting of a pump, chamber, and tubes, that is used to create a vacuum for any of a variety of purposes, including but not limited to medical, dental and industrial applications."[42] Section 34.273 (7) states "Vacuum systems shall not be water-cooled with single-pass potable water when alternative systems are available."[43] SAWS water conservation staff reported no serious community or industry pushback related to this ordinance requirement.[44]

City of Austin
According to a summary report provided by Bill Hoffman, the City of Austin, Texas, offered rebates for dry vacuum pumps from 2000 to 2007. During this period, 38 dry vacuum pumps were installed as part of the rebate program. All were in dental facilities, and included 22 replacements of existing liquid ring vacuum pumps, and 16 for installations in new facilities. The rebates were for both water and energy savings, with a water conservation rebate of $500 for dry vacuum systems under 2.5 hp.[45] According to Austin's 2005, 5-Year Conservation plan, "For dry vacuum pumps of 2.5 or more horsepower the rebate is the lesser of: (1) half the cost of the purchase price of the equipment, or (2) $1.00 for each gallon per day saved up to 30,000 gallons, and then $.50 (fifty cents) for each gallon per day saved up to 20,000 gallons up to a maximum rebate of $40,000."[46] The energy rebate was $168 per each 1 hp reduction in vacuum pump capacity.[47]

Water savings were determined by measuring the liquid ring vacuum pump water use at five sites. Water use was measured to be at least 0.5 gallons per minute per rated horsepower for the pump, and higher for the older pumps.[48] Water savings estimates were based on an 8-10 hour day, and ranged from 240 gallons per day up to 2,000 gallons per day depending on the size of the dental office and pump capacity. The average replacement was projected to save 300 to 800 gallons per day.[49]

Cost-Effectiveness and Water Savings Analysis

Our savings and cost-effectiveness analyses are limited to dental facilities because adequate data are only available for this sector. While liquid ring vacuum pumps are used in a wide range of industries as noted earlier, detailed analyses for each of these additional applications was beyond the scope of this paper since the requisite data are unavailable.

Potential Water Savings and Cost Effectiveness for Dental Vacuum Pumps

The dental vacuum pump specifications for a series of similarly sized pumps manufactured by Midmark are utilized for an analysis of potential water savings in dental facilities. The Midmark vacuum pump series was selected for this analysis due to the accessibility of the specifications, and also because liquid ring vacuum pumps, liquid ring pumps with water recycling modules, dry vacuum pumps, and dry vacuum pumps with variable speed motors could all be compared from a single manufacturer. It should be noted that there are many other vacuum pump suppliers. Water and energy use, particularly in any specific facility, may vary based on the specific pump used and operating parameters of the facility.

Table 1 compares four available vacuum pump technologies, in two comparable sizes from Midmark, and basic specifications provided by the manufacturer.[50] The CV series is a standard, once-thru liquid ring vacuum pump. The CV_R series includes liquid ring pumps with a partial recovery water recycling module. The P series is a dry rotary vane pump. The G series is a dry rotary vane pump with a variable speed motor and represents the latest generation technology. The assumed pump life is based on conversations with Midmark representatives. The liquid ring pumps have a 5-year warranty, and the dry pumps have a 10-year warranty. The liquid rings pumps have a long history of useful life of about 6 to 8 years. For the dry vacuum pumps, Midmark expects much longer life. A conservative assumed life of 15 years was used for the analysis, and may better reflect the limit of how long a dental office facility manager may consider the reliability benefits. However, as long as the filtering mechanism is properly maintained, the Midmark representative believes that the dry vacuum pumps will probably provide 20 years of service.[51]

Table 1
Midmark Vacuum Pumps Utilized in Analysis

Vacuum Pump Model	Max No. Users	No. Pumps	HP	HP Per Max User	Gal/Min Use	Assumed Life in Years
Liquid Ring Pump						
Midmark CV3	3	1	1.25	0.417	0.75	7
Midmark CV3R w/Recycler	3	1	1.25	0.417	0.19	7
Midmark CV6	6	2	2.50	0.417	1.50	7
Midmark CV6R w/Recycler	6	2	2.50	0.417	0.38	7
Dry Vacuum Pump						
Midmark P3	3-5	1	2	0.400	0	15
Midmark P6	6-10	2	4	0.400	0	15
Midmark G3	3-5	1	3	0.600	0	15
Midmark G6	6-10	2	6	0.600	0	15

The Midmark G series vacuum pump units have sophisticated controllers and variable speed pumps. The variable speed pumps and controllers necessitate a three-phase electrical power supply. This results in a larger pump for the G series, relative to the CV and P series pumps. This is reflected in the higher horsepower per maximum user for the pump shown in Table 1. However, since the G series pump is often operating at lower speeds, in a typical day it will tend to consume much less electrical power compared to the CV and P series pumps. This issue helps illustrate the difficulty in assessing an optimum vacuum pump for a specific facility and application without considering the entire system and how it will be used.

There is another important issue to consider with the relatively small vacuum pumps often used in dental facilities. While a dry pump may inherently be about 30% more energy efficient compared to a liquid ring pump with the same hp rating,[52] actually realizing that energy savings may be constrained by pump sizes currently available on the market and the actual number of users it must supply.

Benefit/Cost Ratios and Water Supply Costs

To compare the value of saved water to the up-front cost of either dry vacuum or partially recycled pumps, an estimate of the marginal cost of future water supplies is necessary. We use two scenarios to capture the likely range of these marginal costs. The lower water supply cost of $800/af was selected to reflect the embedded or low-end cost option for new supply that may typically be available to water agencies in California. The higher water supply cost of $2,000/af would reflect the high-cost option for new supply such as seawater desalination presently being considered by many water agencies in California. The $2,000/af for new supply may be higher than frequently used by many water utilities in California for making comparisons to the cost of conserved water. However, the actual cost of new supplies, and in particular seawater desalination given present day technology and energy costs, may be considerably higher than what agencies have assumed in the past.[53]

Table 2 provides a cost comparison of CCF vs. acre-feet. For some water users, particularly those being billed for water in higher billing tiers, an average water cost of $4.59/CCF, which equates to $2,000/af, may not be unusual. Therefore, evaluating water savings at $2,000/af provides a useful customer perspective for costs and benefits of dry vacuum pump systems.

Table 2
Comparison of CCF vs. Acre-feet Cost of Water

$/CCF	$/af			
$0.50	$217.81			
$0.75	$326.72			
$1.00	$435.63			
$1.25	$544.54			
$1.50	$653.44			
$1.75	$762.35	$800/af =	$1.84	per CCF
$2.00	$871.26			
$2.50	$1,089.07			
$3.00	$1,306.89			
$3.50	$1,524.70			
$4.00	$1,742.52			
$4.50	$1,960.33	$2,000/af =	$4.59	per CCF
$5.00	$2,178.15			
$5.50	$2,395.96			
$6.00	$2,613.78			
$6.50	$2,831.59			
$7.00	$3,049.41			
$7.50	$3,267.22			

Table 3 provides an analysis of the potential water savings, marginal cost, and benefit/cost ratio of providing a partial recovery water recycling module on a liquid ring vacuum pump. The benefit/cost analysis considers only the value of water saved, and does not include energy or wastewater costs and benefits. The marginal cost of water saved is $284/AF for the CV3R vacuum pump, and $180/AF for the CV6R vacuum pump.

Assumptions:

7 Assumed life in years for liquid ring vacuum pumps
15 Assumed life in years for dry vacuum pumps
5 Avg days/work week
8 Avg hrs/work day
50 Avg weeks/year operating
2011 Nominal dollars for costs and benefits

Table 3
Analysis of Liquid Ring Partial Recovery Water Recycling System

Liquid Ring Pump	Cap Cost	Cap Cost/Yr	Partial Recycler Cap Cost	Gal Saved/ Life	AF Saved/ Life	$/AF Saved	Partial Recycler B/C at $800/AF	Partial Recycler B/C at $2,000/AF
Midmark CV3	$2,490	$356						
Midmark CV3R (Partial Recycler)	$2,900	$414	$410	470,400	1.4	$284	2.8	7.0
Midmark CV6	$4,780	$683						
Midmark CV6R (Partial Recycler)	$5,300	$757	$520	940,800	2.9	$180	4.4	11.1

Table 4 provides an analysis of the dry vacuum pump alternatives, compared to both the basic, once-thru liquid ring vacuum pumps, and liquid ring pumps with a partial recovery water recycling system. Note that this analysis only considers the value of water conserved, and does not evaluate wastewater, energy use, and O&M impacts. The marginal cost varies from a low of $303/af to a high of $5,513/af. When dry vacuum pumps are compared to once-thru liquid ring pumps at an $800/af cost of new supply, the dry vacuum pumps are only cost effective for the P6 series pump. However, when dry vacuum pumps are compared to once-thru liquid ring pumps and a $2,000/af cost of new supply, the dry vacuum pumps are cost-effective in all cases.

Table 4 also includes a comparison of dry vacuum pump cost-effectiveness to liquid ring pumps with partial recovery water recycling systems. For these examples, only the P6 dry vacuum pump is cost-effective from the water savings only perspective.

Table 4
Analysis of Dry Vacuum Pump Water Savings and Costs

Dry Vacuum Pump Model	Cap Cost	Cap Cost/Yr	Life Water Savings vs CV (AF)	Life Water Savings vs CV_R (AF)	Dry Vac Cap Cost Difference vs CV	Dry Vac Cap Cost Difference vs CV_R	$/AF Saved vs CV	$/AF Saved vs CV_R	Dry Vac vs CV B/C at $800/AF	Dry Vac vs CV B/C at $2,000/AF	Dry Vac vs CV_R B/C at $800/AF	Dry Vac vs CV_R B/C at $2,000/AF
Midmark P3	$9,650	$643	4.14	1.05	$4,314	$3,436	$1,041	$3,273	0.77	1.92	0.24	0.61
Midmark P6	$12,750	$850	8.29	2.10	$2,507	$1,393	$303	$664	2.64	6.61	1.21	3.01
Midmark G3	$12,000	$800	4.14	1.05	$6,664	$5,786	$1,609	$5,513	0.50	1.24	0.15	0.36
Midmark G6	$20,000	$1,333	8.29	2.10	$9,757	$8,643	$1,178	$4,117	0.68	1.70	0.19	0.49

Many water agencies in California are responsible only for water service to their customers. However, in many cases, the water purveyor is also a wastewater utility and/or energy utility. Furthermore, from the customer perspective, these factors are also important for considering the cost-effectiveness of various equipment options. While a detailed analysis of the energy and wastewater impacts was beyond the scope of this investigation, in many cases the wastewater and energy savings will exceed the dollar value of the water supply savings. A "50 Largest Cities Water/Wasterwater Rate Survey" released in 2007 included 8 cities in California. Of the 8 California cities, 4 had higher sewer rates, 3 had higher water rates, and for one city it varied depending on the volume billed.[54]

Table 2 provides a tool for considering the cost of wastewater service in addition to potable water service, since the $/CCF column could represent the cost of water or wastewater service separately, or the cost of water and wastewater combined. Savings from reduced wastewater and energy costs may provide an important motivator for the adoption of more efficient vacuum pump technologies and the considerably more costly variable speed dry vacuum pumps. It also provides an opportunity for water, wastewater, and energy utilities to collaborate and optimize conservation from the best available vacuum pump technology.

Potential for Water Savings in California

Given the lack of existing empirical information on the use of liquid ring vacuum pumps in medical and industrial facilities, a credible detailed analysis is not viable at the present time. A substantial amount of research and on-site surveying of vacuum pump use in a range of industrial facilities would be necessary to develop a reasonable basis for a widespread water savings analysis. Since our preliminary analysis indicates considerable potential for substantial and cost effective water savings in medical and industrial applications, a more detailed study would be a worthy undertaking. However, data exist to develop a reasonable estimate of statewide savings potential for dental facilities.

According to the California Dental Board, there were about 38,000 licensed dentists in California in 2011. According to the American Dental Association, in the U.S. there are on average 4.1 operatories per independent practicing dentist ("operatories" is the term the dental industry uses for dental procedure rooms). Estimates for statewide water savings in California can be developed from liquid ring vacuum pump specifications along with basic assumptions, listed below, of the prevalence of different vacuum pumps types. Table 6 provides an analysis based on these assumptions.

Assumptions:

38,000	Number of licensed dentists in California[55]
4.1	Number of operatories (procedure rooms) per independent dentist[56]
85%	Liquid ring existing saturation (once-thru & partial recovery recycling)[57]
15%	Dry vac existing saturation
70%	Liquid ring, once-thru
15%	Liquid ring, partial recovery recycler equipped[58]
5	Avg days/work week
8	Avg hrs/work day
50	Avg weeks/year operating

Table 6

Dental Vacuum Pump Water Use Analysis	
155,800	Number of Operatories in California
120.0	Gallons/Day/Operatory, Once Thru Liquid Ring
30.4	Gallons/Day/Operatory, Partial Recovery Recycled Liquid Ring
88.6	Avg Gal/Day/Operatory, Assuming 70% Once Thru, 15% Recycled, 15% Dry
10,586 afy	Total Dental Water Used at 70% Liq/nonrec, 15% Liq/rec, 15% dry
1,817 afy	Total Dental Water Used if 50% Liq/Recycled and 50% Dry Vac

Table 7 shows the statewide water savings potential under two scenarios. The first scenario assumes that all liquid ring vacuum pumps are retrofitted with dry vacuum pumps; the second scenario assumes that half are replaced with dry vacuum pumps and half with partial recycled liquid ring pumps. California can be expected to reduce its annual consumption by 10,586 af and 8,769 af per year under these two scenarios respectively.

Table 7

Dental Retrofit Water Savings Potential for Califronia	
10,586 afy	Potential Savings if 100% Retrofitted to Dry Vacs
8,769 afy	Potential Savings if 50% Retrofitted to Dry Vacs, 50% Liquid Ring Partial Recycled, 0% Wet Ring Once Thru

The available evidence suggests there is also a considerable retrofit potential in medical and other industrial applications. Many of these applications will have much larger pump capacities (in some cases hundreds of hp compared to a typical range of 2-10 hp for a dental facility) and correspondingly a much larger water savings potential for the sites being retrofitted. In addition, due to operational needs, many medical and industrial sites operate their vacuum pump systems 24 hours a day, 7 days a week, 365 days per year, compared to the much more limited operating hours for dental facilities. This would significantly increase the relative water saving potential and cost-effectiveness of retrofitting these sites.

Conclusion

Although industry specific data on the use of vacuum pump technologies are limited, this investigation found significant potential for cost-effective water savings benefits from the adoption of dry vacuum pump technology. This conclusion would be even stronger when wastewater and energy impacts are also included in the benefits analysis.

Recycling modules for liquid ring vacuum pumps appear highly cost-effective and would be a viable candidate for mandatory requirement, except in circumstances where materials and processes handled by the vacuum system constrain it, or the liquid for liquid ring pumps is not supplied by potable water.

When replacing a non-recycling, once-thru liquid ring vacuum pump, a dry vacuum pump will be cost effective in many cases solely from the water savings benefit, and generally more so when wastewater and energy benefits are also considered. Replacing an existing liquid ring vacuum pump that is equipped with a partial recovery water recycling system may not be cost-effective in many cases solely from the water savings, but may be cost-effective when wastewater and energy cost savings are also considered.

Based on the limited response to existing rebate programs in California, larger rebates or ordinance requirements may be necessary to adequately stimulate installation of the most water and energy efficient technologies presently available for vacuum pump applications.

Given the present state of documentation for liquid ring and dry vacuum pump technologies, and the limited scope of this initial assessment, it was not possible to provide water savings analysis beyond dental facilities. However, this research suggests there may be a substantial and potentially cost-effective retrofit market in the many vacuum pump applications that exist beyond dental facilities. After dental, medical facilities appear to be the most promising opportunity for service areas that are not heavily industrialized. For the remaining industries a targeted approach involving water purveyors, industry stakeholders, and pump manufacturers will likely be necessary.

While some industry stakeholders would probably welcome a market transformation effort undertaken by water and energy utilities, there may be some industry resistance to transforming the once-thru liquid ring vacuum pump market to more efficient alternatives. Furthermore, for a limited number of applications liquid ring vacuum pumps probably remain the best option. For the remainder, industry resistance may be overcome over time via education and outreach, as in the case of plumbing fixtures used in the home. More efficient toilets faced resistance in the beginning but are now the mainstay of every urban water conservation program. The water savings potential of liquid ring vacuum and compressor pump markets is probably not as substantial as toilets and clothes washers, but there are likely to be many thousands of them in California. Overall, the water savings potential appears to be both significant and cost effective especially when benefits include water, energy, and wastewater savings.

Given the range of vacuum pump uses, and the specialized expertise necessary to properly assess appropriate dry vacuum pump retrofit potential for many applications, effective collaboration with vacuum industry experts and wastewater and energy utilities may be necessary to fully tap the water conservation potential for dry vacuum pump systems.

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Citations & Endnotes

[1] Lane, Gary. Western Regional Sales Manager, Dekker Vacuum Technologies, Inc. Personal phone communication. 3-14-12.

[2] Moskowitz, Frank. US DOE Certified Instructor/Inspector. Recorded telephone interview provided by Ricardo Amón, UC. Davis, CIFAR, provided 2-16-12.

[3] Houston Vacuum Pump & Compressor. "Liquid Ring Vacuum Pumps." Accessed 1-23-12
https://www.scotdesiderio.com/Liquid_Ring_Vacuum_Pumps.html

[4] NES Company. "Liquid Ring vacuum Systems." Accessed 1-23-12
http://www.nescompany.com/liquid%20ring%20systems.html

[5] NES Company. "Installing Liquid Ring Vacuum Pumps." p.1. Accessed 3-25-12.
http://www.nescompany.com/How%20To%20Install%20a%20Liquid%20Ring%20Vacuum%20Pump.html

[6] NES Company. "Installing Liquid Ring Vacuum Pumps." p.1. Accessed 3-25-12.
http://www.nescompany.com/How%20To%20Install%20a%20Liquid%20Ring%20Vacuum%20Pump.html

[7] NES Company. "Installing Liquid Ring Vacuum Pumps." p.1. Accessed 3-25-12.
http://www.nescompany.com/How%20To%20Install%20a%20Liquid%20Ring%20Vacuum%20Pump.html

[8] Webb. Keith. Personal phone communication. Application Engineering Manager, Tuthill Corporation. 2-28-12.

[9] Danielson, Phil. "Matching Vacuum Pump to Process." The Vacuum Lab - A Journal of Practical and Useful Vacuum Technology. p.1. Accessed 2-28-12.
http://www.vacuumlab.com/Articles/VacLab31.pdf

[10] NFPA 99 – Health care facilities Code – 2012 Edition. National Fire Protection Association website. p. 99-31. Accessed 2-8-12.
http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=99

[11] NFPA 99 – Health care facilities Code – 2012 Edition, NFPA Website. p. 99-35. Accessed 2-8-12.
http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=99

[12] NFPA 99 – Health care facilities Code – 2012 Edition, NFPA Website. p. 99-35. Accessed 2-8-12.
http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=99

[13] Guyer, J. Paul. "An Introduction to Plumbing and Gas Systems for Medical Facilities." 2009. p.30. Accessed 2-8-12.
http://www.cedengineering.com/upload/An%20Intro%20to%20Med%20Plumb%20&%20Gas.pdf

[14] Guyer, J. Paul. "An Introduction to Plumbing and Gas Systems for Medical Facilities." 2009. p.33. Accessed 2-8-12.
http://www.cedengineering.com/upload/An%20Intro%20to%20Med%20Plumb%20&%20Gas.pdf

[15] Estimate derived from interviews of vacuum pump manufacturers and distributers, recorded phone interview between Ricardo Amón, UC. Davis, CIFAR, and Frank Moskowitz, 2-16-12.

[16] Beard, Eric. Personal phone communication. California Sales Representative, Midmark Corporation. 11-26-11.

[17] Leister, Branden. Personal phone communication. Conservation Planner, San Antonio Water Service. 12-20-11.

[18] Webb. Keith. Personal phone communication. Application Engineering Manager, Tuthill Corporation. 2-28-12.

[19] Norwood Hospital Website. Accessed 2-23-12.
http://www.stewardhealth.org/Norwood-Hospital

[20] Massachusetts Water Resources Authority. "Water Use Case Study: Norwood Hospital." Accessed 2-23-12
http://www.mwra.state.ma.us/comsupport/ici/norwoodhospital.htm

[21] en.wikipedia.org/wiki/List_of_hospital_in_California
Accessed 1-16-12.

[22] The large hospital facilities repeatedly contacted include:

- California Hospital Medical Center
- Cedars-Sinai Medical Center
- Highland General Hospital
- Los Angeles County-USC Medical Center
- San Francisco Hospital and Trauma Center
- University of California Medical Center

[23] Elmo Rietschle Website, V-Series Rotary Vane Vacuum Pumps. Accessed 2-24-12
http://www.gd-elmorietschle.com/productfinderlist.aspx?id=17360&mi=692&smi=734

[24] Webb. Keith. Personal phone communication. Application Engineering Manager, Tuthill Corporation. 2-28-12.

[25] "Liquid Ring Vacuum Pumps – Applications." Graham Corporation website. Accessed 1-15-12.
www.graham-mfg.com/index.asp?pageId=53

[26] CIFAR's Website. Accessed 2-20-12.
http://www.cifar.ucdavis.edu/who-we-are

[27] CIFAR's Website. Accessed 2-20-12

http://www.cifar.ucdavis.edu/who-we-are
[28] CIFAR Powerpoint/pdf Presentation. Provided in email from Ricardo Amón, 2-16-12.
[29] Amón, Ricardo, CIFAR Energy Management Project Leader. Personal phone communication, 2-13-12.
[30] Canazzi, Gary. Service Technician. Gardner-Denver Corporation. Personal phone communication. 1-16-12.
[31] Webb. Keith. Personal phone communication. Application Engineering Manager, Tuthill Corporation. 2-28-12.
[32] Shannon, John. Water Efficiency Specialist, City of Roseville, Personal email communication, 12-1-11, Personal phone communication 3-12-12.
[33] Cardwell, Ray, Water Conservation Specialist, Contra Costa Water District, Personal email communication, 11-28-11.
[34] Layugan, Elena. Conservation Coordinator, Upper San Gabriel Valley Municipal Water District. Personal email communication, 11-22-11.
[35] Tilkian, Gary. Associate Resource Specialist, Metropolitan Water District of Southern California. Personal phone communication, 12-6-11.
[36] Tilkian, Gary. Associate Resource Specialist, Metropolitan Water District of Southern California. Personal phone communication, 12-6-11.
Mizushima, Greg. Senior Program Coordinator, Honeywell Utility Systems. Personal phone communication, 12-1-11.
[37] "WaterSmart Guidebook, A Water-Use Efficiency Plan Review Guide for New Businesses." East Bay Municipal Water District. 2008. p 23, 24, MED1, MED2, MED4, MED5, MED6, MED7.
[38] "WaterSmart Guidebook, A Water-Use Efficiency Plan Review Guide for New Businesses." East Bay Municipal Water District. 2008. p. MED6, MED7.
[39] East Bay Municipal Water District Website. Accessed 2-23-12.
http://www.ebmud.com/for-customers/for-commercial-customers/conservation-rebates-and-incentives/watersmart-customized-reb
[40] Hazinski, Mike. Personal phone communication. Supervisor of Water Conservation. East Bay Municipal Utility District. 6-20-12.
[41] Leister, Branden. Personal phone communication. Conservation Planner, San Antonio Water Service. 12-20-11.
[42] City of San Antonio, Code of Ordinances, Chapter 34, Water and Sewers, Section 23.271. Definitions.
[43] City of San Antonio, Code of Ordinances, Chapter 34, Water and Sewers, Section 23.273 (7)
[44] Leister, Branden. Personal phone communication. Conservation Planner, San Antonio Water Service. 12-20-11.
[45] Hoffman, Bill. "Summary of Vacuum Pump Rebate Program at the City of Austin, 2000 – 2007."
[46] Water Conservation Plan, City of Austin, Texas, May 2005. p. 18.
[47] "Summary of Vacuum Pump Rebate Program at the City of Austin, 2000 – 2007." Unpublished paper provided by Bill Hoffman in email communication, 10-22-11. p.1.
[48] "Summary of Vacuum Pump Rebate Program at the City of Austin, 2000 – 2007." Unpublished paper provided by Bill Hoffman in email communication, 10-22-11. p.1.
[49] "Summary of Vacuum Pump Rebate Program at the City of Austin, 2000 – 2007." Unpublished paper provided by Bill Hoffman in email communication, 10-22-11. p.1.
[50] Product brochures with additional information on all of these vacuum pumps can be downloaded from the Midmark Corporation website:
http://www.midmark.com/en-us/DentalProducts/AirCompressorsandVacuums/Pages/default.aspx
[51]Zulauf, Bill. Personal phone communication. Senior Product Manager, Midmark Corporation. 12-8-11.
[52] Webb. Keith. Personal phone communication. Application Engineering Manager, Tuthill Corporation. 2-28-12.
[53] Fryer, James. "A Marginal Cost Investigation of Seawater Desalination in California." 3-18-10.
http://r4rd.org/wp-content/uploads/2009/07/Cost_of_Seawater_Desalination__Final_3-18-09.pdf
[54] "50 Largest Cities Water/Wastewater Rate Survey." Black & Veatch. 2007. p. 2-5.
[55] Dental Board of California Meeting Minutes, November 7, 2011. Accessed 1-26-11., p 3
http://www.dbc.ca.gov/about_us/materials/20111107lcp.pdf
Note that the actual number of practicing dentists in California is slightly higher since many are late to pay license renewal fees and are note reflected in the estimated figure of 38,000.
[56] The figure of 4.1 operatories per independent dentist was provided by Amanda O'Dell, Research Analyst II, Health Policy Resources Center, American Dental Association, in a January 27, 2012 personal email communication. The 4.1 figure is derived from a national survey entitled "2009 Survey of Dental Practice: Characteristics of Dentists in Private Practice and Their Patients." The figure of 4.1 operatories per independent dentist represents dentists with an independent dental practice. No California specific figure was available in the report and the California Dental Board does not track this information (as per email exchange with Donna Kanter, Licensing and Examination Manager, Dental Board of California, 1-26-12). There may be some cases of dentists sharing facilities and other cases of dentists operating in more than one facility. Also, independent practicing dentists would not include dentists practicing in public or

government facilities. However, ADA reports that most dentists are independently practicing in a single facility and no credible information was available to refine this number for the purposes of this analysis.

[57] The 85% saturation of liquid ring vacuum pumps in dental facilities is an estimate and based on a personal phone communication with Eric Beard. California Sales Representative, Midmark Corporation. 11-26-11, and "Dry Vacuum Pumps (For retrofit and new construction)." Unpublished paper provided by Bill Hoffman in email communication, 10-22-11. p.1.

[58] The 15% saturation rates for recycling modules on liquid ring vacuum pumps is an estimate based on numerous comments by industry representatives and probably the most adventurous of the assumptions utilized in these calculations.

Bibliography

Aliasso, Joe. How to Control Wet Ring Vacuum Pumps
http://www.graham-mfg.com/usr/pdf/TechLibVacuum/27.PDF
Accessed 1-15-12

Association of Vacuum Equipment Manufacturers. Website Homepage.
http://www.avem.org/
Accessed 1-23-12

Birgenheier, DB and Wetzel, L. Graham Corporation. "Design of Vacuum Systems for Crude Oil Vacuum Tower Distillation."
http://www.graham-mfg.com/usr/pdf/TechLibVacuum/22.PDF
Accessed 1-15-12.

Bott Dan. "Compressed Air is for Pushing, Not Pulling." www.PLANTSERVICES.com, August, 2005. p. 43-45.
http://www.putman.net/brands/ps/downloads/ps_compressed_air_articles.pdf
Accessed 2-8-12

Bott, Dan. "The Ins and Out of Vacuum Generators" Compressed Air Best Practices.
http://www.airbestpractices.com/technology/vacuum/ins-and-outs-vacuum-generators
Accessed 2-8-12

California Dental Association.
http://www.cda.org/
Accessed 1-27-12

Combined Fluid Products, "Vacuum Pumps."
http://www.combinedfluidproducts.com/vacuum_pumps.htm
Accessed 2-8-12

Danielson, Phil. "The Vacuum Lab - A Journal of Practical and Useful Vacuum Technology."
http://www.vacuumlab.com/articles.htm
Accessed 2-28-12

Danielson, Phil. "Making the Oil-Sealed vs Oil-Free Decision." A Journal of Practical and Useful Vacuum Technology.
http://www.vacuumlab.com/Articles/VacLab28.pdf
Accessed 2-28-12

Dekker Vacuum Systems. "Medical Vacuum Solutions – Pumps and Systems for Hospitals and Clinics"
http://www.dekkervacuum.com/pdfs/2010/brochures/50270_medicalLR.pdf
Accessed 2-25-12

EngineeringToolBox.com. "Vacuum Pressure – Converting Units."
http://www.engineeringtoolbox.com/vacuum-converter-d_460.html
Accessed 1-23-12

Gardner/Denver – Food & Beverage Vacuum Pump Overview Webpage
http://www.gardnerdenver.com/industries/food_and_beverage.aspx
Accessed 1-15-12

Houston Vacuum Pump & Compressor . "Laboratory Vacuum Pumps."
https://www.scotdesiderio.com/Laboratory_Vacuum_Pumps.html
Accessed 1-23-12

McAllister Technical Services. "A Short History of Vacuum Terminology and Technology."
http://www.mcallister.com/vacuum2.html
Accessed 1-23-12

MedicalGasInfo.com. "Vacuum Pump Technologies."
http://www.medicalgasinfo.com/content/vacuum.htm
Accessed 1-26-12

PIAB Webpage. "Pharmaceutical Vacuum Use."
http://www.piab.com/en-US/Industries/Pharmaceutical/
Accessed 1-15-12

PIAB Webpage. "Food & Consumer Use"
http://www.piab.com/en-US/Industries/Consumer--food/
Accessed 1-15-12

PIAB Webpage. "Electronics & Semiconductor Vacuum Use."
http://www.piab.com/en-US/Industries/Electronics--semiconductor/
Accessed 1-15-1

PIAB Webpage. "Graphic Industry Use of Vacuum Pumps"
http://www.piab.com/en-US/Industries/Graphic/
accessed 1-15-12

Pump Engineering Company. "Pumps by Type."
http://www.pumpengineering.net/about.html
Accessed 1-15-12

Skelton, Kevin. "Variable Frequency Drives for a Vacuum Pump System." Graham Corporation.
http://www.graham-mfg.com/usr/pdf/TechLibVacuum/219.PDF
Accessed 1-15-12

Smith, Rod. "PIAB Optimizes Food Processing Vacuum Systems." Compressed Air Best Practices.
http://www.airbestpractices.com/system-assessments/vacuum/blowers/piab-optimizes-food-processing-vacuum-systems
Accessed 1-15-12

The Bell Jar. "Some Vacuum basics."
http://www.belljar.net/basics.htm
Accessed 1-24-12

Tuthill Corporation. "Vacuum Pumps and Systems"
http://www.tuthill.com/us/en/products/vacuumPumps.cfm
Accessed 2-25-12

Unique Systems Incorporated. “Liquid Ring Vacuum Pump Systems – Engineering Data”
http://uniquesystems.com/pvs/brochures/Bulletin_PVS-80021301-LVP-LRVP_Systems.pdf
Accessed 1-15-12

US Vacuum Pumps.” Types of Vacuum Pumps.”
http://www.usvacuumpumps.com/types_of_pumps.html
Accessed 1-24-12

Vaccon Vacuum Products. “How Vacuum Pumps Work.”
http://www.vaccon.com/pdfFiles/Understanding%20Vacuum.pdf
Accessed 1-24-12

Vacuum-Guide.com. “Liquid Ring Vacuum Pumps.”
http://www.vacuum-guide.com/vacuum-pump/liquid-ring/liquid-ring-vacuum-pump-america.htm
Accessed 1-25-12

Wetzel, Loren E. “Optimizing vacuum Systems for Energy-Efficient Operation.” Graham Corporation.
http://www.graham-mfg.com/usr/pdf/TechLibVacuum/28.PDF
Accessed 1-15-12

Wikipedia. “Description of Vacuum Pumps and History.”
http://en.wikipedia.org/wiki/Vacuum_pump
Accessed 1-23-12