EXTERNAL RESEARCH & ENERGY EFFICIENCY IN THE PROCESS INDUSTRIES

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INTRODUCTION

The process industries in the United States are under enormous pressure. These industries, even more than US industry on average, face skyrocketing environmental costs, a rapidly changing electricity market, potential climate change policies, aging infrastructure and strong international competition. To be profitable they must reduce their costs and environmental impacts while increasing their product quality, turnaround time, productivity and output. Most of these industries have already cut costs and labor as much as possible[1]. Therefore, to survive, these industries must innovate. History shows that industries that are the most innovative are the most successful[2].

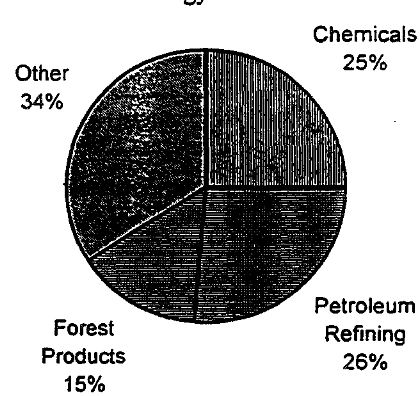
These industries are vital to the US economy. For example, the metals, pulp and paper, chemicals and the petroleum refining industries account for more than $800 billion in products shipped and employ more than three million workers[3]. Although the US has shifted dramatically toward services, with 77% of workers and 74% of GDP now in the service sector, what many have missed is that the process industries are important customers for many of these new services. ServOnly the last two years of NSF industrial R&D data provide any breakout of non-manufacturing R&D. NSF separates the top two groups, SIC 737+871(computer programming, data processing other computer related engineering + engineering, architectural, and surveying services) and SIC 873 (research and development firms), from the reset of non-manufacturing R&D. ices are estimated to constitute 65-75% of most manufacturers' costs and most of their value-added[4]. This paper discusses the past, current and possible future role of external research and development (R&D)--much of which is now in the service sector--in fostering innovation and thus energy efficiency in these industries. We suggest that these industries are more innovative than previously thought because of external research.

ENERGY USE AND EXTERNAL R&D IN THE PROCESS INDUSTRIES

The process industries are the most energy-intensive industries

The chemicals, forest products and petroleum refining industries account for more than 65% of U.S. manufacturing energy use (See Figure 1)[5]. These three industries are the top three in energy use, with petroleum refining first at 5.9 Quads, chemicals a close second at 5.5 Quads and forest products third at 3.3 Quads. By the "energy intensity" (energy use per dollar value of output) measure, these industries are also in the top three. Petroleum refining is far out in front using 44,300 BTUs per dollar value of shipments. Pulp and paper is second using more than 18,500 BTUs per dollar value of shipments and chemicals is a close third requiring nearly 16,000 BTUs per dollar of product shipped in 1994.

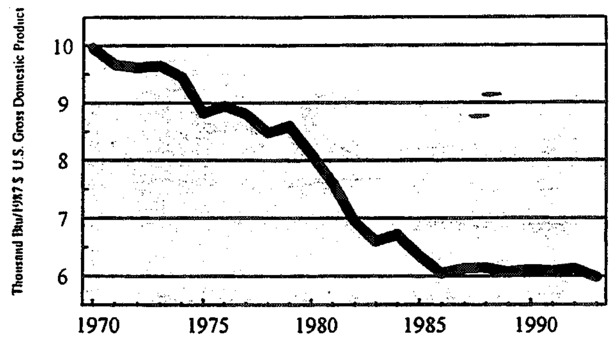
Figure 1. Process Industries' Share of Manufacturing Energy Use



Total =22.6 Quads (MECS 1994)[5]

Although these industries have made significant strides in energy efficiency over the past 20 years, these efficiency gains have slowed noticeably over the past ten years (Figure 2)[5]. While the recent flat cost of energy was a factor, energy efficiency continued to increase in the late 1980s, even as energy prices went down (sometimes to record lows). Many experts believe that the continuing drop in industrial energy intensity in the 1980s was partially due to the availability of new energy efficient technologies[6]. The current stagnation in energy efficiency may suggest that a new cycle of innovation is needed. Recently, in these industries, there has been a marked shift toward the use of electricity for power. One of the most important factors affecting this shift to electricity is that it is the only power source for many new electronically controlled technologies. The ability to control the technology precisely more than makes up for the intrinsic inefficiency of electricity generation. The impending deregulation of the electric power industry has made these industries reluctant to increase their dependency on the electric grid. Thus, we expect, the process industries' interest in energy efficiency, especially in electricity, to increase.

Figure 2. U.S. Industrial Energy Intensity Trends

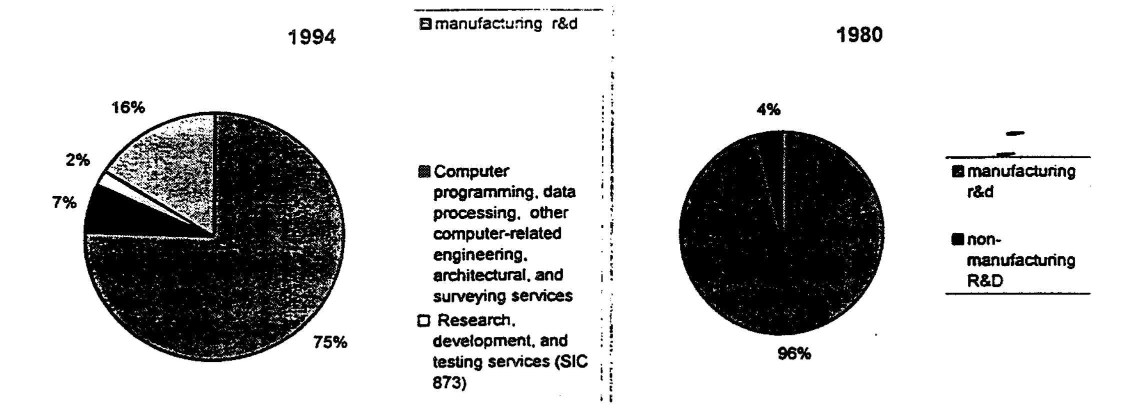


Innovations in Basic Processes are required to further Reduce Energy Use
Most of the energy use in these three process industries occurs while turning the feedstock into the finished products. Ancillary energy usage (e.g. lighting, heating) is small in comparison. For example, distillation by the refining and chemicals industries consumes 11% (2.4 Q) of total US industrial energy use annually[7]. In pulp and paper mills, the process of forming the wood into pulp, paper, or board consumes 90% of the mill's energy. More than 60% of the energy used in refineries is obtained from burning gaseous fuels in refinery heaters. Innovations in any of these basic processes should therefore have a dramatic impact on the entire industry sector's energy efficiency. The industrial R&D in these industries is, by definition, energy efficiency R&D. In what follows, we explore the important role of external research in these basic process innovations.

Future R&D Trends
According to the National Science Foundation (NSF), non-manufacturing R&D has risen dramatically in the past few years[8]. NSF's non-manufacturing R&D data captures two types of external R&D: contract R&D and in-house R&D conducted by service providers. These data indicates the latter and possibly the former have grown dramatically. Overall, service sector R&D increased from 4% of all industrial R&D in 1980 to more than 25% by 1994 (Figure 3)*. Another category of external R&D, external partnerships, also has increased dramatically in recent times.

* Only the last two years of NSF industrial R&D data provide any breakout of nonmanufacturing R&D. NSF separates the top two groups, SIC 737+871(computer programming, data processing other computer related engineering + engineering, architectural, and surveying services) and SIC 873 (research and development firms), from the reset of non-manufacturing R&D.

Figure 3. Non-Manufacturing vs. Manufacturing R&D, by U.S. Industry[8]



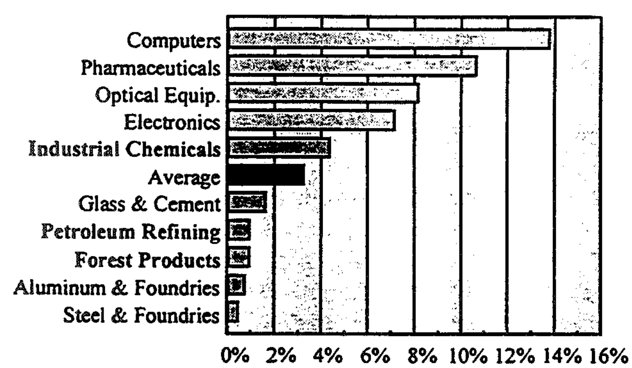
INNOVATION IN THE PROCESS INDUSTRIES

Innovation is difficult to measure, but industry analysts often use industries' expenditures on R&D as a percentage of sales (R&D/sales ratio) as a metric. While industry spending on R&D has increased steadily, the R&D/sales ratio varies widely across industry sectors. The electronics and the biotechnology industries spend well above average whereas process industries (except chemicals) spend less than one third the industry average on R&D (Figure 4)[8]. Given their need to innovate, decision makers in the process industries could be making a strategic error by not spending as much on R&D as other industries. But the evidence seems to point away from this. These industries have continued to exist and even to thrive in recent times. There is likely some explanation other than lack of innovation for these industries' low R&D/sales ratio. We posit that the R&D/sales ratio is not the right metric for comparisons across industries. We also propose that the apparent under investment in R&D by the process industries may be due to undercounting of external R&D--especially R&D on basic processes that consume the most energy. We explore alternate means of measuring innovation and conclude that these industries can spend their R&D funds more efficiently if they use external R&D.

Definitions

External Research in this paper refers to research done by both for-profit (e.g. technology consulting firms) and nonprofit (e.g. research institutes) entities. Examples of the former are Arthur D. Little (ADL)[9] and UOP (formerly known as Universal Oil Products); examples of the latter are Battelle Memorial Institute[10] and universities. External research providers have arisen in many ways. Some began by providing contract research. Others began by providing technical services and then began to perform contract research. Still others began with a breakthrough invention that was then widely licensed. Finally, there are partnerships with competitors, suppliers and users.

Figure 4.R&D/Sales Metric for various Industries[8]



Source: National Science Foundation, 1995.

Contract Research is research for a client who has a specific goal or problem to solve. Contract research in this paper is a subset of external research. Contract research performers are often classified in the non-manufacturing service sector under SIC 873, research and development firms or SIC 871--testing, engineering, architectural, research, development and data processing services industries. These firms also perform many related services to make the R&D useful to their clients.

Partnerships: Partnerships are another subset of external R&D. Partnerships can be with competitors, suppliers, vendors, customers, universities, the government, consulting firms and institutes. For the purposes of this paper, we focus on the latter two categories because their primary mission is external research. Although they are more cumbersome, well managed partnerships can reduce the costs of basic research and provide specialized technical expertise that individual companies cannot afford.

History of external sources of industrial R&D

U.S. industrial research as such began more than 100 years ago and it has been increasing ever since. During this time, the emphasis on external research in the process industries has waxed and waned. For the purposes of this paper, we divide the past century into three eras. In the first era, up until WWII, external research was fairly important simply because most companies then had no internal research. The first contract research was done with the idea of providing R&D capabilities to smaller firms that could not establish their own central R&D lab. In the second era, WWII to end of Cold War, external research diminished in importance as companies profited more from in-house research. Contract research was mainly used for "routine" research such as testing and by firms with strong in-house research capabilities to supplement their own research[11]. In house research grew dramatically during this era. In the third era, international competitiveness has lowered profit margins so that companies began to look even to research as a service to outsource. Although these trends have been derived from data on all industrial R&D, it is reasonable to assume that they apply equally to the process industries.

Current Industry Motivation for external sources of R&D

It should come as no surprise that the process industries are outsourcing R&D. Stigler[12] hypothesizes that "vertical disintegration" occurs as a new industry grows and matures. Initially, the firms in the new industry perform most functions for themselves. But as the industry grows, demand increases and eventually it is reasonable for firms in the industry to spin off many functions to specialized firms that can carry them out on a larger scale and thus more cheaply. There are additional specific barriers to outsourcing R&D, but recently there have also been more incentives.

Because of the rapidly changing factors described earlier, the traditional linear in-house innovation cycle is too slow. In the past, it has taken from five to thirty years for R&D on more energy efficient technologies to produce measurable energy savings[13]. For the capital intensive technologies that are typical of the process industries, there are substantial technical and financial risks that can be mitigated via external research. In addition, unlike other services, external research helps companies get more out of their in-house R&D.

Some companies have discovered that contract research is now cheaper and faster. This is because the best consulting firms have developed methods to maximize their R&D resources and to decrease the time frame for innovation. The most successful external research providers recognized early on that research must be managed. These companies also use advanced information technologies and techniques. ADL, for example, features statistically designed experiments. In addition, the process industries want more "high tech" services. They can no longer afford services that do not add value. For example, when they hire an environmental engineering firm, it should do more than help them comply with environmental regulations using expensive end-of-pipe technologies. Thus, service providers in these areas now do more of their own R&D to keep up in a rapidly changing field. Partnerships are appropriate for longer term research that integrates and aligns industry participants. Because the partners must agree on which research is most important, partnerships focus scarce basic research resources.

In what follows, we examine case studies from the three process industries--pulp and paper, petroleum refining and chemicals-- that use the most energy. The focus is on their use of external R&D and its impact on energy efficiency. In some cases we can show that external research has been key to innovations in the basic processes that consume the most energy.

FOREST PRODUCTS CASE STUDY

Description of Forest Products industry

The U.S. forest products industry has total shipments valued at more than $247 billion per year, employs more than 1.3 million people and ranks among the top ten manufacturing industries in the United States[3]. Despite major advances in productivity over the last several decades, the forest products industry remains one of the most energy-intensive industries in the United States. Although the industry makes extensive use of renewable fuel (generating 57% of its own energy needs from its waste biomass), it is the third largest user of fossil fuels in the U.S. industrial sector. Environmental protection is another major cost of production. Expenditures on pollution abatement and related equipment exceeded $2.9 billion in 1993 and environmentally related costs are expected to increase in the years ahead with the issuance of the proposed cluster rule. We focus on the pulp and paper segment of the industry which generates $120 billion of the industry's $200 billion in sales.

The pulp and paper industry is dominated by a few processes. These convert fiber, usually from wood, into paper, pulp or paperboard, and then into a variety of products. The manufacturing of paper and related products requires that a fiber source, normally wood, be chipped, digested, bleached, formed into paper or board and then dried. The process of pulping involves digesting the wood at elevated temperatures and pressures in a caustic chemical solution. This pulping process separates the cellulose (fibers) from the lignin. The lignin is the portion of the wood which holds the fibers together and makes them stiff. The cellulose is then further processed, refined and (optionally) bleached to make pulp and paper products. The residual lignin, which is approximately 60% of the mass of the wood, goes into a solution with the caustic pulping chemicals referred to as black liquor. The black liquor which is 15% solids as it leaves the digester, is concentrated in a series of evaporators to about 75-80% solids. It is then burned in a recovery boiler to recover the inorganic caustic pulping chemicals and the fuel value of the black liquor as steam. The steam is then used to meet mill energy demands either directly, as steam heat for paper drying or indirectly in steam turbines to generate electricity. The energy efficiency of boiler electricity generation is less than 25%. In paper manufacturing especially, any technology that reduces the use of steam and the need for heat, uses more of the available biomass fuel sources, or balances steam and power needs will improve the performance of the industry. What follows are two examples of external R&D's contributions to process R&D in the pulp and paper industry.

Examples of External R&D that Impacts the Pulp and Paper industry's Energy Efficiency

The forest products industry has a long history of external cooperative research. For example, a group of U.S. companies provides the funding for the Institute of Paper Science and Technology (IPST). The Pulp and Paper Education and Research Alliance (PPERA) is an alliance of twelve universities led by the IPST. According to its mission statement, the university programs comprising PPERA work together in research which is mutually beneficial and collectively leverages the groups' contributions to the pulp, paper and allied industries. Currently the Forest Products Industry is involved in a large, comprehensive, industry wide collaborative research program to advance the energy efficiency, environmental performance and international competitiveness of the industry. This research is part of an industry wide vision described in *"Agenda 2020" - A Technical Vision and Research Agenda for America's Forest Products Industry.* This vision document serves as a basis for guiding the research agenda.

Gasification, Combined-Cycle Turbine Technology

An example of an exciting renewable energy-efficient technology developed collaboratively is the black liquor gasification combined-cycle (BLGCC) process. Black liquor gasification has the potential to generate process steam and electricity at far higher efficiencies than existing recovery boilers. BLGCC technology also has far lower capital costs than conventional recovery boilers. This technology is well suited to a pulp mill environment since it is tolerant of changes in fuel quality, requires less attention to fuel drying and produces a medium Btu gas. Medium Btu gas can be readily used by existing oil- or gas-fired equipment with little or no retrofit. It generates less steam but 2-3 times more electricity. Efforts to make mills more environmentally friendly have changed mill's energy demand toward electricity and away from steam, and this technology matches this trend. The majority of recovery furnaces and conventional power boilers in existing pulp and paper mills are twenty to thirty years old. More than 50% of these will be replaced or upgraded in the next five to fifteen years. There is thus a significant window of opportunity for installing new gasification technology in these plants very cost-effectively during this normal capital replacement cycle. If this BLGCC technology is installed when the old boilers are retired, it would represent eight gigawatts of power generation capacity.

Polyoxometalate Bleaching

Another successful collaborative effort is the development of an alternative to chlorine bleaching called polyoxometalate bleaching. This technology removes lignin to produce a desirable soft white fiber. The impetus for developing this technology was the need for a nonchlorine bleaching process with a selectivity comparable to chlorine or chlorine dioxide. However, like most process innovations in this industry, this technology has an important energy efficiency benefit. Compared to chlorine-based systems the new process promises to reduce electrical energy consumption of pulp bleaching by 50%. Polyoxometalates are highly selective and can be regenerated within the process.

PETROLEUM REFINING CASE STUDY

Description of Petroleum Refining industry

The petroleum refining industry employs nearly 100,000 people with an average hourly wage of $21/hour. There are 175 U.S. petroleum refineries in 34 states. In 1994, U.S. petroleum refiners spent more than $6 billion on environmental controls[3]. These costs will increase due to stringent requirements on both refineries as stationary emission sources and on petroleum products through fuel composition and performance specifications. Increased competitive forces have led to many refinery realignments as well as the closing of less efficient processing units. Even so, there is widespread agreement that petroleum-based fuels will continue to constitute the dominant supply for the transportation market. Fewer U.S. refineries are now producing more, higher quality transportation fuels, yet the cost of gasoline in constant dollars today equals 1950s prices.

This industry's basic processes convert crude petroleum into gasoline, diesel, fuel oil and lubricants. First, the crude is first separated into different products in five "cuts." It is then recombined into various final products. The separation is done through energy intensive processes such as distillation and cracking (breaking up large molecules) that require high temperatures and pressures. The quality of the crude strongly affects the separation difficulty and thus the energy use. Unlike most process industries, the petroleum refining industry's energy intensity has recently increased. Clean air regulations governing plant emissions and vehicle emissions have resulted in process changes (e.g. reformulated and oxygenated fuels) that have added steps to the refining process. Since more of the supply is now heavy crude, its greater processing requirements also require more energy. Yet the technology in most basic petrochemical processes is now quite mature. Therefore, significant increases in energy efficiency will come only through entirely new process concepts and/or catalysts.

Examples of External R&D that Impacts Refiners' Energy Efficiency

What follows are examples of external research's contributions to energy efficiency in the petroleum refining industry. UOP, now a division of Union Carbide, was founded in the 1920s based on a patent infringement suit with Standard and other major oil companies[14]. In the course of tests to support the lawsuit, new cracking techniques, that were dramatically better than available techniques, were discovered and UOP embarked upon its long career of innovating and licensing. UOP has been responsible for the major innovations in several areas important to energy efficiency including improved catalysts, molecular sieves and adsorbents, and process equipment.

The petroleum refining industry is also considering adopting a new cooperative research framework that is more focused on core technologies[15]. One example of this is the Petroleum Environmental Research Forum (PERF) which was formed in 1986[16]. PERF allows oil companies to perform joint research on petroleum- related environmental issues and technologies. PERF has 25 member companies. Under PERF, member companies propose research projects to the Forum and if there are enough interested companies, it becomes a PERF project. The results of PERF projects are usually confidential to the parties that contributed. Together, PERF has about 40 research projects that are either active or completed.

Catalysts
Improved catalysts (capable of functioning at lower temperatures and pressures) reduce the energy used by decreasing the reaction temperature of the various processes. This increases product selectivity and provides greater throughput. UOP pioneered and continues to improve its so called "platforming" process which involves a platinum-based catalyst to process straight run naphtha into high-octane gasoline. One of the major innovations in the 1970s was the continuous catalyst regeneration (CCR) platforming process. CCR platforming has been important to energy efficiency since it typically increased yields by 7-8 percent. It also produces usable hydrogen. By the early 1990s, UOP had licensed 186 CCR platforming units in 41 different countries while its competitors had sold only eight[14]. UOP has also made key contributions to the fluid catalytic cracking (FCC) process that converts fourth- and fifth-cut gas oil and asphalt to gasoline. UOP's FCC reactor design modifications improved gasoline octane and selectivity and thus saved energy. UOP also developed a system that allowed more complete combustion of carbon to carbon dioxide within the FCC regenerator. This minimized carbon monoxide, improved heat release, and increased the energy efficiency of FCC plants considerably.

Aromatic Chemicals
UOP processes produce most of the annual 90 billion pounds of basic aromatic chemicals produced in the world. These include benzene, toluene, and xylene. Derivatives of these include synthetic rubber, styrene products, phenolic resins and synthetic fibers. Many of these processes have relatively poor conversion efficiency. Because of this, manufacturers try to improve the overall process performance by operating with a substantial amount of recycle. This results in larger throughput in the process, requiring larger units and thus increased energy consumption and waste emissions. This is an opportunity for UOP research.

UOP also is an example of how external sources of R&D must provide related services in order to be successful. In addition to R&D, UOP works on process technology, process plants and equipment, engineering, technical services, and manufacturing[14]. UOP also helps plan, design, engineer, and commission new installations and advises on the operation and performance of facilities in the majority of petroleum refineries and petrochemical plants located throughout the world. UOP's success demonstrates that petroleum refining provides unusually good opportunities for external sources of R&D. UOP now holds 25,000 patents worldwide and services more than 5,600 process units in more than 100 countries. The success of new partnerships such as PERF is still difficult to measure.

CHEMICALS CASE STUDY

Description of Chemicals Industry
This industry, which pays wages that are 32 percent above the average U.S. manufacturing wage, is the largest exporting industry in the U.S. It supplies more than $1 out of every $10 of U.S. exports and has the highest export trade surplus of the manufacturing industries . It employs more than one million people at an average wage of $15.60 per hour. Comprising more than 30 industries, 9000 firms and 70,000 products at 12,000 plants, the U.S. chemical industry is too complex to characterize as a single industry[3]. For this analysis we have excluded pharmaceuticals and medicines, focusing on industrial chemicals.

The chemical industry's R&D is generally internally focused and is viewed as a key source of competitive advantage. The industrial chemicals sector has an above average R&D/sales ratio (4.4) and has long been viewed as more innovative than the other process industries. It has highest environmental costs ($6.3B) and the highest R&D/sales ratio of any process industry[8]. Not surprisingly, the industry devotes a high percentage (perhaps as much as ½) of this research to environmental issues.

In chemical manufacturing, heat and pressure are used to separate and combine chemical building blocks into salable products, either to final consumers or to other manufacturing. As with the other process industries, the most promising technologies to reduce energy use in the near term are those that reduce heating or cooling or bring the two into better balance. However the chemicals industry provides the energy for its multiple basic processes in many different ways. Some products – chlorine and other – industrial gases – are made electrolytically or by using electricity directly to compress and liquefy gases. Other processes, such as petrochemical processing, depend on direct combustion of fossil fuels to produce high temperatures and pressures. The most energy-intensive segment is basic chemical production which includes petrochemicals, industrial gases, and other organic and inorganic chemicals.

Examples of External R&D that Impact Chemicals Industry Energy Efficiency
The chemicals industry is both quite complex and highly proprietary. Thus, there are few examples of external based technologies that cut across the entire industry. But this complexity means that there is a need for broad technical information services. SRI International, an independent, nonprofit corporation, that is one of the world's largest research, technology development and consulting organizations, found that the chemicals industry provided an excellent market for chemicals reference information. SRI's *Chemical Economics Handbook*, first published in the 1950s, is still published annually and is considered the de facto industry guide. The handbook analyzes the chemicals and specialty chemicals areas now available for worldwide markets.

Process Integration Techniques
Another information-oriented external technology used in the chemicals industry is process integration. One well known process integration technique, the "pinch" technique, was developed in the 1970s and 1980s at several universities. This technique saves energy because it finds the "pinch" point--the point with the best match between available and needed heat. This allows the heat exchanger (waste heat recovery) system to be optimally sized for greatest cost effectiveness. In early applications, energy savings averaging 30%, with capital cost savings in new plant designs and a one year pay back in retrofits were common. Refinements to the technique have resulted in typical savings of 50% in new plants and retrofit pay back periods of six months.

More recently the "pinch" technique has been applied as a general optimization tool. By the mid-1980s, largely with the assistance of external sources of R&D such as technology consulting firms, the use of pinch analysis became widespread in the chemicals industry. AspenTech, a technology firm, provided a substantial amount of process integration technology to the chemicals industry. It was founded in 1981 to commercialize technology developed by the Advanced System for Process Engineering (ASPEN) project at MIT. It is now a leading supplier of modeling, control, optimization, and process information software services to the chemicals and related industries. AspenTech's success--its customers include more than two-thirds of the 50 largest chemical companies in the world--demonstrates that this type of external R&D is important in the chemicals industry .

Partnerships
The Center for Waste Reduction Technologies (CWRT)--a division of the American Institute of Chemical Engineers (AIChE)--provides examples of recent successful industrial chemicals industry partnerships. CWRT has more than 20 member companies doing industry-sponsored research to develop innovative waste reduction technologies and methodologies. In one project, CWRT partners are developing a database/tool on separations technology for clean process advisory systems. In another project, CWRT partner researchers are investigating chemical precipitation and recovery of ammonia and amines. CWRT partners also participated in a workshop and book that discussed emerging separation technologies and separative reactors.

WHY R&D OUTSOURCING HAS BEEN RELATIVELY RARE

Given all the benefits, it is surprising that external research has not been more important for the process industries. But R&D is very different from services that are outsourced. The benefit of doing research internally and the costs of doing research externally are both higher than for other services. Thus, external research must have an unusually high value or low cost to be worthwhile. In addition, intellectual property protection must be strong for external research providers to find it profitable. On the benefit side, unlike many other services, research that leads to innovation can supply a major competitive advantage. Most companies have historically been able to profit more from doing R&D internally[17]. For example, many users of new technologies could profit more on innovative process machinery if they built it in-house and protected it as a trade secret. Such profits can be more significant than any scale-related economies potentially offered by a specialized process equipment manufacturer. Since the 1990s, the most innovative firms have set a goal of having 50% of their sales from products introduced in the last four years. Of these, at least 50% should be completely unique and new to the world.

On the cost side, either the client or the provider must invest more if research is external. If the client bears the burden, his cost is to maintain in-house research that can assist in the absorption of external technology. If the client has little or no relevant in-house research, he cannot readily use the R&D and so the research provider bears the cost of developing enough client company-specific expertise to assist theclient in using the R&D. Cohen and Leventhal invented the term "absorptive capacity" to describe the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends[18]. They suggest that it is largely a function of the firm's level of prior-related knowledge. If a firm has no researchers of its own, or if it isolates the researchers, it will have a hard time understanding the value of external research and innovation. External research providers can and do surmount these barriers. For example, they often detail employees to the client firm to assist them in absorbing the external R&D.

INVESTMENT IN EXTERNAL RESEARCH VARIES BY INDUSTRY TYPE

To illustrate why the R&D/sales ratio fails as a means to compare innovation across industries that use external research, we present two extreme types of hypothetical industries in which research is either completely external (alpha-type) or completely internal (beta-type). In alpha industries, the entire industry contributes to and receives the benefits of this external research (either through a consulting firm that everyone buys licenses from or through a research consortium). There are only two processes being used and researched by the alpha industry which comprises 10 companies. This low number is plausible since sharing of external research is more likely when there are only a few basic processes in the industry. In the beta industry, the internal research is strictly proprietary and therefore not shared with other companies. Since this situation is more likely when there are numerous unique processes, we assume that each of the beta industry's 10 companies does research on one (its own) process for an industry total of 10 unique processes. We will also assume that both industries have the same total sales ($10 billion) and that beta spends $2 billion and alpha spends $1 billion on R&D. Table 1 illustrates that by the traditional R&D/sales metric, beta industries appear to spend more on R&D. Whereas using the R&D/process metric, the alpha industry spends more as a whole, but each company spends far less on R&D.

Table 1: R&D/sales and R&D/process ratios for external- and internal-research biased industries

	R&D/sales	R&D/process $M	R&D/process/company $M
alpha (external only)	10%	500	50
beta (internal only)	20%	200	200

While alpha and beta are useful heuristic devices, real industries have both alpha and beta characteristics. Using the R&D/sales ratio assumes that there is only the beta type. The previous sections have documented the process industries' use of shared external R&D. Thus, these industries must be a mixture of alpha and beta types. We propose that the process industries be divided into types A & B. Type A industries (e.g. pulp and paper) involve a limited number of basic processes. Type B industries (e.g. chemicals) involve numerous complex processes. Table 2 lists the R&D/sales and R&D/process ratios for these industries. The number of processes used is for illustrative purposes only. It is intended to reflect the number of energy intensive processes used in the respective industries.

Table 2: Research Relevant Statistics and R&D Metrics for Three Process Industries

	R&D $billion	# processes	R&D/sales(%)	R&D/process $M
Pulp and Paper	1.4	5-10	1.1	140-280
Petroleum Refining	1.7	10-20	0.8	85-170
Industrial Chemicals	5.2	500-1,000	4.4	18-36

Pulp and Paper, with the lowest R&D/sales ratio and the highest R&D/process ratio, and Petroleum Refining appear to have more "alpha" characteristics and thus are "Type A." Industrial chemicals has more beta type R&D and thus is "Type B." In the following, we explore the relationship between greater use of shared external R&D and other industry characteristics.

Type A: In these industries, a limited number of processes are common to industry as a whole. Many of the basic processes are so widespread that they are not crucial to protect to maintain the companies' competitiveness. Any modifications or improvements to the basic processes are capital intensive. These are commodity industries in which prices are not set by individual companies. Thus, most companies profit through a "low- cost supplier" strategy or slight product differentiation. Because of these features, there are greater opportunities for external R&D including both collaborative and contract R&D. External research providers such as technology consulting firms are more likely to conduct R&D for a group of clients in these industries. These industries typically have a below average The R&D/sales ratio. Thus, these industries are supposedly low on innovation. But in fact, because they have a smaller number of products using a much more limited set of processes, type A firms may be jointly spending a significant amount on R&D per process. In addition, since the basic process is NOT the source of competitive advantage for the company, they are far more likely to be able to partner with each other or jointly engage external R&D providers.

Type B: These industries feature numerous complex processes--many of which are proprietary. These processes are often key to companies' competitive advantage. However, this complexity provides an opportunity for information oriented external research providers. High skills external technical services are in demand. Type B industries offer more opportunities for technical services, information and information technology. In Type B industries, fewer companies benefit from research on any given new product or process. Only some of the industry's processes are capital intensive. A given company may produce some commodity products, but it is free to set prices on many of its specialty products. The low-cost supplier strategy is less prevalent because companies offer unique products. While small partnerships can work in specific cases, R&D collaborations involving the entire industry are rare. The industry's R&D is internally focused and is viewed as a key source of competitive advantage. Because of these factors, the industries tend to have a relatively high R&D/sales ratio and are viewed as more innovative than Type A industries.

Our hypothesis is that Type A firms are not necessarily less innovative than Type B firms. For example, a Type B industry have a higher R&D/sales ratio, but if the Type A industry use the external R&D and it is shared, it may have equal or higher R&D/process than the Type B firms. Thus, Type A companies do not need to spend as much on R&D as type B firms. In addition, the greatest opportunities for shared external research are in Type A industries. Any given R&D can be more catalytic since genuine process innovation can be used by the entire industry.

CONCLUSION

In order to prove the suggested connections between use of external R&D, number and proprietary nature of basic processes, and energy intensity, more data is needed from both the process industries and from those who provide the external R&D. For example, comprehensive data on sources of innovations and funding for energy-intensive processes are needed. In gathering this data , intellectual property, both on the R&D and on the strategy for using and providing external R&D, needs to be protected. More study of all the issues relating to the full complexity of the sources and motivations for innovation and its relation to energy and resource efficiency is also needed. Based on this preliminary analysis, however, we expect that external research will play an important role in dramatically more productive and energy efficient innovations in process industries. In the United States, contract R&D, partnerships and the demand for technology transfer and commercialization skills will continue to increase. Process industries will collaborate even more on R&D on energy intensive key processes. Global pressures will cause these process industries to change more in the next few years than they have in several decades. External research is key to the transition to more sustainable process industries.

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