

TECHNICAL COMPETITIVE ADVANTAGE:
A STUDY IN THE ENGINEERING SERVICES INDUSTRY

by

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ABSTRACT

The management of technology has been recently emerging as a recognized interdisciplinary field. This has occurred largely as a result of the ever increasing importance of technology in virtually every industry. At the heart of its importance is the competitive advantage that can be obtained through technical innovation.

This thesis investigates the nature of technical competitive advantage (TCA) in that segment of the engineering services industry engaged in the design of petrochemical plants. Fundamental elements related to the development and sustaining of TCA are presented in a conceptual framework applicable to any industry. The focus on a single industry segment facilitates a deeper study of the essential features of TCA, but also illuminates elements of broader applicability. Elements identified as central to obtaining and sustaining TCA are compared to relevant features of two case studies of the role of engineering firms in new process development.

The basic concept of "knowhow" is identified as the most critical element of sustainable TCA. Technical advantage is derived from superior knowhow in specific process engineering technologies which enables innovative solutions to complex engineering problems. This ability is manifested in improved designs of engineered equipment and systems and the commercialization of new processes evolving principally from manufacturers' basic R&D efforts. The primary measure of the existence of TCA is recent past performance of the engineering firm. This can be either in terms of effective solutions to complex engineering problems associated with new process development or improvements to existing processes or in terms of the physical performance of recently engineered plants.

With intense competition in the industry, firms seeking *technical* competitive advantage focus on one or more market niches but leadership is seldom secure. The continuing technical competition results in a general pattern of one firm gaining advantage, reflected by a significant portion of contract awards, followed by a shift in leadership to another firm as its evolving technical capabilities are demonstrated by their recent performance. Loss of TCA seldom results in exit from competition, but rather a continuation of the cycle by ongoing technical development efforts.

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1.0 Introduction

The ever increasing intensity of both domestic and foreign competition in virtually all industries has focussed a significant degree of effort towards the understanding of the broad issues of "sustainable competitive advantage." Notable among many works in this area is that of Michael Porter (Ref. 1). This thesis will examine the role of technology as a significant factor in the establishment of competitive advantage. Clearly this is a broad subject in and of itself with many elements of varying degrees of importance in differing industries. In order to enable a reasonably detailed study, a single industry segment is studied herein.

This thesis investigates the nature of technical competitive advantage (TCA) in that segment of the engineering services industry engaged in the design of petrochemical plants. While specific findings are directly applicable to this industry segment, they are presented in a general framework applicable to any industry. In this manner, findings can be compared or contrasted with corresponding characteristics of TCA in other areas, although that is beyond the scope of this study.

Chapter 2 provides background information on the petrochemical industry. A brief summary of its origins and current structure are presented as a backdrop for subsequent discussions of engineering firms. Given this setting, the specific issues to be studied and the framework to be employed are presented.

The fundamental elements and issues of TCA in the subject industry segment are presented and discussed in Chapter 3. The ideas and findings presented are based on personal experience in engineering (although not

specifically in process plant design), interviews with personnel in a number of engineering firms, and literature reviews (primarily trade journals).

Section 4 presents two case studies of the development of petrochemical process innovations in which engineering firms provided the primary technical leadership. Features of these cases are then reviewed in terms of the evidence they provide in support of the model of TCA developed in Chapter 2.

An overall summary and conclusions are provided in Chapter 5 and a record of interviews is contained in the Appendix.

2.0 Background and Central Issues

2.1 Petrochemicals and Production Processes

Petrochemicals are chemical compounds (principally organic) produced by chemical reactions from hydrocarbon feedstocks obtained from petroleum (crude oil or natural gas). The petroleum industry produces hydrocarbon fuels, lubricants, and petrochemical feedstocks. The petrochemical industry is less precisely defined but fundamentally is that sector of the chemical industry engaged in the production of large-scale quantities of basic organic chemicals and their derivatives. The petrochemical industry is quantitatively small compared to the petroleum industry given that less than 5% of petroleum produced is used as petrochemical feedstock. However, with the value of petrochemical products often being more than ten times that of petroleum products, annual sales of petrochemicals are on the order of \$100B.

The family of petrochemicals is related in a hierarchical manner. Each compound is produced by a chemical reaction which adds, removes, or restructures elements of one or more "upstream" chemicals. Although there is no precise definition, petrochemicals are often categorized into three groups: basic hydrocarbons, petrochemical intermediates, and end products. The "end products" are not further altered chemically but are often either formulated with other materials as differentiated chemicals for specific industrial or consumer applications, or used by other industries for fabricating their products. The predominant end products are polymers used to manufacture plastic materials, synthetic fibers, and synthetic elastomers. Other end products are used in fertilizers, pesticides, adhesives, detergents, paints, pharmaceuticals and many other applications.

Figure 2.1 presents an abbreviated illustration of the relationship of the major petrochemicals and their categorization. The two major groups of basic hydrocarbons are olefins (primarily ethylene and propylene) and aromatics (benzene, xylene, and toluene). Olefins plants can use a variety of feedstocks including ethane and propane from natural gas, refinery gases, and naphtha, a light distillate. Ethylene is the predominant petrochemical building block with annual production running nearly 40 billion pounds while propylene, a co-product of olefins plants, is produced at a rate of approximately 18 billion pounds per year. Butadiene is also produced primarily as a co-product of olefins plants. Aromatics are produced primarily from naphtha with benzene produced in the largest quantity at approximately 16 billion pounds per year.

The fundamental processes used in petrochemical plants have been largely adopted from refinery practice. In fact, large scale petrochemical plants resemble refineries although they are often more complex. The two major functional elements of a plant are the reactor and downstream separation and extraction units.

The reactor is the heart of the operation, wherein the synthesized petrochemical compound is created by means of pyrolysis and/or catalytic reactions. In pyrolysis reactors, high temperatures alone cause the cleaving or "cracking" of carbon-carbon and carbon-hydrogen bonds and the subsequent recombining of molecules into different hydrocarbon compounds. The principal application of pyrolysis reactors is in olefins plants with reactors operating in the range of 1400° to 1600° F. In other applications, as in the production of vinyl chloride, the process is somewhat more complicated with the ethylene dichloride feed flowing through catalyst filled tubes during pyrolysis.

Basic Hydrocarbons	Petrochemical Intermediates	Petrochemical End Products	Product Uses		
Ethylene		Polyethylene	Film or Sheet		
	Ethylene dichloride	Vinyl Chloride	Polyvinyl chloride	Pipe or Sheet	
	Ethyl benzene	Styrene monomer	Polystyrene	Packaging	
	Ethylene oxide	Ethylene glycol		Antifreeze	
	Acetaldehyde	Acetic Acid	Vinyl acetate	Polyvinyl acetate	Paints and adhesives
Propylene		Polypropylene		Injection molded plastics	
	Cumene	Phenol	Phenolic resins	Laminates and adhesives	
	Isopropanol	Acetone	Methyl methacrylate	Transparent products	
	Acrylonitrile			Acrylic fibers	
	Propylene oxide			Various plastics	
Butadiene		Styrene butadiene rubber		Synthetic elastomer	
		Vinyl butadiene		Synthetic elastomer	
		Nitrile rubber		Synthetic elastomer	
Benzene	Cyclohexane			Nylon fibers	
Xylene	Terephthalic acid/dimethyl terephthalate	Polyethylene terephthalate		Polyester fibers	
Toluene				Gasoline additive	

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Selected Major Petrochemicals
Figure 2.1

Most petrochemicals intermediates and many end products are produced by catalytic processes. These include hydrogenation or dehydrogenation (addition or removal of hydrogen), alkylation or dealkylation (addition or removal of paraffin radicals) as well as oxidation and chlorination. The key to these processes is the identification or development of effective catalysts. Also, the process often becomes increasingly complex as the product becomes further removed from its origins and also more chemically complex.

Downstream operations are fundamentally simpler, generally involving physical processes alone rather than chemical reactions. Separation of the petrochemical products(s) from the reactor outflow is normally performed by one or more of the following processes.

- Distillation: separation based on differences in volatility of components in the mixture.
- Absorption: separation by contacting gases with a liquid solvent.
- Liquid-Liquid Extraction: separation by selectively dissolving one of the components in an immiscible solvent.
- Adsorption: separation by concentration of a component on the surface of a porous solid.

Major objectives of the entire design process, beyond production of the product itself, are to achieve the highest possible yield from the feed materials and to obtain high purities. Additionally, most processes are energy intensive and energy efficiency has become increasingly important, primarily in terms of heat recovery throughout the process.

2.2 Structure of the Industry

As is the case with most technological developments, commercial development of petrochemicals significantly lagged scientific understanding of the phenomena. Not long after the real onset of the petroleum industry in the 1850s, it was recognized that petroleum could be used as a base material for the manufacturing of chemicals. The first petrochemical plants were not built until the early 1900s, however, and larger scale plants were not built until the 1930s. Prior to this time, the chemical industry relied primarily on coal as its base material.

The earliest petrochemical plants used hydrocarbon feedstocks that were incidental by-products of oil and natural gas refineries. As demand increased, special processes were developed to provide the required quantities and purities of feedstocks for downstream operations. These developments brought the petroleum and chemical companies into close association in this new and rapidly growing industry. Oil companies integrated forward into the realm of petrochemicals in order to create added value from their operations. Chemical companies were reoriented from coal to petroleum as their raw material and integrated backward into the production of petrochemical intermediates and basic hydrocarbons from petroleum feedstocks.

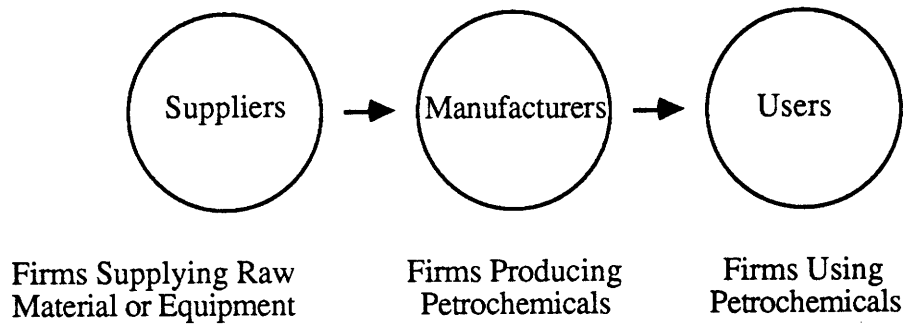
As a result, today's petrochemical industry could generally be characterized as being comprised of the downstream operations of "petroleum companies" (usually by subsidiaries) and the upstream operations of "chemical companies." Following is a more specific characterization of the current structure of the industry.

As a starting point, a simple model depicting the relationship between suppliers, manufacturers, and users is shown in Figure 2.2. Manufacturers include virtually all major chemical companies. In fact, only 10% of the 100 largest U.S. chemical companies do not manufacture basic or intermediate petrochemicals. Suppliers are comprised of two groups: those supplying raw materials and those providing for the physical plant. Users include all the industries which produce finished goods manufactured from petrochemical end products.

As a first elaboration on the industry model, it is essential to recognize two major overlaps between suppliers, manufacturers, and users. First, as mentioned previously, all major petroleum companies have integrated forward into the production of petrochemicals, thus eliminating a distinct division between raw material suppliers and manufacturers. Second, most major chemical companies also produce differentiated chemical formulations and fabricated products from petrochemicals, thereby becoming users as well as manufacturers. These characteristics are presented in Figure 2.3.

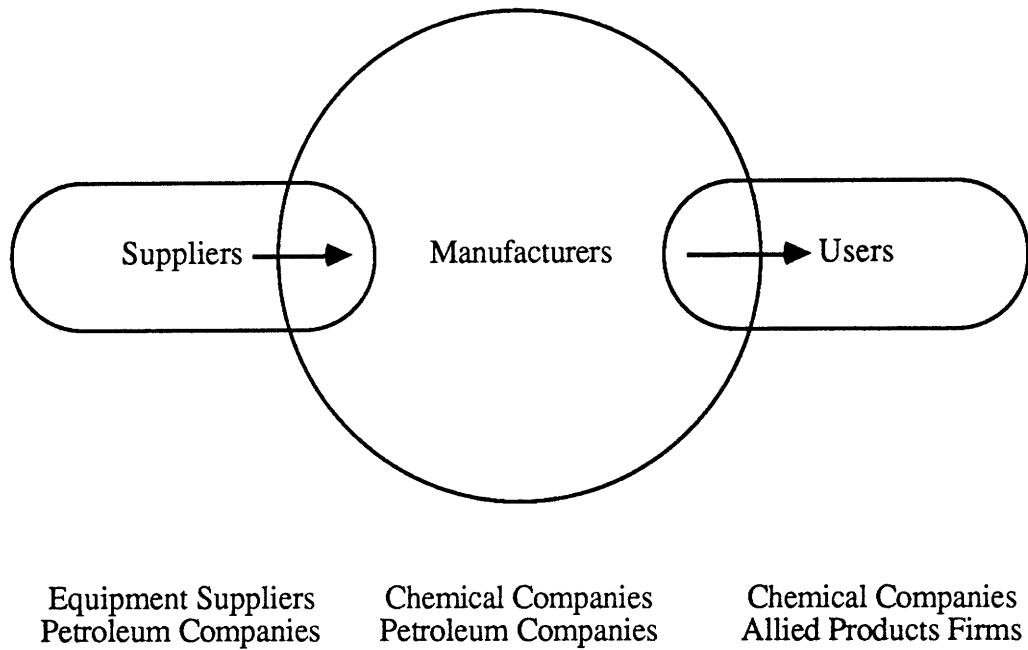
Finally, and central to this thesis, is the role of the petrochemical plant design firm. Due to the complexity and scale of petrochemical plants, the engineer/constructor plays a key role in the commercialization of new processes and the efficient and improved design of plants employing established processes. In general, plant design can be thought of in terms of two distinct elements: process design and detailed engineering.

For an established production process the process design package is typically prepared by an engineering firm and in its simplest terms includes a process flow diagram which presents schematically the sequential process



Basic Industry Model

Figure 2.2



Industry Model with Overlaps

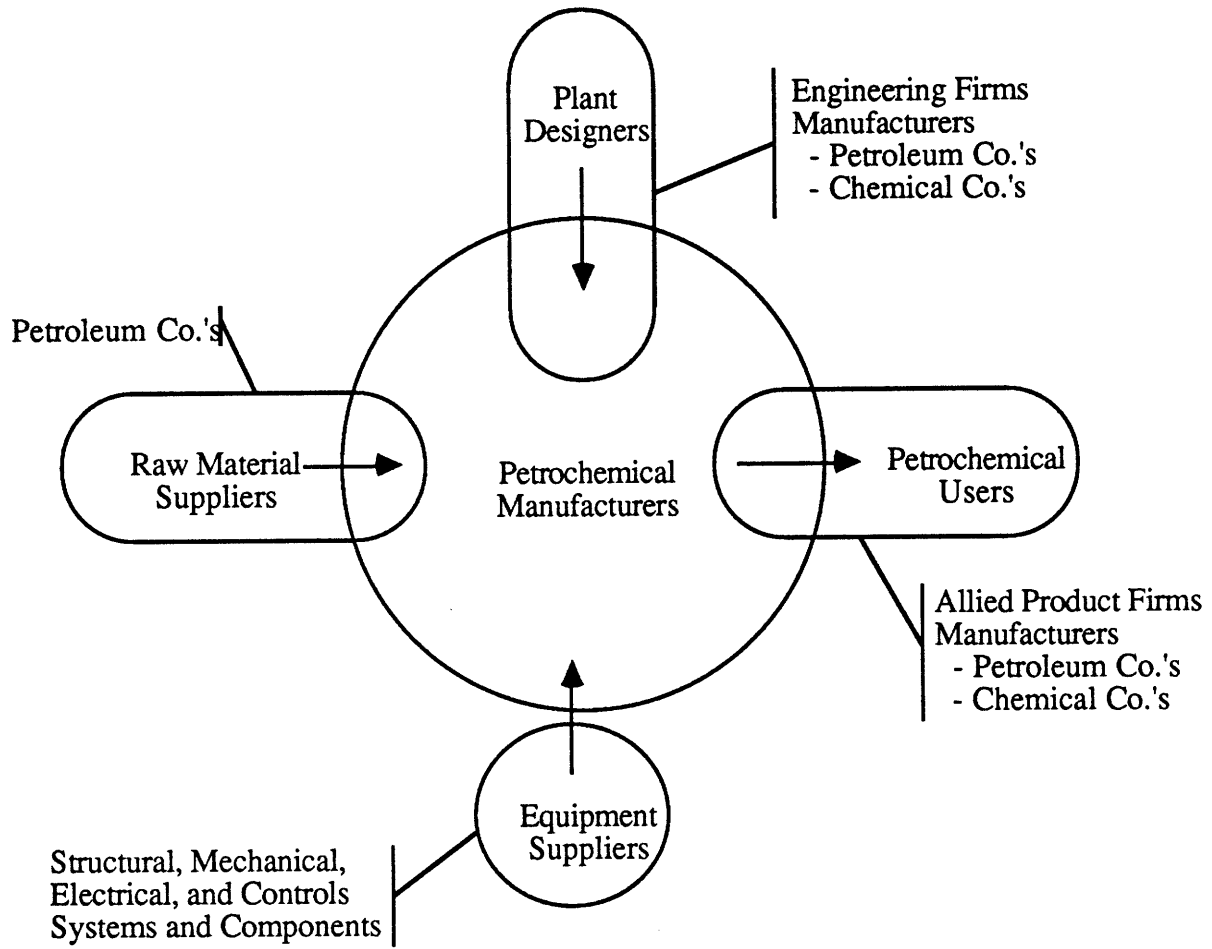
Figure 2.3

operations and process equipment specifications, all of which must be tailored to the unique characteristics of each plant. Preparation of the process design package is the technological heart of the plant design. Even for plants using the same fundamental process, both feedstock and product specifications may vary and by-products may also be utilized in varying ways. The degree of technical expertise provided by the firm developing the process design package will significantly influence the final optimization of all design parameters.

Preceding preparation of the eventual commercial process design packages is the actual development of the process itself. Process development (including basic research, analytical development and bench scale testing) most commonly originates from R&D by manufactures, although there are many cases of active involvement by engineering firms, as will be discussed later.

Detailed engineering includes engineering calculations and analyses leading to the preparation of fabrication and construction drawings for structural, mechanical, electrical and controls systems and the preparation of procurement, fabrication, and installation specifications. Detailed engineering is virtually always performed by engineering firms. Exceptions are in the cases of plant modifications which may be handled in varying degrees by the engineering staff of the chemical company or in a limited number of cases where the largest chemical companies have a sufficient engineering staff to handle a complete plant.

The addition of the elements of plant and process design to the industry model is shown in Figure 2.4. As described above, process design overlaps between the chemical companies and engineering firms.



Petrochemical Industry Model

Figure 2.4

There are hundreds of chemical companies operating in the U.S. today. Table 2.1 identifies the top twenty in total chemical sales and their sales from plastics products and synthetic fibers. Also shown is their ethylene plant capacities. Several points are worth noting with respect to the data in this table.

1. Five of the top ten and nine of the top twenty firms are petroleum companies. Not coincidentally, these include the eight largest petroleum companies.
2. The relatively lower sales of plastics and fibers by the petroleum companies bears out the fact that their concentration is primarily on the basic hydrocarbons and intermediates. ARCO, with its separate Polymers Division, is a major plastics producer, however.
3. Ethylene capacity is a good indication of the degree of upstream integration of the chemical companies. Six of the eleven have major ethylene plants.

A large number of firms offer engineering services in the area of petrochemical plant design. These include companies spanning a wide range of sizes from over \$5B to under \$50MM in annual revenues. Due to the diversity of operations of many of these firms and the large differences in the sizes of individual projects, it is difficult to specifically rank order them in terms of "market share" in the petrochemical industry. Table 2.2, however, identifies several of the important competitors and provides an indication of their market size, although the percent of business in petrochemicals varies greatly. Additional discussion in terms of their bases of competition is contained in Chapter 5.

Petrochemical Manufacturers		Annual Sales (\$B)(1)			Ethylene Capacity (bil#/yr)(2)
Petroleum Companies	Chemical Companies	All Chemicals	Plastics & Resins	Synthetic Fibers	
	Dupont	11.5	1.3	2.8	2.3
Exxon		6.7	0.3	-	2.6
	Dow	6.0	3.0	-	4.0
	Union Carbide	5.8	1.0	-	3.9
	Monsanto	5.2	2.0	1.1	-
Chevron		3.4	0.3	-	2.6
	Celanese	2.9	0.1	1.5	-
Shell		2.6	0.5	-	4.0
Amoco		2.5	0.2	0.2	2.2
Occidental		2.1	0.2	-	-
Phillips		2.1	0.4	-	2.5
	Hercules	2.0	0.7	-	-
	Eastman	1.8	0.2	0.5	1.3
Mobil		1.6	-	-	1.0
ARCo		1.5	0.9	-	2.8
	USS Chemicals	1.3	0.5	-	0.5
	Rohm & Haas	1.2	0.6	-	-
	Allied	1.2	0.1	0.2	0.7
Texaco		1.0	-	-	1.4
	Ethyl	1.0	-	-	-

(1) 1980 data (Ref. 2) but indicative of relative structure

(2) 1986 data (Ref. 3).

Major Petrochemical Producers
Table 2.1

Representative Firms Engaging in Process Plant Design

Engineering Firm	Total 1986 Design Related Contracts (\$MM) (1)
The Parsons Corp.	9169.
Bechtel Group Inc.	9169.
M.W. Kellog Co.	5347.
Fluor Daniel	3756.
Brown & Root Inc.	2574.
Lummus Crest Inc.	2335.
Jacobs Engineering Group, Inc.	2001.
Foster Wheeler Corp.	1975.
Stone & Webster Engineering Corp.	1974.
Sante Fe Brown, Inc.	915.
Barnard and Burk Group, Inc.	442.
John Brown E&C Inc.	352.
The Badger Co., Inc.	<100.

(1)Includes design only and design-construct contracts in all business segments (Ref. 4).

Table 2.2

2.3 Central Issues of Investigation

As stated in the introduction, the objective of this thesis is to investigate the nature of technical competitive advantage (TCA) in a single industry (engineering services) and a specific segment within it (petrochemical plant design). At the same time, it is desired to do so within a generally applicable framework. Such a framework is provided by the following central questions:

1. What constitutes technical competitive advantage?
2. How is technical competitive advantage obtained?
3. How is technical competitive advantage protected?
4. How is technical competitive advantage lost?
5. What happens if technical competitive advantage is lost?

Proposed answers to each of these questions will be presented and discussed in Chapter 3 as they specifically relate to the subject industry segment. In doing so, distinction will be drawn between the essential elements of TCA and other factors which may be valuable prerequisites to competing, but in and of themselves provide no distinguishable advantage. Also, although much of the discussion will inherently be qualitative, objectively measurable elements will be provided to the extent possible.

3.0 Technical Competitive Advantage in the Design of Petrochemical Plants

This chapter presents a discussion of the fundamental elements of technical competitive advantage (TCA) in the subject industry segment within the framework presented in Section 2.3. The extent to which findings may be unique to the industry segment studied or of more general applicability will be discussed in Chapter 5.

3.1 Constituents of Technical Competitive Advantage

The concept of technical competitive advantage may call to mind a wealth of images. Marketing literature of engineering firms is filled with descriptions of attributes such as:

- full range of engineering services, worldwide capability
- __ years of experience, more than __ projects completed
- best in the business, excellence and superior quality
- large projects on time and within budget
- computer aided engineering and design
- able to answer special needs of customer
- experienced people, skilled personnel, creative engineering
- innovative problem solving, creative engineering
- proprietary technology, acquired patents, licenses and knowhow
- process evaluation, process improvement, process commercialization

Several of these characteristics are indicative of technical competitive advantage while others, although important, are more indicative of competitiveness based on factors other than technical leadership. Also, without

getting at the substance underlying these features, they may in fact represent no more than the fundamental prerequisites to being in the business and as such provide essentially no distinguishable competitive advantage.

This section will identify and discuss the underlying attributes which are considered to be the basic constituents of TCA. Again, that is not to downplay the importance of cost related and other commercial bases for competition, but the distinction is essential.

Although most would agree that it goes virtually without saying, the absolute essence of TCA is technically sound and creative engineering personnel. This may be implicit in any characterization of TCA, but is of such importance as to warrant unique identification. Whereas the quality of personnel is important in any industry, it is especially so in engineering services, where the capabilities of the personnel are the heart of the capabilities of the firm. To emphasize the point, consider the concept of the diffusion of technology. Although other mechanisms may be more common, none are more effective than the movement of key personnel within whose body of knowledge the key elements of advanced technology are embodied.

But all engineers are "talented." The distinction of consequence is that between the ability to perform basic (not meaning simplistic) engineering and design tasks and the ability to develop creative solutions by means of associative processes drawing from a depth and breadth of basic technical knowledge. Any firm which reaches a position of technical leadership will have such personnel at the forefront. Firms that do not have as creative a staff will be hard pressed to compete on a technical basis.

Given the prerequisite of a talented and creative engineering staff, perhaps

the functionally most significant element of TCA is the possession of state of the art capabilities (superior "knowhow") in one or more of the basic engineering technologies applicable to process plant design. In this era of high-tech electronics and biotechnology, "state of the art" may at first bring to mind rapidly evolving technologies such as these and seem at first thought inconsistent with "basic engineering." The key, however, is that all technologies *are* evolving, regardless of the rate and, by definition, only a small number of firms can be said to possess or be advancing the state of the art in even the long established fields of mechanical and chemical engineering.

The specific technologies of greatest value can be characterized as "enabling" technologies, i.e., those which enable innovative advances in the design of engineered process equipment and systems. The distinction is intentionally made between such engineering technologies and those more closely related to basic science. The role of even the most technology oriented engineering firm is ultimately to design reliable and economic commercial facilities. Although an understanding of the process chemistry is essential, the engineering firm is not in competition with the manufacturer, and maximum advantage is derived from a state of the art position in the basic enabling engineering technologies.

The scope of relevant technologies does change, however, and those firms which are leading the way in terms of application of new technologies or which are able to quickly adapt will gain technical competitive advantage. Two brief examples are given below which will illustrate the point without going into technical detail. The first relates to leading positions in well established technologies while the second relates to adopting an emerging technology.

First, consider the technology of fluidized bed reactors. Feedstocks are mixed with a catalyst and the reaction occurs while the mixture is flowing through a vessel at the required pressure and temperature. Beyond the chemistry of the reaction, the basic technology requires knowledge of heat transfer, fluid dynamics, and solids circulation. All engineering firms competing for projects employing such a process will have capabilities in these areas. However, those firms with the most sophisticated expertise and analytical tools in these areas - coupled with creative engineers - will derive technical competitive advantage from their ability to solve design problems in innovative ways unlikely to be arrived at by the competition.

As another example, consider the case of computerized control systems. Clearly there was a time when any application of computerized systems was far from being an established technology. It was not long, however, until the benefits of computerized process controls were evident to all. Although this would be considered an established technology today, those firms who led the way of introduction or who continue to advance the state of the art in terms of sophistication of applications today certainly had or have a technical competitive advantage as a result. It is noted that the advantage came not from research on computer technology, per se, but from the pursuit of creative engineering applications.

The second potential element of TCA is the possession of superior knowhow in a competitive production process. Whereas the first element of TCA is of potentially broad applicability, the second relates to unique expertise in all facets of production of a particular petrochemical. These differing forms of expertise are often closely related but offer advantages of different natures. Firms with superior knowhow in a given process have a technical advantage in

competing for associated plant design awards. The degree of advantage will be directly related to the degree of competitiveness of the process. In contrast, firms with superior knowhow in a particular area of process technology are more likely to be sought to solve unique problems, evaluate new processes, and potentially participate in new process development.

Finally, a third element of technical competitive advantage is or can be the possession of rights to a superior process technology. Although "superior technology" ultimately implies one offering a commercial advantage, its technical features would include one or more of the following:

- higher product yield or purity
- greater feedstock flexibility
- fewer process steps
- greater energy efficiency
- less "down time"

Possession of rights to such a process technology may take one of several forms:

- sole or joint ownership of the process patent
- exclusive or restrictive rights to market the process (owned by another party)

Possession could also be in the form of a superior but unpatented process, but this is unlikely.

The critical element here, in terms of TCA, is not so much the form of possession, but that the process is indeed superior or at least strongly competitive. While rights to other, even many, patented processes does in fact

allow competition in those markets, if the process is not technically superior, no TCA is associated with such process rights.

In summary, the fundamental constituents of technical competitive advantage are:

- Superior "knowhow" in a specific area of process technology
- Superior "knowhow" in a competitive production process
- Rights to a competitive production process

The essence of the first two elements of TCA, both related to knowhow, is quite subjective and as such must have some associated objective means of assessment. The means by which such advantage is demonstrated by the engineering firm (and evaluated by the potential client) is by evidence of recent successful project performance. Although it takes time to develop and establish a reputation for technology leadership, "what have you done lately?" is the real test of a firm's knowhow at any point in time.

In considering any contract bids, the client, among other considerations, will assess the credence of technical claims by evaluating actual results of equivalent or analogous recent projects. Such efforts will always be emphasized by the engineering firm and can be confirmed by discussions with prior clients. If the award at hand requires the solution of novel engineering problems, evidence of successful experience employing that area of expertise is the demonstration that such knowhow exists. Even if the firm does not have explicitly applicable experience, evidence of other complex and generally analogous problem solving can serve to demonstrate the underlying knowhow.

The third element of TCA, rights to a competitive process, is inherently

less subjective, but again is demonstrated by recent performance. A client can compare process claims made by competitors for the design of a new plant against performance of their latest projects in quantitative terms such as product yield and purity, energy consumption, and other operating costs.

In all cases, recent relevant projects can be viewed as the engineering firm's "product" and as such provides the basis of comparison of relative technical advantage.

3.2 How Technical Competitive Advantage is Obtained

As discussed in section 3.1, the heart of technical competitive advantage is a highly skilled and creative engineering staff. This is obviously achieved primarily by selective recruitment of talent. Movement of key personnel between firms does not appear to be common in this industry and most new employees come directly from college or via a relatively early move after a first job. Having the right personnel alone, however, is not sufficient. In order to take full advantage of the unique strengths of individuals, the firm must foster a reasonably innovative atmosphere. Given the intense competition in the industry today and the associated small profit margins which are prevailing, tight cost control and relatively rigid structure are the norm. Under these conditions, it is no small challenge to create an atmosphere of reasonable creative freedom, but one which must be attempted if innovation is to be achieved.

Development of state of the art technology capabilities is fundamentally an on-going in-house process characterized by "success breeding success." Although it is a simple concept, the most effective means of increasing expertise is via actual experience and the better the firm is technically, the more likely it is

to obtain technically challenging projects.

In somewhat of a limiting extension of this concept, a firm with an established position of technology leadership becomes a leading competitor for the commercialization of a new process developed by a chemical company. Having this opportunity both enables the firm to increase its technical expertise by application of existing skills to inherently new design problems and also results in the ability to claim unique experience when competing for subsequent project awards. Given the benefits of a commercialization project, competitive firms will strongly seek such opportunities. In many respects this is analogous to the "lead user" concept presented by von Hippel (Ref. 5). If a firm can anticipate such developments and establish early mechanisms for technical assistance or participation, the stage will be set to play a dominant role in future implementation of the new process.

Other means also exist for increasing technology strengths, particularly from outside sources. For example, the M.W. Kellogg Co. has arrangements with engineering software firms through which it acts as a testing ground. Through this process, Kellogg is able to both influence software developments and also obtain advance access to improved products.

Similarly, the Badger Co. has a collaborative arrangement with an artificial intelligence company. Together they are working on AI routines that could be used in conjunction with Badger's process simulation software for troubleshooting of plant operational problems.

University research would also appear to be a potential source of advanced technology, but this does not appear to be the case. Apparently such research is considered to be too far removed from near term applicability to warrant active

pursuit. (The validity of this concept could be an interesting subject to investigate.)

Obtaining rights to a superior process may or may not stem from an established position of technical leadership. If the process has been developed solely by a chemical company a number of factors come to play in establishing arrangements with engineering contractors.

The first issue is whether or not to grant exclusive marketing rights. Doing so reduces the number of ensuing legal complications but also may limit the potential for future sales of the process, particularly in terms of the global market. If exclusive or restricted marketing rights are not granted, no significant TCA is derived specifically from rights to use the process, although TCA may still be obtained by exploiting the opportunity to expand technical expertise.

If exclusive rights to the process are to be awarded, they will not necessarily go to the current technology leader. Another firm with a broader market presence or one offering better commercial considerations may also be a strong contender. Existing technology leadership will be of relatively increased value, however, if the new process entails a significant departure from traditional designs.

Process rights will accrue directly to the engineering firm if they have been actual party to the process development. Depending on the degree of participation, the result could range from exclusive access to the process to a joint ownership and sharing of royalties. Clearly this situation is most likely to develop for a firm that has the state of the art technology to bring to the development process.

Sole development of a patented process by an engineering firm may also occur, but is the exception. Such cases can typically trace their origins to earlier collaboration with the manufacturer, but for a variety of reasons resulted in subsequent spin-off of independent efforts. In most such cases the basic chemistry of the process is well understood and process improvements were derived primarily from significant advances in equipment design and system configuration. Although these situations are of significant value to the engineering firm, as mentioned, such opportunities are infrequent.

Given the establishment of a talented and creative staff, the process of obtaining TCA can be summarized as a largely interdependent combination of the following mechanisms.

- Experience
- Research and development
- Acquisition

The opportunity to increase knowhow and develop technical advances in conjunction with the experience of ongoing design projects is perhaps the most common means of increasing TCA. Most effective is the experience and knowhow that can be obtained from a new process commercialization project. Whether experience has in fact led to TCA can be evidenced by the degree to which a firm's technical capabilities have actually increased over time.

In-house R&D appears to be most effective when focussed on those basic and emerging engineering technologies which will enable innovative advances in the design of engineered process equipment and systems. Basic research in process chemistry is infrequently the domain of an engineering firm for two basic reasons. First, the direction of such research is best dictated by market needs

and the engineering firm is one step removed from first hand knowledge of such requirements. Second, with revenues derived fundamentally from the sale of services (manifested in drawings, specifications, and technical reports) as opposed to a manufactured product, there is not a separate cash flow from which to fund such research. Therefore, venturing into new areas is best done in concert with the needs of a client company. Opportunities of this nature may arise from problems developing in operating plants or from R&D projects originating within the client's organization.

Acquisition of rights to a new process will not necessarily be granted to the current technology leader, but such a position may significantly increase the likelihood. Possession of such rights are stressed in a firms' marketing efforts and generally known of through industry publications (Ref. 6, 7).

3.3 How Technical Competitive Advantage is Protected

The petrochemical industry is a mature one and by many current standards the rate of technical change is comparatively slow. Technology in any field is not static, however, and a firm that has reached a position of TCA will not automatically retain that position.

Trade secrets, also commonly referred to as proprietary information, are a pervasive mechanism of guarding a firms technology. (Maintaining strict confidentiality regarding a firm's technical capabilities also protects against disclosure of areas of weakness.) Virtually all firms require all professional employees to sign non-disclosure agreements. Most visible, however, are the detailed secrecy agreements executed by multiple parties involved in the design of a new plant (which typically utilizes a licensed proprietary process). Even when entering into initial discussions with a prospective client, confidentiality

agreements must be signed before any technical details of the process are discussed. When a contract is awarded, detailed non-disclosure and non-use terms are included, typically for a period of about 15 years. Such agreements not only protect the technology, but also serve to tie future plant modifications to the original engineering contractor.

Subcontract awards for major equipment items which employ proprietary technology are also covered by similar confidentiality agreements. As the technology becomes further removed from the source, e.g, goes to subcontractors, the ability to police the maintenance of confidentiality diminishes. Breaching of agreements is uncommon, however, with a strong motivation being the value of retaining a reputation for integrity. This is true at all levels, given that a tarnished reputation will result in serious consequences, not only in terms of legal liability but also in terms of prospects for future work.

Also essential to protecting TCA is the common mechanism of patenting. Consistent with the fundamental role of the engineering firm, most of their patents are for equipment rather than processes. The degree to which firms file for patents is somewhat a matter of philosophy. The trend however appears to be related to the potential commercial value of the invention and the perception of the degree of competition. The greater the potential value or the likelihood of a competitive design, the more likely the firm is to patent as opposed to relying strictly on trade secrets.

With respect to patent filing, innovative inventions may often occur in the form of a group of related designs or as one with separable features. In an attempt to somewhat obfuscate the integrated value, it is not uncommon to employ multiple filings for the separable elements.

A third mechanism of protecting TCA is through the terms of a process licensing agreement. As discussed earlier, TCA can be obtained by acquisition of rights to market a competitive process, the heart of the design package. The value of this form of TCA is directly related both to the degree of competitiveness of the process and also to the extent that it is protected through terms of the agreement. If a firm is able to acquire exclusive rights to market the process, an excellent degree of protection of the technical advantage has been achieved.

Protection is only of value in the relatively short term, however, and sustaining TCA requires continual technical advancements. Such advancements can be made independently in each of the three elements of TCA: knowhow in a specific area of process technology or of a competitive process or rights to superior processes. No unique discussion is necessary with respect to how this is accomplished, other than observing that it is a continuing evolution of the process which originally led to the achievement of TCA, with perhaps one exception. Once a technical advantage has been gained in some area, this can be further capitalized upon by seeking out new areas of application. This could be the result of a partnership process development, a commercialization project, or in-house efforts to make improvements to established processes.

It should also be emphasized that within the highly competitive environment of engineering services, the establishment of a dominating technical advantage, even in a narrow area, is not common and lesser technical advantages are often short-lived. Therefore, to assure ongoing commercial success, a firm must also establish a competitive position on other non-technical bases, e.g., breadth of engineering services, effective management systems, and generally efficient engineering practices. In other words, the value of TCA is

diminished if the firm is unable to offer a commercially competitive total engineering services package.

To summarize the means of protecting and sustaining TCA, the essential mechanisms are:

- Trade secrets
- Patents
- Licenses

The degree to which trade secrets are used as a means of protection cannot be readily quantified. Their importance is evidenced, however, by the pervasive emphasis placed on guarding proprietary information, both in daily practice and by the standard practice of employing secrecy agreements with clients and contractors when proprietary technology is involved. The extent to which protection is sought by patents and licensing agreements is also difficult to rank, but their use is directly observable.

In order to be effective, however, these means of protection must be accompanied by ongoing pursuit of technical advances in order to sustain or increase TCA in the long run. Strengthening of non-technical bases of competition will also leverage the value of TCA.

There are two sides to this issue. A firm can never lapse if it hopes to retain TCA, but conversely, TCA if properly exploited can grow on itself. Having an established position will promote obtaining new opportunities, but failure to capitalize on the opportunities will result in the loss of TCA.

3.4 How Technical Competitive Advantage is Lost

It has been stated that failure to sustain TCA will result in losing it. This is true because of the inevitable advances that will come from the competition. The most common means by which TCA is lost is that of evolutionary advances made by the competition. These are two sub-elements to this mechanism. In one case, the paths of technology development being followed by competitors are fundamentally similar and the one who progresses more quickly will eventually achieve a leadership position. In the second case, rather different technical approaches are being pursued, each of which will have differing ultimate limits. The firm pursuing the approach with the lower ultimate limits, even if initially gaining TCA, will unavoidably be surpassed eventually by the competing firm.

Another mode of losing TCA is by means of a revolutionary, rather than evolutionary, change in technology. Examples could include radical changes in an existing process technology or emergence of an entirely new process. Such changes will of nature often originate from sources outside of the established competition. Breakthroughs in technology not originally directly related to an existing process may be transferable to other applications, resulting in a sudden shift in technology leadership. Although it is not easy to react to such a change, the firm with the greatest strength in the basic technologies will be in the best position to adapt to such a change. With existing expertise and creativity, the firm will be able to not only adapt, but also develop innovative improvements to the new technology and find additional applications.

Finally, TCA may be lost through external factors related to market demand. In the extreme case, even a uniquely strong advantage in a particular process technology may be rendered of little value if demand for the product

declines significantly. Such an event could occur for technical or non-technical reasons. Technology based circumstances could include the emergence of a superior substitute product or, for an intermediate product, the development of a new process for making the end product without use of the current intermediate. Non-technology based factors could include changes in prices of raw materials or changing environmental regulations relating to the product process or its usage.

Although such changes in market demand may be unavoidable, their consequences may be minimized in two ways. First, and quite obvious, is the need to be continually monitoring market changes (both technology and non-technology driven) in order to better anticipate and prepare for the change. Second, is to maintain as competitive a technical position as possible in all basic process technologies, in order to enable a flexible response from a strong established position.

The various means by which TCA can be lost can be summarized as the following:

- Faster evolution by the competition.
- Radical technology changes by others
- Significant changes in the product market.

The loss of TCA in a given area will be readily seen by a decline in a firms' presence in that market segment. Should either of the first two circumstances develop, new awards will quickly shift to the firm that offers the demonstrably superior technology. In the third case, the number of new projects will obviously diminish for all firms.

The first means of losing TCA is best avoided by continued pursuit of

technical excellence enabling technology advances in step with or leading the competition. Technical creativity must also be maintained to enable innovative applications of technical skills.

Two elements are necessary to minimize the consequences of either of the last two means of losing TCA. First is just that summarized above, maintenance of a high level of technical competence which will allow a rapid and flexible response to change. Second is an ongoing monitoring of both technical and market trends. Such an effort will allow the firm to better anticipate significant changes and plan accordingly.

3.5 What Happens if Technical Competitive Advantage is Lost

If for any of the reasons given in Section 3.4 TCA has been lost (in any particular area), the most dramatic response would be to exit from competition in that particular segment of the business. Whether or not this is the appropriate action will depend primarily on the degree to which the previous advantage has been lost and the likelihood of being able to regain it. Given that a prior position of leadership existed and the inherently strong technical capabilities associated, it is unlikely that withdrawal from competition would be warranted. Even a radical technical change can usually be "engineered around."

The most difficult situation, however, would be one in which a competing firm establishes exclusive rights to a superior new process technology. Unless a competitive breakthrough was already in sight by the previously leading firm (perhaps via a collaborative effort with an operating company) such an occurrence may dictate exit from competition. Another outcome, however, may be spurred efforts to advance the existing technology. This decision must be carefully evaluated but on theoretical limits of advancement compared to limits

of the new technology.

Alternatively, at least in the interim, the firm may continue to compete on non-technical bases. Cost cutting of various forms may enable continued competition while evaluating or pursuing means of regaining technical advantage.

In general, the most likely response to loss of TCA due to any cause, would be a focussed effort to regain it. The focus of the effort will be dictated by the nature of the setback. If the loss was due to being marginally surpassed by incremental advances, concentrated efforts to meet or exceed these improvements should be effective. Even if the change was radical, efforts to improve the old or adopt features of the new can be effective, although it may take more time.

In summary, three possible reactions may follow from loss of TCA:

- Exit from competition in that segment of business.
- Compete on non-technical bases.
- Attempt to regain TCA.

Typically, the decision to leave the market would not be made quickly. Attempts to regain competitiveness while competing by cost cutting measures is the more likely course of action. At some point, however, failure to regain TCA may force the firm out of competition, particularly if the new technology was substantially superior and tightly controlled.

3.6 Summary of Technical Competitive Advantage

The preceding sections have addressed the basic issues related to obtaining, sustaining, and potentially losing TCA. The essential elements of the proposed answers to the questions raised at the beginning of this chapter are presented in Table 3.1 and summarized below.

First, however, the importance of the engineering personnel must again be emphasized. Innovative concepts ultimately stem from the ideas of individuals and a firm cannot hope to attain TCA without a core of process engineers who are both technically expert and creative.

Given the primary function of the engineering firm, that of providing professional services, it is only logical that the primary constituent of TCA is "knowhow." All competing firms, however, possess knowhow and therefore, in order for it to provide a true technical competitive advantage, that knowhow must be distinguishably superior in one of two regards.

First, superior knowhow in one or more specific areas of process technology can provide TCA by enabling innovative solutions to complex design problems arising from efforts to develop or improve any production process employing that technology. For example, superior expertise in the technology of fluidized bed reactors will enable advances in the production of several petrochemicals for which such reactors are part of the process. Second, superior knowhow in one or more competitive production processes can provide TCA by enabling the best (most efficient, highest quality, most economic, etc.) possible plant design based on the current state of the art. For example, superior expertise

Summary of Technical Competitive Advantage

1. What Constitutes TCA?

- Superior "knowhow" in a specific area of process technology
- Superior "knowhow" in a competitive production process
- Rights to a competitive production process

2. How is TCA Obtained?

- Experience
- Research and Development
- Acquisition

3. How is TCA Protected?

- Trade Secrets
- Patents
- Licenses

4. How is TCA Lost?

- Faster evolution by competitors
- Radical technology change by others
- Significant change in the product market

5. What Happens if TCA is Lost?

- Exit from competition
- Compete on non-technical bases
- Attempt to regain TCA

Table 3.1

in all facets of polyethylene production will enable the best possible polyethylene plant design at any given point in time.

The third element of TCA is the possession of rights to a competitive process technology. Such rights may be in the form of sole or joint ownership or in the form of an exclusive or restricted license to market the process of another party. Possession of process rights provides TCA by providing monopolistic control and the degree of TCA is directly related to the degree of competitiveness of the process. Rights to a process which is not competitive or which is licensed on an unrestricted basis maybe of value in gaining access to the market but provides no TCA. This third element of TCA often goes hand in hand with the second, but this is not essentially so.

The fundamental manifestation that a firm possesses any of these forms of TCA is through recent project performance. The resulting "product," be it a new plant or the solution to a complex engineering problem, provides a subjective basis for evaluating the underlying TCA.

Technical competitive advantage is perhaps most commonly developed through experience in plant engineering and design. In this business it may well be true that "experience is the best teacher," giving value to firms' marketing emphasis on years of experience. Experience will only lead to TCA, however, if each project is exploited as an opportunity to advance the firm's technical capabilities by building upon rather than simply employing existing knowhow. TCA may also be obtained through self-sponsored, client funded, or collaborative R&D efforts. Such efforts offer great potential but obviously involve greater costs and risks as well. With keen cost competition and corporate conservatism prevalent in the engineering services industry, basic research is usually not a

significant element of a firm's operations. Any firm that has achieved or strives for technical leadership will be marked by a higher level of applied process and equipment development work, however.

Acquisition is the third source of TCA, most commonly in the form of negotiated rights to a process technology. An established position of TCA will be of benefit in obtaining such rights, particularly for a radically new process, but other commercial considerations may be of equal importance.

Given the central role of knowhow as the foundation of TCA, associated trade secrets are the dominant means of protecting TCA. Virtually all facets of a firm's operations are strongly guarded by confidentiality agreements of several forms and information sharing between firms is very rare. Patents of new equipment designs and process features are also a common means of protecting applicable elements of a firm's technology and used to an extent increasing with potential commercial value and degree of competition. Licensing agreements, in addition to being a means of obtaining a technology, also offer protection to a level directly related to the degree of exclusivity of the agreement.

Loss of TCA does not normally occur as a result of disclosure of trade secrets or expiration of patents. Trade secrets have traditionally been effectively guarded and ongoing development renders patent expiration of little consequence. TCA is most commonly lost by means of independent superior advances by others. These may be in the form of more rapid evolutionary advances by competitors or revolutionary technology changes, frequently originating outside of the competition. TCA may also be effectively lost, i.e., rendered of little value as a result of significant changes in product demand. If for any of a variety of reasons demand for a product disappears, leadership in its

production technology will be of little value unless it can also be applied elsewhere.

If TCA is lost in any area, the most dramatic result would be an exit from competition in that area. Less dramatic, and potentially effective for an interim period, would be a shift to competition on non-technical bases. This would entail an increased focus on cost-cutting measures and other commercial considerations. Given that TCA had existed, however, it is more likely that attempts to regain TCA will be pursued either through continued development in that area or by seeking new applications for existing technical strengths (potentially changing the focus of competition if not specifically withdrawing).

With intense competition in the industry TCA is indeed difficult to maintain indefinitely and cycles of establishing, losing, and regaining technical competitive advantage are an ongoing occurrence. These cycles are often not dramatic, but can be seen in the shift of contract awards over time in the various segments of the industry.

4.0 Case Studies in Petrochemical Process Innovation

As discussed in Section 3.1, implicit in the elements of technical competitive advantage is the ability to develop innovative solutions to complex engineering problems. Although the most common manifestation of this ability is in the development of incremental improvements to the design of engineered equipment and systems, more illustrative of the range of issues discussed in Chapter 3 are cases of new process development. Such cases will also draw out some of the commercial and not strictly technical considerations that come to play an important role in the exploitation of TCA and will additionally highlight the associated risks.

Two cases are presented in Sections 4.1 and 4.2 involving Stone & Webster Engineering Corp. and the Badger Co., respectively. In each case the origin of the new process concept was with a petrochemical producer, but the engineering firm provided the technical leadership in transforming a potentially viable concept into a commercial plant design. Section 4.3 summarizes the major aspects of each case, as related to the issues of TCA, and relates them back to the framework developed in Chapter 3.

4.1 The Gulf/Stone & Webster Thermal Regenerative Cracking Process

Thermal Regenerative Cracking (TRC) is an innovative process for thermal cracking of hydrocarbon feedstocks to produce olefins, predominantly ethylene (Ref. 8,9,10). This process was developed jointly by Gulf Oil Corp. and Stone & Webster Engineering Corp. (SWEC) and is the primary focus of this section. Also discussed is the Quick Contact (QC) process which was developed solely by SWEC as an outgrowth of the TRC development and has wider

applications than TRC. These processes are new and have not yet been implemented in any commercial installations, but active negotiations with prospective clients are currently in process. Before describing these processes and their development, some background on the traditional technology will be presented.

Virtually all olefin production today and for the past several decades has been via the process of steam pyrolysis (thermal cracking in the presence of steam) in tubular furnaces. The essence of the process is the simple fact that at elevated temperatures the atomic bonds in hydrocarbon molecules are broken creating simpler molecules and radicals which subsequently recombine into a transformed hydrocarbon mixture. The presence of steam does not change the basic process but does serve to affect the relative composition of the product mix and also lowers the tendency to form coke on the furnace tube walls.

Paraffins are hydrocarbons with the molecular form C_nH_{2n+2} , e.g., ethane, C_2H_6 , and propane, C_3H_8 . These simple paraffins and more complex paraffinic hydrocarbons contain strong single bonds between carbon atoms and are the primary constituents of olefin plant feedstocks. Olefins are hydrocarbons with the molecular form C_nH_{2n} , e.g., ethylene, C_2H_4 , and propylene, C_3H_6 , and have less stable double carbon atom bonds. In the simplest example of olefins production, heating of ethane (typically to 1500 - 1600°F) results in the transformation (through a chain of reactions) to ethylene and hydrogen gas. Due to their greater reactivity, simple olefins do not occur freely in nature. It is this same feature of reactivity that makes olefins the primary building block of most petrochemicals today.

In conventional tubular furnaces, the feedstock flows through an array of

high temperature alloy tubes with heat transfer occurring indirectly from furnace burners through the tube walls to the vaporized feedstock. Composition of the product (relative percentages of ethylene and other byproducts) is determined primarily by the temperature and time in the furnace tubes. Increased temperature increases the reaction rate, thereby reducing the required residence time to achieve the same degree of conversion, and also increases the percentage of ethylene in the product mix.

Furnace technology, the heart of olefins plant design, has evolved incrementally over the years with no radical changes in the basic concepts. Tube configurations and burner locations have continuously changed, resulting in more efficient heat transfer and better temperature distributions, and improved alloys have been used in the tubes, allowing operations at higher temperatures. Incremental improvements have also occurred steadily in downstream distillation units and overall plant energy efficiency.

Although each change has been relatively minor, the cumulative effect has been significant. Plants built in the 1950s achieved fluid temperatures of 1400° F with residence times of 2 to 3 seconds and ethylene yields of 15 to 20% by weight. Today's plants operate at temperatures of 1600° F and higher with residence times measured in milliseconds and ethylene yields on the order of 40%. Higher yields coupled with increasingly larger plants have also resulted in plant capacities today of over one billion pounds per year, an increase of ten times since the early 1950s.

The first commercial ethylene plant using petroleum feedstocks (rather than coal derivatives) was built around 1940. Based on advances in the understanding of organic chemistry and using processes developed in crude oil

refining, the original process design concepts originated within oil and chemical companies. Engineering firms with refinery experience such as Stone and Webster and Lummus Engineering were also involved from the outset, providing the basic engineering knowhow to translate the demonstrated process into an economically viable plant. Such involvement by engineering firms is natural, but their evolving role to one of technology dominance is more the exception in process industries. Whereas refinery process technology leadership generally comes from the oil companies and chemical process technology from the chemical companies, commercial olefins technology has been led by engineering firms since the early days.

Two major reasons appear to have caused this situation. First, ethylene can be thought of as a product which divides refinery operations from subsequent petrochemical operations. Prior to the oil companies' integration into petrochemicals on a large scale, ethylene production, although adding value to their operations, was dwarfed by their basic refinery operations. Research and development efforts therefore continued to be predominantly on refinery processes. Chemical companies, although rapidly making the transition from coal derivatives to petroleum based raw materials, did not initially have the experience with the refinery based processes to take the lead in olefins process developments. This situation then created an opening for the engineering firms. Having experience in the basic cracking and distillation processes, seeing the potential economic benefits to be gained by leadership in this emerging technology, and with the opportunity left open to them, engineering firms soon took the lead.

Another factor existed which enabled the engineering firms to assume this position. Once the basic process was demonstrated, the key technical challenge

became one of improving the performance of the system and engineered equipment, particularly the furnace. The basic chemical reactions were relatively straight-forward and increased understanding of the reaction kinetics came from the analysis of empirical data from operating units rather than from basic research.

Stone & Webster developed an early leadership position and by the 1960s had engineered and/or constructed 60% of the world's ethylene capacity. Lummus was also active from the outset and by the early 70s, had developed a furnace which claimed slightly higher yields from heavier feedstocks. With significant growth in ethylene demand in the 70s, and a shift towards the use of heavier feeds, Lummus did very well during this period and today claims design responsibility for approximately 50% of world capacity with over 100 units built. M.W. Kellogg built their first ethylene plant in the 1950s, and has since built over 40 plants, including the world's three largest. Their "Millisecond" furnace, developed shortly after SWEC and Lummus short residence time furnaces, offers the shortest residence times of the three. C.F. Braun has also been active in this field, but today the "Ethylene Club" is comprised of Kellogg, Lummus, and SWEC. With extremely competitive technologies which reached practical limits of improvement in the 1970s, the basis for competition has turned largely to cost and commercial considerations in the past ten years and profit margins have all but vanished.

Many studies have documented the fact that when existing technologies have matured, radical changes are often introduced by sources outside of the established competition. Although it has not come to fruition, this same pattern began to emerge in the ethylene industry in the late 1960s. At that time both Union Carbide and Dow (major ethylene producers), began experimenting with

new processes. Whereas existing technology relied on indirect heat transfer from burners through tube walls and had become limited by tube metal temperatures, their processes achieved direct heat transfer by mixing the feedstock with a hot gaseous heat carrier. Both the Union Carbide Advanced Cracking Reactor (ACR) and Dow's Partial Combustion Cracking (PCC) process extended the limits of the existing technology with departures from the tubular furnace allowing reactions at temperatures from 2500 to 3400° F. Both processes were developed to the large scale test phase by the early 1980s but for a variety of technical and economic reasons further development has been postponed. Gulf Oil Corp., another large producer also began experimenting with a new technology in 1971. This process became known as Thermal Regenerative Cracking and its development will be described in more detail.

Like the ACR and PCC processes, TRC also extended the existing technology limits by means of direct heat transfer to the feedstock. Unlike ACR and PCC, however, TRC uses an inert solid heat carrier. In the TRC process micron sized solids are preheated to approximately 1800° F and fed along with the vaporized feed to a reactor in which heat transfer occurs directly from the solids to the vapor. The dilute mixture is then rapidly quenched upon exit from the reactor and the solids are separated. During the reaction coke is formed on the solids rather than on the reactor walls and is burned off during reheating of the solids (hence the name Thermal Regenerative) which are continuously recycled.

The kinetics of the process are essentially the same as those of conventional tubular furnace pyrolysis, but higher temperatures (potentially much higher) are achieved. The primary advantages of the process are:

- Insensitivity to coking which permits the cracking of heavier feeds.
- Extended temperature range which permits greater selectivity of the product mix.
- Wider feedstock range from ethane to gas oils to residues.
- Lower dilution steam requirements.
- Use of less expensive fuels.
- Lower capital investment due to smaller physical size and lesser steam generation requirements.

Also, since the physical reaction is essentially the same as that in conventional furnaces the product is compatible with existing downstream recovery equipment. The TRC unit can therefore be installed as a retrofit for conventional cracking furnaces in an existing plant.

The development of the TRC process began in 1971 with experiments by Gulf to investigate the feasibility of using fluidized catalytic cracking (FCC) technology for the production of olefins. FCC, which employs hot circulating catalytic solids, had been developed as a refinery cracking operation and Gulf had made recent improvements to the process. The motivation for TRC was to allow cracking of increasingly heavy feedstocks which was becoming the trend as the lighter feeds were becoming relatively more costly.

In 1972 Gulf approached both Lummus and SWEC with requests to evaluate their laboratory work in terms of its technical and economic feasibility for scaling up to a commercially viable operation. Both Lummus and SWEC had built ethylene plants for Gulf and both had the expertise to perform the evaluation. For reasons that are not clear, Lummus apparently showed less interest in the concept and SWEC was given the evaluation task.

Thus began what was to become a lengthy new process development which can be characterized as evolving through four distinct phases:

1. Conceptual design
2. Basic development
3. Large scale testing
4. Demonstration and commercialization.

An overall time table for this evolution is shown in Table 4.1. Following is a discussion of the major features of each phase.

The conceptual phase had begun with Gulf's initial idea and laboratory experiments. The original evaluation by SWEC concluded that the process had promise and specific additional laboratory tests were recommended and performed. With this additional data, SWEC proceeded with additional evaluations resulting in:

- a conceptual design of a commercial scale plant
- an economic analysis of such a plant
- a technical assessment of the competing new processes.

The strengths that SWEC brought to bear in this conceptual phase were:

- superior knowledge of basic ethylene synthesis technology.
- superior basic engineering skills required to transform a small lab scale process into a commercial plant.
- superior ability to estimate the costs of design and construction of a large scale plant.

A significant development (in terms of SWEC's future involvement) at this early stage was the introduction of innovative changes in major equipment design by SWEC. Existing FCC technology could achieve contact times on the

Gulf/SWEC TRC Process Timetable

Time		
Conceptual Phase	71	Gulf begins investigation, lab experiments.
	72	Gulf approaches SWEC for evaluation.
	73	Additional experiments; agree to joint development
Basic Development Stage	74	Legal discussions, concept design, economic studies, assess competition.
	75	Gulf process patent; more lab tests.
	76	Overall plant design, SWEC equipment patents, economic studies, cost-benefits of proceeding, set FTU scale.
Large Scale Test Phase	77	
	78	Begin serious FTU work.
	79	Sign new agreement; announce process.
	80	Finalize FTU design.
	81	Complete FTU construction.
	82	FTU testing.
Demonstration and Commercialization Phase	83	Evaluate data, Plan for demonstration and commercialization.
	84	
	85	SWEC announces QC.
	86	Pursuit of TRC/QC clients,
	87	continuing design improvements.

Table 4.1

order of 1 to 6 seconds, not short enough for efficient olefins production. Although shorter times were achieved in Gulf's laboratory tests, SWEC found that simple scaling up of the unit would increase the residence times substantially and significant design changes in the mixing and circulation patterns were recommended. Given the promising potential of the process, as improved by SWEC's input, the two firms entered into a joint development agreement in 1973.

Conceptual development continued in 1974 with the emphasis on planning the future direction of the program. Legal negotiations also took place with respect to the terms of the joint development agreement. With minimal financial investments required for the near term, costs were generally shared equally.

The basic development phase began in 1975 with additional lab testing of the revised concepts that came out of the conceptual phase. SWEC assumed the technical leadership position at this time with Gulf personnel performing the lab testing and actively providing technical critique of the progress. During this period a more complete system design was developed, economic studies were refined, and basic equipment designs were firmed up. Per terms of the joint agreement, Gulf patented the basic process while SWEC filed patents for the equipment designs. These included such components as the reactor, solids separator, and high temperature solids flow control valves. Finally, cost-benefit analyses were performed for the various options for subsequent work which resulted in, among other decisions, the selection of the scale for larger scale testing.

At this point, the issues associated with greater financial investment began

to raise a variety of conflicting philosophies between the two firms. The primary objective of the operating company, both at this point and as the project continued, was to achieve an economically superior process that would give them a competitive advantage with minimal risk, i.e., the "best workable design." While this was certainly a reasonable goal for the engineering firm as well, their ultimate goal was the development of the "most saleable design." This would be one which offered even superior performance to that which Gulf would find acceptable, but one which would require more experimentation, more risk, and ultimately greater financial investment.

Also critical at this point was the issue of placing value on the contributions of the two parties or, more specifically, balancing the value of technical contributions and creativity against the shouldering of financial risk. The resultant decision was that Gulf would provide the capital, approximately \$10MM, for a large scale test unit while SWEC would continue to lead the technical effort.

Serious design work on a field test unit (FTU) began in 1978, while additional details of the ongoing development agreement were worked out. The final agreement was signed in 1979, including provisions for division of future licensing royalties -- a 50/50 split, exclusively of engineering contract rights -- subject to performance conditions, and terms regarding licensing to direct competitors of Gulf. Also in 1979, the development of the new process was publicly announced in trade journals, although virtually no technical details were provided at this time. Progress on the FTU was somewhat delayed during this time due to changes in choice of the FTU location, but construction was completed at Gulf's Cedar Bayou Plant near Baytown, Texas in 1981.

The FTU had a capacity of 5 mil.lb./yr. (compared to a typical commercial furnace capacity of 100 mil.lb./yr.). An array of tests were run, first on the solids circulation system and then with the introduction of feed. Testing was completed and the FTU was shut down at the end of 1982. Analysis and evaluation of data concluded that all goals had been met and subsequently published articles cited a wide array of advantages, particularly with respect to the cracking of heavier feeds -- which had been the driving motivation for the development effort.

Three major occurrences were taking place, however, that significantly hindered progress towards commercializing the process. First, late in 1982, as field testing was winding down, Mesa Petroleum began attempts to take over Gulf. Throughout 1983 Gulf was involved with offers and negotiations with other firms as well, and ultimately taken over by Chevron in 1984. Although Gulf was largely out of the picture at this time, SWEC did proceed with the development of a commercial scale design.

Second, construction of new ethylene capacity during the 1970s had outstripped increases in demand (which had virtually levelled off) resulting in approximately 20% excess in operating capacity with another 20% of constructed capacity idled. This excess capacity virtual eliminated demand for new capacity, although a few units (of conventional design) have been constructed in the Far East in the 1980s.

Finally, and perhaps more importantly, feedstock economics did not evolve as had been predicted ten years earlier. With discoveries of large new reserves of natural gas, lighter feedstocks have actually become the more economical raw material today. With relative feedstock economics potentially shifting frequently in the near future, perhaps the most important technical

feature of an olefins plant today is that of feedstock flexibility. However, even with the superior flexibility of the TRC process, it is unlikely that it will be commercialized before existing capacity is again fully utilized.

This is not the end of the story, however. Although TRC had been developed specifically as a new cracking process for the production of olefins, the essence of the technology development was the invention of a physical means of contacting gases with solids and then separating them more rapidly than had previously been possible. This capability can provide advantages over a relatively wide array of existing petrochemical and refinery processes based either on pyrolytic or catalytic technologies.

Since the early 1980s, SWEC has refined the TRC process and expanded its versatility. The resultant system has been patented and is known as the Quick Contact (QC) process. With the new applications of the QC process, market opportunities have opened up and negotiations for commercial demonstration plants are currently under way with a number of prospective clients.

This example has been illustrative of two complementary facets of technical innovation. First, both existing technology expertise and enabling technology knowhow were required for the engineering firm to capture the opportunity to develop a new process. SWEC was initially approached by Gulf because of their current expertise in olefins technology, but without the ability to introduce creative and technically sound new ideas, their role may well have ended after the initial evaluation task.

Second, this example clearly identifies the risks associated with the development of a new technology. These include not only those due to the uncertainty of technical success, but also those due to perhaps even more

unpredictable external influence.

Regardless of the final outcome, however, SWEC's technical position has been strengthened by the new knowledge obtained as a result of the overall effort. As was seen, this new knowledge may lead in unanticipated directions (QC evolving from TRC), but should be expected to provide rewards in the long run.

4.2 The Mobil/Badger Ethylbenzene Process

Ethylbenzene (E-B) is a petrochemical intermediate manufactured from ethylene and benzene. It is a large volume commodity product (current domestic production is approximately 10 billion lb./yr) used virtually exclusively for the production of styrene. Styrene in turn is used to produce an array of polymers, but primarily polystyrene. Although the processes of E-B and styrene production are distinct, because of their intimate coupling, facilities are combined and the operation is referred to as an E-B/styrene plant or often simply as a styrene plant. The original process developed for commercial production of E-B in the late 1930s has undergone evolutionary changes but the dominant process was fundamentally unchanged until the development of the Mobil/Badger process (Ref. 11,12). Before discussing the Mobil/Badger process and its evolution, however, the traditional production process will first be described. The basic chemical reaction in the production of E-B is the alkylation of benzene with ethylene (uniting of ethyl radicals with benzene molecules) to form the more complex E-B molecule. This reaction takes place in the presence of an aluminum chloride catalyst and hydrogen chloride as an additional promoter. The ethylene and benzene feeds are mixed with the catalyst in the

reactor in a liquid state. Reactor effluent flows through a catalyst separator, is washed with water and caustic, and then proceeds to the E-B recovery stage. About 98% yield is achieved with the E-B then flowing directly to the styrene production units.

Dow Chemical began work to develop a commercial E-B/styrene process in 1934 and started the first plant in 1937, using this basic E-B process. Monsanto, Carbide, and Koppers also were working on similar processes which were expeditiously commercialized in 1943 as a result of the war. Styrene production in large capacity had become essential as a major ingredient of synthetic rubber, with natural rubber supplies cut off, and a great deal of cooperative effort between the previously competing firms took place during this time. Five plants were built in 1943 boosting capacity from the single small Dow plant to a total of 200 mil lb/yr in 1944.

Demand for E-B/styrene continued to grow rapidly after the war and the Lummus engineering firm was well positioned, having been involved with Monsanto in the joint development of Monsanto's styrene finishing process. The Badger engineering company also became very active through work with Cosden Chemical Co. which had developed their own E-B/styrene process in the late 1950s. (Although not directly pertinent to this study, the Cosden process did employ a fundamentally different method of producing E-B.) Subsequent collaborative efforts between Union Carbide, Cosden, and Badger led to the Carbide/Cosden/Badger process in 1965 which became dominant through the 1970s with the Monsanto/Lummus process providing strong competition. Although both processes still closely resembled the original Dow process they had become significantly more efficient and by 1980 the worldwide capacity of

plants using the Carbide/Cosden/Badger process was over 10 bil lb/yr and that of plants using the Monsanto/Lummus process was about 6 bil lb/yr.

The first major change in the dominant E-B production process, as is often the case in technical innovation, had its origins outside of the established competition. In the mid to late 1960s, intensive R&D by Mobil Oil Corp (not a E-B/styrene producer) led to the development of a new family of catalysts for which they began exploring a number of applications. One potential application was in the production of ethylbenzene and they began laboratory experimentation in this area, as well as others.

At the macro level, the application of Mobil's new catalyst did not fundamentally alter the E-B production process. Benzene was still alkylated with ethylene in the presence of the catalyst and E-B was recovered in similar downstream distillation units. The process was a revolutionary advance, however, because it totally eliminated the sole significant problem with the existing technology, i.e., the highly corrosive nature of the liquid catalyst and resulting pollutant effluent from the reactor product washing operation.

The evolution of process development from the original idea through commercialization can, like the Gulf/SWEC TRC process, be characterized as having gone through four distinct phases: conceptual, basic development, large scale testing, and commercialization. An overall timetable is shown in Table 4.2.

The conceptual phase obviously began in the Mobil R&D organization. A small, "room-size," pilot plant was built in which to study the basic chemistry of the new catalytic reaction. Benzene to ethylene ratios and temperatures were the primary variables studied in trying to optimize product selectivity and yield.

Mobil/Badger E-B Process Timetable

Time		
Conceptual Phase	mid 60s	Mobil develops new family of catalysts.
	late 60s	Mobil begins conceptualizing E-B application.
		Mobil does pilot experiments.
	71	Mobil approaches Badger for evaluation.
		Badger does evaluation; concludes it's feasible.
	72	Mobil decides not to proceed.
Basic Development Phase	72	Mobil/Badger agree to terms of Badger development.
	to 73	Pilot unit moved to Badger R&D facility. Badger does tests/simulations; concludes its commercializable.
Large Scale Test Phase	74	Badger designs semi-works unit. Semi-works unit constructed at Foster Grant.
	to	Semi-works unit operated .
	75	Foster Grant decides not to proceed.
		Badger studies use of dilute ethylene as feed.
	76	Semi-works moved to Cosden. Cosden testing completed.
Demonstration and Commercial- ization Phase	77	First commercial unit sold to Shell.
	80	Second commercial unit sold to American Hoescht. American Hoescht unit goes on line.

Table 4.2

Having achieved reasonably promising results, Mobil approached the Badger company in 1971 with the request for an evaluation of the commercial potential of the process. Badger was chosen because of their engineering experience with the currently leading Carbide/Cosden/Badger process. In addition to being able to perform the general evaluation, their intimate knowledge of the existing process also allowed them to perform detailed benchmarking of the new results with existing data.

Badger performed the technology assessment, conceptualization of associated process modifications (particularly downstream of the reactor), and an economic analysis of commercialization. The conclusion reported by Badger was that the process had sufficient merit to warrant further development efforts. During 1971 and into 1972 Mobil continued with the additional pilot plant experiments while weighing the decision of whether or not to proceed towards a commercial unit.

On the surface it appeared reasonable to assume that they would proceed. Mobil already was a large producer of both ethylene and benzene and also of polystyrene, with the styrene being purchased from others. Also, forecasts at this time predicted continued growth in the demand for styrene. However, an economic analysis by Mobil concluded that the capital costs involved would not result in any financial advantage over their current situation of selling ethylene and benzene and the buying back of styrene. In 1972 they decided not to proceed.

Badger, however, with entirely different economic motivations, wanted to proceed and entered into negotiations with Mobil. The result was an agreement in which Mobil would continue to work on catalyst improvements while Badger would independently proceed with process development. If successful, Mobil

would manufacture the catalyst and Badger would have exclusive engineering rights. Both parties would share royalties from process licensing.

With this agreement in place, the pilot unit was moved to Badger's R&D facilities and the basic development phase began. This development stage encompassed many facets of work. Additional pilot plant experiments were conducted to confirm catalyst performance and to generate process data. Overall system design optimization was based on computerized process simulation, an area in which Badger was particularly strong. Also ongoing were the specific elements of equipment design and/or specification and continued analyses of engineering and operating economics. The conclusion of the basic development phase was that the process would be commercially competitive and a client was sought on whose facilities a large scale "semi-works" unit could be built.

In 1974 an agreement was reached with Foster Grant to build a 40 mil lb/yr unit at their Baton Rouge, LA facility. The unit was constructed and large scale testing was performed during 1975. All claims for the new process were confirmed. E-B yields were 98%, competitive with the existing process, and all associated system performance features were demonstrated, including catalyst regeneration and effective recycle of E-B recovery by-products.

Meanwhile, further process research was continuing at Badger's R&D facilities. Whereas development and testing to this point had been based on the use of high purity ethylene as a raw material, as in the conventional process, it was speculated that the new catalyst could work effectively with dilute, and less costly, ethylene feedstocks. Pilot unit tests were successful but, for non-technical reasons, Foster Grant chose to back out of the arrangement. A new arrangement was then established with the Cosden Co. and the semi-works equipment was

moved to Cosden's Big Spring, TX site in 1976 where an existing 40 mil lb/yr facility was converted to the new process. Here testing was performed using dilute ethylene recovered from refinery processes (as opposed to a high quality olefins plant product). In addition to performing successfully, catalyst operating cycles were found to be longer than when using high grade ethylene. Testing was completed in 1977 and had demonstrated a commercially superior process.

Advantages included:

- Elimination of the corrosive liquid catalyst which required use of special alloy materials in the reactor and piping.
- Elimination of polluting waste products which required special handling.
- High energy efficiency resulting from effective heat recovery from the high temperature vapor-phase reactor.
- Simple design using a fixed bed reactor which does not require catalyst separation and recycle.
- Over 99% yield resulting from more effective by-product recycling.
- Ability to use a dilute ethylene feedstock.

The use of dilute feed has not been employed in commercial plants, however, due to limited supply of such a refinery byproduct and the overcapacity of quality ethylene.

With the proven performance of the Cosden semi-works facility, the first commercial unit was sold to Shell Oil. Co. in 1977 for a 600 mil lb/yr plant in Saudi Arabia. Since then, almost all new commercial units sold worldwide have used the Mobil/Badger process. The single exception has been one contract for two plants in China using the Monsanto/Lummus process. With this rapid technology transition, Badger has moved from a dominant to near exclusive position in the design and engineering of new E-B/styrene facilities.

As in the TRC example, two elements were essential for the engineering firm to capture the opportunity to advance their technical competitiveness. Their existing technical expertise was the prerequisite for initially being approached by Mobil, but again, the combination of strong process technology skills and creative personnel were required to proceed with the new process development.

Also, although this story led more quickly to commercial success than the TRC example, the risks were still there. Ultimate success was due in part to ongoing catalyst improvements made by Mobil which fortunately materialized. Additionally, although the market for styrene slowed considerably during the 1970s, resulting in temporary excess capacity, it did recover making rapid commercialization of the new process possible.

Finally, independent of the commercial success, new knowledge and increased technical competence were developed by Badger as a result of the effort. Although the value of this alone is difficult to measure, it certainly should not be discounted in terms of its value in promoting future business opportunities.

4.3 Comparison of Case Studies to TCA Model

This section will review the case studies presented in the previous two sections in terms of the elements of the TCA model presented in Chapter 2. Factors of the TCA as they existed both prior to and after the respective new process developments will be discussed.

Table 4.3 presents the key elements of Stone & Webster's TCA position before and after development of the TRC olefins production process. Prior to the onset of the TRC development, SWEC's TCA (in olefins plant design) derived

Stone & Webster TCA in Olefins Plant Design

	<u>Before TRC Development</u>	<u>After TRC Development</u>
1. <u>What Constituted TCA?</u>		
•Knowhow in Specific Area	Yes Furnace Design*	Yes Solids Cicalation**
•Knowhow of Process	Yes Olefins Production*	Yes Olefins Production**
•Rights to Process	Yes Sole Ownership	Yes Joint Ownership
	*Highly competitive performance of recent designs	
	**Solution of complex problems demonstrated in innovative large scale test unit.	
2. <u>How was TCA Obtained?</u>		
•Experience	Yes 90+ plants built	No Not Commercialized
•R & D	Yes Ongoing Improvements	Yes Large Develop. Effort
•Acquisition	Yes Early Collaboration	Yes Technology Sharing
3. <u>How was TCA Protected?</u>		
•Trade Secrets	Yes Secrecy Agreements	Yes Secrecy Agreements
•Patents	Yes Process & Equipment	Yes Process & Equipment
•Licenses	No Sole Ownership	Yes Exclusivity Provision
4. <u>How could TCA have been Lost?</u>		
•Evolution	Yes Comparable Competitive Process Spec.'s	Yes Adoption by Others
•Revolution	Yes ACR or PCC	Yes But Unidentified
•Market Change	Yes Overcapacity	Yes Feedstock Economics
5. <u>What would have happened if TCA was Lost?</u>		
•Exit from Competition	No But Possible	No But Possible
•Non-technical Competition	Yes/No Always a Factor	Yes/No Always a Factor
•Attempt to Regain	Yes TRC Effort	Yes QC Effort

Table 4.3

from ownership of a competitive production process and the associated expert knowhow in all facets of the process. The specific area of technological expertise that was the most significant was that of pyrolysis furnace design, founded on the traditional disciplines of fluid dynamics, heat transfer, kinetics, and metalurgy. Although SWEC's technology was in extremely close competition with that of Kellog and Lummus, these three firms clearly had a dominating TCA over any other domestic engineering firms as evidenced by the split of recent awards between these firms.

SWEC's TCA had been obtained primarily through gradual evolutionary developments made over a period of thirty years, afforded by the experience of designing and/or constructing approximately 90 olefins plants. Early process concepts were acquired from joints efforts with producers in the era of first commercialization. Their position was protected by process and major equipment patents and a strong guarding of knowhow in the form of trade secrets. Central to trade secrets were design details not disclosed in patents and specific operational data of the process, all specifically protected by secrecy agreements. Since the process was their own, terms of agreement with a licensor were not applicable.

Although not lost, the degree and value of SWEC's TCA was being diminished by the strong competition that had evolved and the slowing product demand that had led to overcapacity of production facilities. Also, had Union Carbide's ACR process or Dow's PCC process proven successful, TCA could have shifted to whichever firm that obtained process rights. At this same time, however, SWEC was attempting to regain a stronger TCA through the TRC process development effort, providing evidence that exit from competition is not

normally the result of losing TCA, although still a possibility. Competition on non-technical bases is always a factor, but with profit margins already slim due to keen competition, little more could be done in this regard.

Even though the TRC process has not been commercialized, SWEC's technical position has been influenced and related factors of TCA can be discussed. Through the development process SWEC did in fact gain TCA in the specific area of solids circulation systems. Their knowhow which was greatly increased in this area (and demonstrated by the innovative design) was one of the factors which led another petroleum company to come to SWEC for assistance in development of a new fluidized catalytic cracking process. This effort eventually led to an exclusive licensing agreement and several resultant contract awards. SWEC also established a joint ownership position in the TRC process which, although not yet sold, still offers potential as a superior design of the future.

This new TCA (or potential for it) was obtained through technology sharing (acquisition) with Gulf and the associated R&D effort. Since no commercial plants have been built, the potential benefits of experience have not yet been a factor. As in the old technology, trade secrets are a strong factor in protecting the technology as well as the use of patents. While Gulf (Chevron) has the basic TRC process patent, SWEC has patented major equipment designs and the spin-off QC process. SWEC also had exclusive rights to plant design using the TRC process.

The potential benefits of TCA were lost primarily due to market changes. The failure of feedstock prices to move towards favoring heavier feeds rendered the TRC process of marginal value, even though it had achieved its goals of

superior performance with the heavier feeds. Had it been commercialized, TCA initially attained could have been eventually lost by adoption of basic concepts and evolutionary development by competitors. Since the changes, although revolutionary, were in the realm of mechanical design, not in the chemistry of synthesis, means of engineering around patented designs surely could occur.

Finally, as evidenced by SWEC's progression of the TRC development into the subsequent QC process is again indicative of the trend of ongoing attempts to regain or increase TCA rather than withdrawing from competition. In extreme cases withdrawal is still a real possibility, however, but only likely if a major technical development or permanent market change has occurred.

Table 4.4 presents key elements of Badger's TCA position before and after development of the Mobil/Badger E-B process. Many aspects of this case are similar to those of the previous case and discussion will therefore focus on areas of difference.

As is the previous case, Badger's TCA (in E-B plant design) derived from rights to a competitive process and expert knowhow in all facets of the E-B production process. They also had developed a strong position in the specific area of process simulation, which proved to be of great importance in the new development effort. In addition to increasing their process knowhow through substantial experience and ongoing development of incremental improvements, early knowhow was enhanced through prior joint development work with Cosden of a competitive E-B/Styrene process. Their TCA was protected strongly through trade secrets, equipment patents, and exclusive rights to the Cosden/Badger and later the Carbide/Cosden/Badger E-B/styrene processes.

Badger TCA in Ethylbenzene Plant Design

	<u>Before Mobil/Badger Development</u>	<u>After Mobil/Badger Development</u>
<u>1. What Constituted TCA?</u>		
•Knowhow in Specific Area	Yes Process Simulation*	Yes Process Simulation*
•Knowhow of Process	Yes E-B Production**	Yes E-B Production**
•Rights to Process	Yes Joint Ownership	Yes Joint Ownership
	*Used successfully in several commercialization projects	
	**Highly competitive performance of recent designs.	
<u>2. How was TCA Obtained?</u>		
•Experience	Yes 20+ E-B plants	Yes 15 Subsequent Plants
•R & D	Yes Collaboration with Carbide and Cosden	Yes Large Development Effort
•Acquisition	Yes Technology Sharing	Yes Technology Sharing
<u>3. How was TCA Protected?</u>		
•Trade Secrets	Yes Secrecy Agreements	Yes Secrecy Agreements
•Patents	Yes Equipment	Yes Equipment
•Licenses	Yes Exclusivity Provision	Yes Exclusivity Prov.
<u>4. How could TCA have been Lost?</u>		
•Evolution	Yes Comparable Competitive Process Spec.'s	Yes But still Superior
•Revolution	Yes But didn't Occur	Yes U.O.P. Styrene process
•Market Change	Yes But didn't Occur	Yes But Process Looks Steady
<u>5. What would have happened if TCA was Lost?</u>		
•Exit from Competition	No But Possible	No But Possible
•Non-technical Competition	Yes/No Always a Factor	Yes/No Always a Factor
•Attempt to Regain	Yes Mobil/Badger Process	Yes Various Means

Table 4.4

That TCA in fact existed is demonstrated by the performance of Badger designed plants, leading to a majority of contract awards over a period of several years.

Also, as in the case of olefins production, Badger faced strong competition from Lummus and the Monsanto/Lummus process, although both firms possessed a significant TCA over other engineering firms. Given the mature state of the process technology and the strongly protected positions of the two major competitors, a revolutionary change could be expected to be the most likely cause of a major change in TCA. This indeed occurred, originating from Mobil's development of a new family of catalysts.

By virtue of Badger's participation in the new process development, their TCA was in fact greatly increased. In this case, although their knowhow was further increased through the development effort, the key to increased TCA was the possession of rights to the new process which proved to be superior and was rapidly adopted by the market. Rights to the new process were an inherent result of having led the development effort, with the opportunity for participation stemming from their prior knowhow in E-B plant design. Again, Badger's renewed position of TCA was protected by trade secrets, patents, and the exclusive process rights.

With regard to the issue of losing TCA, this case provides a good example in terms of the consequences for Badger's prior competition. Since first commercialization of the Mobile/Badger process, Lummus was effectively put out of competition, at least temporarily, in this area. Despite ongoing development efforts which had led to reasonably significant improvements in the Monsanto/Lummus process, only one contract has been awarded in the past several years for a plant employing this process. Given the strength of Badger's

position today, loss by competitive evolution is unlikely. Possible mechanisms for a radical change could include the emergence of another competitive catalyst or a significant technical change in the downstream styrene production process. (Such a development is in fact underway by Universal Oil Products.) Should either case arise, it is unlikely that Badger would be forced to withdraw from competition, but as was seen with respect to Lummus, such a result is not unheard of, particularly if the technology change results in a significant TCA for the innovating party.

5.0 Conclusions

This study has investigated the nature of technical competitive advantage in one segment of the engineering services industry within a generally applicable framework. A summary of the elements proposed as the essential constituents of TCA and the fundamental factors related to obtaining and sustaining TCA were presented in Section 3.6. Chapter 4 presented two case studies which provided examples of how these features actually come to play a role in the course of a firm's evolving competitive position. It is concluded that the model of TCA presented in Section 3.6 is supported by the evidence of the case studies.

The primary findings are:

- The essence of TCA is superior process engineering knowhow which enables innovative solutions to complex engineering problems. These may be associated with improvements to existing processes or the scaling up of new process operations for large scale testing or commercialization.
- Evidence that such TCA exists is provided by recent past performance.
- This form of advantage requires expert and creative engineers and is gradually obtained primarily through experience.
- TCA can also be obtained through R&D activity. Although there are exceptions, basic process research appears best left to the manufactures. Engineering capabilities are most effectively applied to developing technically feasible and economically viable large scale designs for new process concepts.

- Stemming from a strong established technical position can be a more explicit form of TCA, possession of or rights to a superior production process.
- Protection of TCA relies heavily on trade secrets. Secrecy agreements between owners of proprietary technology, contractors, and users are rigorously employed.
- Patent policy varies. Inventions are more likely to be patented if they are of significant potential commercial value, but fear of disclosure and engineering around the concept may result in reliance on trade secrets.
- Loss of TCA comes about by faster evolution of competitors or by radical change, often originating outside of the established competition.
- TCA can generally be regained by ongoing efforts to improve existing technologies or adapt newly emerging ones.
- These features lead to a cyclic pattern of TCA. Once established, technical superiority demonstrated by recent work leads to more contract awards. As a competitor evolves into a leadership position, contract awards will begin to shift and the cycle repeats.

Whereas these findings were based solely on a study of petrochemical plant design, it is considered to be evident that all findings are applicable to all segments of petroleum and chemical product industries ranging from oil refineries and gas processing facilities to all commodity and specialty chemicals. The applicability would only diminish in the case of specialty chemicals produced on a small scale where the critical technology is that of the unique chemistry of the product with no unique engineering problems associated with

the design of the plant itself.

Also, although no attempt is made to study broader applicability, it would appear that most elements of TCA identified are factors to varying degrees in most industries. The single element that may be most unique is the value of rights to a superior process technology, but this could be generalized to most manufacturing industries in terms of their specific manufacturing technologies. Uniquely absent is any explicit consideration of physical "product" design, although again one could generalize to consider the actual petrochemical plant as the "product" of the engineering firms.

With respect to the engineering services industry, one general trend can be seen relative to TCA. The largest firms have reached their current status through profits that have historically been made from the construction side of the business. Firms such as Bechtel, Fluor, Parsons, and Brown and Root are world leaders as construction contractors. Their engineering strategy has been to complement their construction business through effective project management and efficient engineering practices enabling the completion of large projects on time and within budget. Their technical capabilities are certainly to be respected, but they are not generally thought of as "technology leaders."

As the size of the firm decreases, the ability to compete on these terms, especially for the largest projects, decreases and more of an emphasis is placed on technology. Mid-range firms such as Lummus, Kellogg, and Stone & Webster all offer full engineering and construction services, but awards are typically won based on some facet of superior technology. Also, in many cases, these firms may obtain the contract for the process design package based on their TCA in that area while another firm offering lower cost general engineering and construction

may be awarded the detailed engineering and construction contract.

Smaller firms such as Badger, Jacobs, Heyward-Robinson and Crawford & Russel rely very strongly on TCA in one or more market niches and typically compete for smaller, but often relatively higher value, projects.

This general structure is expected to continue even as the state of the art of process technology continues to advance. There are and will continue to be effectively two markets to be supplied. Those firms with strong technical advantages will continue to find opportunities to exploit these strengths through process improvements and the commercialization of new processes. The need for lower cost general engineering and construction will always remain, however, and the current industry structure should continue to provide an effective means of satisfying the combined engineering market requirements.

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Appendix: Interviews

The following pages contain a record of substantive discussions with industry personnel experienced in petrochemical plant design. The final page lists additional personnel with whom briefer discussions were held.

Aspen Technology, Cambridge, MA
Peter Lewis
(former Section Manager with Badger)
(617) 497-9010

Q: Rick Sturges at Badger has told me that you were responsible for Badger's development work for the Mobil/Badger ethylbenzene process. What were the origins of Badger's involvement?

A: In the mid 1960s, Mobil had developed a new family of catalysts having many potential uses. In the late 60s they began looking at application for the production of ethylbenzene. The existing process generated a highly corrosive liquid which required equipment made of rather exotic materials and a polluting waste product was also generated. After experimenting in the late 60s with the new catalyst, which avoided these problems, they approached Badger in 1971 for an evaluation of their process.

Q: Why did they approach Badger?

A: Badger was the current leader in E-B plant design, using the Carbide/Cosden/Badger process.

Q: Why does a chemical company often seek an engineering firm for a new process evaluation?

A: It's usually because of their reputation in that process area. Also, they need to be able to respond to unique circumstances.

Q: How does the client know of the firm's technical capabilities?

A: This is generally subjective based upon the firm's reputation. They also talk to previous customers and see if they were satisfied.

Q: What was the nature of Badger's initial evaluation?

A: Mobil had done bench scale testing. Badger looked at the technical feasibility of scaling up the process. We also did an economic study.

Q: What were the respective roles of Mobil and Badger as the development evolved?

A: Our evaluation indicated that the process looked feasible and Mobil did some additional pilot work. In 1972, however, they decided for non-technical reasons not to pursue further development. Badger was still interested and negotiated an agreement. The pilot unit was moved to Badger's research facility for continued development and if it became commercializable, Mobil would supply the catalyst.

Q: How did the development proceed?

A: We did many studies on the pilot unit but also made heavy use of our process simulator and by about 1973 concluded that the process could be commercialized. A semi-works unit was built at Foster Grant's E-B/styrene plant and tested during 1974. The tests were successful but Foster Grant also decided not to proceed and we moved the equipment to Cosden's plant.

Q: I understand from articles that at Cosden you experimented with the use of a dilute ethylene feed. Did this become a feature of future plants?

A: No. At that time we thought the new process was only marginally economically competitive and thought this would improve the economics. The dilute feed worked fine but there wasn't and isn't a sufficient supply to make it workable. Virtually all ethylene comes from the large olefins plants which are producing the high purity ethylene.

Q: Did you have difficulty finding your first commercial customer?

A: No. While we were testing at Cosden in 1976, the market was heating up and we licensed the first plant to Shell in 1977. It was a 600 mil lb/yr plant in Saudi Arabia. The first one on line was actually the second unit which was a 900 mil lb/yr plant licensed to American Hoescht which started

operating in 1980.

Q: Were there any special considerations given to Shell due to the risk associated with commercializing a new unit?

A: They were not required to make royalty payments. This is typical for a new process. After that, Mobil and Badger share the royalties, with a portion going to Cosden for their role with the semi-works unit.

Q: How well has Badger done with this process?

A: They got every world contract until 1985. Then Lummus got a contract in China using the Lummus/Monsanto process.

Q: Is Lummus catching up?

A: It will be hard. The Mobil/Badger process isn't overwhelmingly economically better but is much better with respect to the waste product. Also Monsanto has sold off their E-B/styrene operation and Lummus may be hurt by Monsanto's getting out of the business.

Q: Do you see any significant new developments on the horizon?

A: Not strictly in E-B, but UOP is working on a new styrene process that they claim is much better. If this turns out it could change the competition.

The Badger Co., Inc., Cambridge, MA
Rick Sturges
Manager-Business Analysis
(617) 494-7972
[first discussion]

Q: The market for engineering services is extremely competitive. Maintaining technology leadership in one or more areas appears to be essential for competitiveness. Do you agree?

A: Not necessarily. Take Fluor for example. They do very little in terms of technology development but within their large and diversified organization they have developed streamlined engineering procedures and management skills that make them competitive in terms of total project cost. They design plants using other firms processes under license.

Q: The seeds of new process concepts come from the manufacturers. Why is this, since you hypothetically could develop a staff with comparable technical expertise?

A: Cost is a major factor. A million dollar R&D effort can be much more easily accommodated by a large chemical company with much greater revenues. Also, maybe more critical is their intimate knowledge of the market for the end products. It is the unique demands of their customers and the market in general that dictate the directions of process development that are likely to be profitable. We certainly could come up with something new, but without the market it would be wasted effort. We have taken the lead and developed innovative improvements to existing technologies, such as:

Acrylonitrile - Sohio

Benzonitrile - Mitsubishi Gas Chemical Co.

Isophthalonitrile - Mitsubishi Gas Chemical Co.

Ethylene dichloride - B.F. Goodrich

Phthalic anhydride - Sherwin Williams

Q: How did you come into these arrangements?

A: Badger has a reputation for expertise in reactor design, especially fluid bed reactors. In many cases we were approached by the petrochemical firm seeking assistance. Other cases have come about through our marketing efforts, seeking to collaborate or provide assistance.

Q: Have you ever developed processes strictly in house?

A: No. We've always worked with another firm, although in cases we have really led the way.

Q: How would you characterize your scope of services and business orientation?

A: We provide a full range of engineering, procurement, and construction services, although we are not as strong as some competitors in terms of construction. We consider ourselves to be a technology leader and consider this to be our focus and major selling point.

Q: In what areas do you consider yourself to be a technology leader?

A: We have designed and constructed a wide range of petrochemical plants. Our current strengths are in ethylbenzene, styrene, and polystyrene; vinyl chloride, and polyvinyl chloride; and acrylonitrile.

Q: How were these technologies developed?

A: Generally in collaboration with petrochemical companies. The E-B process was developed with Mobil Chemicals and the styrene process was developed with Cosden Chemicals. In both of these cases we are "co-owners" of very competitive processes. In several other areas we also worked closely with petrochemical companies to commercialize new

processes, either from the early research phase or from the conceptual design stage.

The Badger Co., Inc., Cambridge, MA
Rick Sturges
Manager-Business Analysis
(617) 494-7972
[second discussion]

Q: Badger has a strong technology orientation. Why do you feel this is of such importance?

A: Historically, this was promoted by proximity to M.I.T., Northeastern, and Tufts which provided a ready source of talented personnel. Having a creative staff became part of our culture. We really don't do basic research, however. Our philosophy is to be able to take concepts from client companies' R&D and to commercialize them. We have also shied away from other forms of competition, such as an emphasis on low cost construction. Clients will go to Fluor or Bechtel if that's what they want, but may still use a Badger technology package. We do complete engineering and construction, however, and have done reasonably well in that area.

Q: How are large firms like Fluor and Bechtel able to do well without a technology focus?

A: Historically, the big money was in construction and by concentrating in this area they have developed management strengths and controls to establish a strong reputation for getting projects completed on time and on schedule.

Q: If a smaller firm can achieve an advantage by a strong technology position, why don't the construction oriented firms do this as well?

A: There is not an easy answer. It's probably because they are so large and diversified that process plant work is only a small part of their overall business. For example, Parsons has a major focus on infrastructure work and Fluor has gone after major construction projects such as new cities in

Saudi Arabia. If you look at their profits in the process industry, there's probably not a lot available to invest in development work. Also, it's difficult when other firms are established with strong technologies. Fluor did start a small technology group, but this may have been largely as a marketing device.

Q: What are the essential elements of technical competitive advantage?

A: One advantage that we have is a high percentage of chemical engineers -- 12-20% versus 5-6%, which is typical. Most important is experience. We have had experience in the design of a wide array of plant types and have worked with all types of clients from big oil and chemical companies to small chemical companies and biotech firms. We have also worked in many foreign countries.

Q: What technical advantages have enabled you to get this wide array of work?

A: Experienced personnel. We have people who have worked in many diverse process areas. When needed we can pull out the knowledge of past experience in almost any area. Experience is what the client wants. Even commercialization projects and process modernizations come down to basic chemical engineering. All firms have this basic ability. The choice often comes down to who can claim past performance.

Q: If the key is successfully demonstrated past performance, how does a firm originally develop a technical advantage?

A: There's no simple answer. It evolves over a long period of time.

Q: In addition to experience, what else can a firm do to increase or improve technical advantage?

A: Keep in front of the competition by continued development efforts. We try to keep 6 to 8 development jobs in process at any time -- again, these

are not basic R&D projects, but process development coming out of previous R&D. Our laboratory is used primarily for catalyst testing and obtaining process design data.

Q: What part of your development work is self-sponsored?

A: Very little. It's mostly under client contract with some cco-funding projects.

Q: How do you obtain these projects?

A: Heavy marketing. Even though we think we have an established reputation, our V.P. of advanced technology is constantly on the road talking to R&D organizations of potential clients.

Q: You say that your experience in development work led you to a technology leadership position. How would you characterize what this really means?

A: It comes down to knowhow. Not just in chemical engineering, but the ability to solve complex mechanical engineering problems. It's a combination of creative and chemical and mechanical engineers. This has led to unique experience in many different unit operations including the design of some unusually complicated units such as a plant for Sasol which required 20 non-ideal distillation steps. Even if we haven't had experience in the production of a specific product, we can rely on our knowledge of most process unit operations from other types of plants. For example, we're now using our knowledge of polymer operations to get into ceramics which requires analogous process steps. We also make heavy use of computer process simulation which is of general applicability.

Q: Where is the greater potential to exploit these technology skills - in improvements to mature commodity processes or in newer downstream

product processes?

A: It's obviously harder to make a significant improvement in the mature commodities, but with the larger markets more sales will result. We've had successes in this area such as with ethylbenzene and acrylonitrile. At the other end are low volume special use products that may only end up with two or three plants worldwide. These have a much greater unit value, however. For example, whereas a 900 mil lb/yr styrene plant may cost \$100MM, a 12 mil lb/yr polyethylamine plant may cost \$50MM.

Q: Is there a trend in the focus of technology oriented forms?

A: Yes. It's towards the more technology intensive products. There are good opportunities here. This doesn't put the Fluor's and Bechtel's out of business either. They will still go after the construction.

The Badger Co., Inc., Cambridge, MA
Wilfred Baranick
V.P. and General Counsel
(617) 494-7245

Q: Are most patentable process and equipment designs developed by engineering firms actually patented?

A: Engineering firms do a significant amount of patenting, but there are different philosophies as to the extent. Patenting can be a good defense and can also be exploited as a sales tool.

Q: What types of inventions are generally more likely to be patented?

A: It's more likely if the technology is strong - likely to be of significant competitive advantage. But many are still not patented, relying on trade secrets. Again, it's a matter of philosophy.

Q: Is disclosure through patent filing a concern?

A: To some extent, but you needn't disclose all critical details in the filing. Process patents need only to contain lab scale descriptions. Also, you can hide the total value of some innovations by the use of multiple filings.

Q: Are patent infringement cases common?

A: They're not uncommon, but most firms aren't geared to police patents. Especially in the case of process patents, you may never know if a company is using your technology.

Q: Is a review of patent filings a useful source of information?

A: It can be. Badger subscribes to publications of U.S. and European patent filings and generally reviews them weekly.

Q: You mentioned trade secrets earlier. By what means are they protected?

A: First, all professional employees sign non-disclosure agreements. This is a common policy and is also required of us by other firms from whom we license technology.

Q: Do firms ever try to recruit key personnel from competitors because of their inside information?

A: Rarely. Also, departing employees are reminded of their legal obligations in this regard.

Q: What about secrecy agreements with clients?

A: These are essential. We offer many processes under license from others and live or die by maintaining the secrecy of their technology. We can't afford to have any finger pointing. Economic assessments as well as technical information must be protected.

Q: What is the typical nature of a secrecy agreement?

A: Engineering firms' agreements with licensors obligates them to maintain confidence. Subsequent discussions with clients or vendors require similar agreements. Non-disclosure and non-use provisions are typically in force for about 15 years. These are very common regardless of whether patents are involved. There are some standard exclusions, however. Firms are not liable for disclosure by second parties with previous knowledge or by third parties.

Q: When you're marketing your services, what can you tell potential clients without such agreements?

A: Only general information such as the summary process descriptions published in trade journals. If they're serious, confidentiality agreements must be signed before getting into any further detail.

Q: Are trade secrets regarding equipment designs hard to maintain, given that fabrication is sub-contracted to vendors dealing with many firms?

A: Vendors must sign similar secrecy agreements before bidding for equipment considered to be critical. This selection can be a bit subjective but is made by the technology owner. Vendors have historically abided by

these agreements, since their reputation depends on it also.

Q: We've talked about licensing agreements in terms of secrecy. What does it take to obtain an exclusive license?

A: Both superior technical strength and an international market presence. Non-exclusive licenses or ones restricted to different regions maximize world exposure. Foreign firms may be able to obtain better project financing in different regions. Special technical capabilities are also important. For example, Badger has designed nearly 200 fluidized bed reactors and would be a strong competitor for an exclusive or restricted license for a process employing this technology. A good sales job by the engineering firm is also required.

Q: What are typical royalty provisions?

A: There are three or four different arrangements:

- A fixed amount paid in a few installments.
- An initial payment plus future payments based on production.
- A percentage of dollar sales.

Q: Can the engineering firm make modifications to a licensed process?

A: This would usually result from a formal collaborative development project. Sometimes there is no formal agreement, however. If the engineer makes an improvement, both parties can still benefit.

Q: What does it take to become a technology leader?

- A:
1. Creative process engineers - ones who see alternate ways of doing things.
 2. A technology oriented philosophy with actual success under your belt.
 3. Supportive management with long term commitment.

Foster Wheeler, Corp., Livingston, NJ
Tino Valencia
Proposal Manager
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Q: What would you say are Foster Wheeler's major competitive advantages in process engineering (as opposed to your equipment manufacturing business)?

A: It's not low cost. Our services are average to high priced. We compete on other factors including our own technology, experience, and prior client relations.

Q: What are the fundamental requirements to compete on a technology basis?

A: First, there are few areas where you can compete on technology alone. Many projects are generally run of the mill, but firms can specialize in one or two areas. In refinery operations, for example, we are leaders in the design of delayed coking units. Foster Wheeler has designed 60% of world capacity in delayed coking.

Q: What does it take to be a technology leader in a specific area, such as that?

A: Technical knowhow that clients can see based on historical data. The client must perceive your expertise.

Q: How do you develop this expertise and reputation?

A: There must be a market demand. If it's there, development work can lead to economic successes.

Q: Is internally funded R&D effective?

A: It depends on the vitality of the industry. In the 70's you could do it, but demand slowed in the 80's.

Q: How do you protect a technical advantage?

A: You have to actively go after all projects to keep gaining experience and

you must have secrecy agreements. Secrets can't be kept indefinitely but you can prevent use and minimize diffusion. Patents are used sometimes but details can be changed and concepts engineered around.

Q: How is technical advantage lost?

A: By loss of key people. Also, if you have a real advantage, some other firm will always attack it. If that firm has the right people, someone will rise with new ideas and make developments that can make that firm a new leader.

Q: What happens if a firm loses its leadership position?

A: Of course it's best if a firm is always looking ahead. Unfortunately, many firms dismiss new developments being made by others. Even if the changes are good, some will continue to argue against them. Eventually they may be forced to jump on the bandwagon with their own version, but if they've waited too long, they'll end up managing by crisis and it may be too late. If they take action early, they can usually regain competitiveness.

Lummus-Crest Engineering, Bloomfield, NJ
Steve Stanley
Process Design Manager - Ethylene Group
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Q: What portion of Lummus's business is in petrochemicals as opposed to refineries or other process work?

A: I'm not really in a position to say, but can describe the position of the firm as a whole. The top tier of contractors consists of large firms like Bechtel and Fluor. Lummus is in the mid-range contractor group with firms like Stone & Webster, Kellogg, Linde and Technip (last two foreign). Our range of contract sizes is from about \$30 MM to \$3 B with about \$500 MM being a common size. Firms in this range look for a "technology niche" as a basis of competition. The third group is small "pots and pans" firms like Heyward or Jacobs who often work with operating companies to design small proprietary process plants. Their jobs are too big for most operating companies but too small to interest larger engineering firms. The jobs are typically in the \$2 MM to \$3 MM range.

Q: How does the Lummus Technology Center fit into your organization?

A: Lummus is primarily divided into two areas. On one side are the engineering divisions, domestic and overseas, which perform the fundamental engineering, procurement, and construction activities. On the other side is the Technology Division. It has a Process Design Division with about 130 people who produce licensed process packages either for our own engineering divisions or under subcontract to other engineering firms. The Technology Division also has a development arm of 70 to 80 people involved in R & D. Functionally the Technology Division is similar to analogous groups in other mid-range firms, except perhaps being unique as a separate profit center. Also, it has one of the largest labs

of engineering firms.

Q: With the industry slowdown of the past several years, has Lummus become more or less technology oriented?

A: Definitely more technology oriented. Also, there has been a dramatic upturn in business in the past six months. With the slowdown came severe competition. Overseas firms offer engineering man-hour rates less than half of U.S. rates. Also, as technology matures, it is diffused to these firms and the U.S. must offer technology that is one step ahead if we are to compete at all. Since new technology becomes basic after five to ten years, the U.S. must keep advancing the state-of-the-art. We must provide better engineering - process modifications that are cheaper and more efficient - and new processes.

Q: Is it really feasible for engineering firms to get involved with research into new process reactions?

A: Lummus thinks so and has spent a lot of time on catalyst development. We also do a lot of bench scale development work. We think in-house R&D is good.

Q: What are the essential underlying elements that provide technical competitive advantage?

A: Knowhow of specific process steps and tricks to optimize performance. Experience is also a critical factor.

Q: How important are rights to a superior process?

A: This is the ultimate. A much higher man-hour rate can be charged for contracts employing an exclusive process. Profit margins are typically only \$2/hr on bulk engineering work.

Q: How do you obtain these technical advantages?

A: Primarily through R&D.

Q: Is R&D more effective if the focus or origins came from a client company?

A: Yes, very much so. Exclusive rights that come from these efforts are in your interest. Also, your resources are limited and cooperative efforts spread the burden. They also will result in royalties, usually split 50-50.

Q: What does the engineering firm bring to the joint development?

A: The engineering experience needed to scale up and the ability to integrate systems for energy efficiency. We can also bring together mechanical design and reactor design specialists to design complex reactors.

Q: How is technical competitive advantage protected?

A: Secrecy agreements are the major means and are religiously maintained.

Q: What about patents?

A: We don't rely heavily on patents for a number of reasons, but primarily because we don't want our technology to become public knowledge. Most patents can be engineered around based on the patent concept. Also, if the patents are written in a general form to minimize disclosure, they're harder to defend. Finally, there are the costs associated with patenting.

Q: How is technical competitive advantage lost?

A: By getting too comfortable with the current situation and not continuing to make advances. Also through staff attrition. Technology is always changing and cannot be written down. It is in people's minds. Maintaining a continuous staff is hard, however, in a cyclic market which requires ongoing ups and downs in staffing. We really lose few people to competition, though, partly because we are geographically separated from our major competition. We try to protect against losses by having one or two layers of backup to key people and simply trying to keep them happy through compensation, the nature of the work, and by keeping up morale. People are our machinery and must be greased and oiled. Ongoing

development of staff is also essential and we try to keep bringing up new people.

Q: Was the Mobil/Badger ethylbenzene process development an example of a new development significantly hurting your competitiveness?

A: Only temporarily. We went back to the drawing board and think our process is now about equal to theirs. There's good competition in the basic commodity markets and no one stays ahead for too long. If we're losing advantage, we try to find out why. After every contract award we've bid for, we do a "post-mortem" and try to obtain as much information as we can as to why a competitor got the contract. We usually can't find out specifically how they were able to have won, but we can find out what we have to do better. We re-examine our own ways after successes and non-successes.

Stone & Webster Engineering Corp., Boston, MA
Robert Gartside
Development Manager
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Q: I have read about the Gulf/Stone & Webster Thermal Regenerative Cracking (TRC) process in journal articles and would like to ask you some related questions. What was the original source of the concept?

A: Gulf had developed a new fluidized catalytic cracking (FCC) unit design for their refinery operations. Coming out of this work was the idea to use this basic technology for olefins production.

Q: How did Stone & Webster (SWEC) get involved?

A: Gulf had begun lab work using FCC riser technology to make olefins and approached SWEC for a process evaluation in 1972.

Q: Why was SWEC approached?

A: Both SWEC and Lummus had built ethylene plants for Gulf and both were approached. It's not clear specifically why SWEC was selected. We had done previous successful development work for Gulf in the early 60's.

Q: Is there any fundamental reason why this new concept originated with a manufacturer rather than with an engineering firm?

A: Engineering firms' strengths are in basic engineering, not new process development. Most new process concepts come out of R&D by the operating companies.

Q: Why do these firms then come to the engineers for evaluation or assistance?

A: Their research is usually directed at developments in chemistry. Most have minimal capability in basic engineering. They can develop lab scale units but can't effectively scale them up to a commercial unit.

Q: What was the nature of SWEC's initial evaluation?

A: We looked at whether or not their design could be scaled up and found that it wouldn't based on the interaction of the process kinetics and fluid dynamics. We recommended some design changes and specific additional tests. We used some of their basic features but ended up with a design that was really quite different.

Q: What happened next?

A: The tests were performed and looked promising. The next two years were spent discussing what direction future development should take and terms of a joint development arrangement. The real basic development then took place from 1975 to 1977.

Q: What was the nature of the joint development agreement?

A: We would both contribute our respective knowhow to the development, share costs, at least initially when they were relatively modest, and share use of each others' patented designs.

Q: What was done during this basic development phase?

A: An overall system design was developed, commercial economic studies were performed and more lab testing was done. We also filed for basic equipment patents during this time and set the scale for a field test unit.

Q: What were the relative contributions of the two firms?

A: Through the basic development stage there were relatively equal contributions. We made more of the design recommendations while they performed the lab testing, as well as making technical contributions. When we began serious field test unit development in 1978 the roles did change with SWEC taking real technical leadership. We also worked out a new test phase agreement.

Q: How did this differ from the original agreement?

A: It was fundamentally the same, but with a lot more detail. Specific terms

of funding, responsibilities, and commercial benefits were spelled out.

Q: I see from the literature that field tests were quite successful. Why hasn't the process yet been commercialized?

A: First, just as FTU testing was being completed, Mesa Petroleum began attempts to take over Gulf. Others also got involved and Gulf was eventually taken over by Chevron in 1984. We continued planning and design of a commercial scale unit but couldn't conduct serious commercial discussions during the takeover proceedings.

Q: What about today?

A: Chevron thinks the process has merit, but doesn't commercially need another plant. We're conducting discussions with other firms, but current demand is not strong and the shift to an economic advantage of heavier feeds hasn't materialized.

Q: How does the TRC process relate to SWEC's Quick Contact (QC) process?

A: Shortly after FTU testing we began thinking about other applications of the physical process beyond olefins production. These included other areas that used thermal or catalytic processes. Whereas the solids in the TRC process are inert, we've worked with catalyst vendors and modified the process for use in propylene production by propane dehydrogenation and for styrene production. The QC process can also be used in a number of refinery operations.

Q: Where does QC stand today?

A: We have firms that are interested and we're currently conducting discussions regarding terms of demonstration plant design.

Stone & Webster Engineering Corp., Boston, MA
Jim McNeill
Assistant Manager - Process Technology
(617) 589-7353

Q: What are the essential elements of technical competitive advantage?

A: People are our assets and experience is essential. Beyond that there are three basic mechanisms to gain advantage. First is through licensing arrangements, preferably exclusive rights. To get these you have to be able to sell the process, essentially becoming a marketing arm of the owner. Having established the licensing arrangement, you may also be able to make improvements to the process. If they're significant you may also be able to get into a position of sharing royalties.

The second mechanism is through R&D, from lab work to testing to pilot plant development. This is usually limited by costs and such efforts must be carefully focussed. You should concentrate on what you know well and possibly look for new applications. Firms who do this well develop a reputation which they can build on. Eventual profits are limited by market growth.

The third mechanism is through joint ventures with oil or chemical companies. R&D is expensive and sharing reduces the costs (but also the royalties). The complementary skills of the engineering firm is what makes this approach effective.

In any case, technology won't stay stagnant. You have to keep moving to be one step better.

Q: How do you convince a client to enter into a joint development effort?

A: Some you never will. Others are more entrepreneurial and you have to seek out those that are more willing to take a risk. You have to be able to show your experience in previous commercialization project successes.

Your past record is essential. You must provide a superior product. This doesn't come from theoretical chemistry but the assets of people in areas like kinetics, cryogenics, and vessels. You must be best at chemical engineering in unit operations. It takes a combination of a "think tank" and basic production engineering. Both are needed and management must avoid a we/they attitude between R&D and production.

Q: How do you obtain such a technical advantage?

A: The best way is to obtain an exclusive license. This requires a leading technical competency. This is not too common, though, because it may limit marketing potential. An advantage to the licensor, however, is that there is only a single technology transfer required.

Q: How is technical advantage protected?

A: For an engineering firm patents are usually filed on equipment designs and process improvements. Also on joint process development.

Q: Is patenting the rule?

A: Not always. Sometimes you rely on secrets. Beyond patents is knowhow. The specific knowledge of people is important, such as having an expert in the kinetics of olefins versus general expertise in kinetics. Technology is also protected by confidentiality agreements.

Q: Is knowhow commonly diffused by the movement of people?

A: Maybe, but Stone & Webster has maintained a stable group.

Q: What happens if technical advantage is lost?

A: If it's a large market, there's lots of ways to proceed. You can usually make an improvement to move ahead again.

Q: If a process is mature and near physical limits, might a radical change pose a tougher challenge?

A: Even a radical change usually doesn't come out of the blue. You have to

be looking to the future and try to anticipate what may happen. You should be evaluating all fundamental ways of getting through existing technical barriers. For example, if metal temperatures are a barrier, you should be looking at alternatives such as ceramics.

Q: What trends do you see in the industry?

A: It's hard to predict the future. Big firms have laid off thousands of employees and are taking on smaller jobs. Mid-range firms are moving up and down as a function of the market. The best approach is to be flexible to move with shifts in the market.

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