Product Development in the Industrial/Chemical Process Industry

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Submitted to the System Design and Management Program
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ABSTRACT

After an initial discussion of the traditional product development process (PDP), this thesis concludes that there are a number of additional system-level issues to be considered when the product is a chemical process rather than a manufactured good. One important distinction is that the super-system issues such as: 1) economy and access to financing; 2) regional/national support and stability; 3) regulatory regime; 4) protection of intellectual property/rights; 5) human capital; 6) industry structure; and, 7) industry value propositions must be considered.

The chemical and mining industry structure is discussed in detail.

A series of industry value propositions for different "products" (supply of manufactured goods, process design & equipment, equipment only, equipment with protected IP, equipment & parts, sector-limited licenses, use of equipment, services in the developing world) is presented.

This thesis postulates that for products which are process-based (as opposed to manufactured goods) the industry structure and the other system-level aspects (described above) are important to take into consideration when answering the question "What is the product?" The field work for this case study came from a three week internship at EFMB in Coleraine, Northern Ireland (UK), which looked at opportunities to exploit the process-based intellectual property (IP) owned by EFMB. EFMB is exactly in the position where it needs to look at the system-level issues to determine how it should proceed and what type of company it should become.

EFMB is used as a case study to look at all of these issues. The EFMB technology is simply described, and the two main competing technologies are discussed in technical detail in the areas of equipment needs, design conditions, operating parameters and costs, and primary industrial uses. Advantages and disadvantages are discussed. The EFMB situation is used to discuss the system-level issues described above, and the framework for answering the question "What is the product?" is applied to this case.

BIOGRAPHY

Dr. Carol Ann McDevitt, P.Eng. received her Bachelor of Science in Engineering (Chemical Engineering) degree in 1981 from the University of New Brunswick. While working at Dow Chemical Canada Inc. as a production engineer from then until 1985, she completed the requirements for a Master of Applied Science in the same field through the University of Waterloo's part-time program. Dr. McDevitt was licensed as a Professional Engineer in 1983. She returned to the University of New Brunswick for her doctorate in chemical engineering, the experimental work of which was completed at the Atomic Energy Canada Ltd. labs at the Whiteshell Nuclear Research Establishment. She was awarded her doctorate in 1991.

Dr. McDevitt has considerable experience in the design, installation and evaluation of chemical processing equipment. She has been involved in the design, control and installation of treatment systems, including oil/water separators, air strippers, aeration systems, activated carbon removal equipment and biological treatment facilities. In addition, she has been involved in the design and/or specification of many different unit operations including distillation, adsorption, separation and mass transport operations.

Previous experience with the mining and pulp & paper industries, thermal power generation facilities, the chemical industry and a lead smelter have given Dr. McDevitt the opportunity to cross traditional boundaries and gain an understanding of engineering principles in many areas. Her industrial projects have included equipment design and specification; efficiency studies; mass, energy and exergy balance calculations, and process control strategies. Dr. McDevitt has published extensively, primarily in the fields of toxicology, chemical safety and nuclear testing.

ACKNOWLEDGEMENTS

This thesis was initiated from a very interesting opportunity awarded the author through the Global Entrepreneurship Lab (G-Lab) course at the Massachusetts Institute of Technology. In this course, students are matched with entrepreneurs and start-up companies in a global setting. Special thanks are due to Professors Simon Johnston, Richard Locke and Sandy Pentland for running this course, and Ken Morse, Director of the Entrepreneurship Center.

The author's G-Lab project was funded through the University of Ulster Science Research Park, and thanks are due to Professors Terri Scott and Chris Barnett. Mrs. Veronica Farrell provided all of the logistical support to the team, including accommodations, arrangements, food, and transportation advice, for which many thanks are due.

Both Professor Tony McHale and Dr. Cathal Riordan of EFMB were always available for help and provided useful comments and direction. Mr. Peter Corrigan provided both encouragement and thought-provoking questions, and many thanks are due the whole EFMB team.

On a personal note, the author would like to thank all of the System Design and Management students. The SDM program provides the students with a very valuable peer group, from different academic backgrounds and with different work histories. Interaction with this group of very special students has been invaluable.

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1.0 INTRODUCTION

1.1 Background

To a chemical engineer, product development often means coming up with a new process. Chemists develop a new pathway to a compound, new information about physical properties of mixtures leads to new unit operations, new sensing techniques are developed so that previously discarded process pathways are now feasible because they can be controlled. Given these opportunities, the chemical engineer develops a new process.

During the very early stages of the research, there is no interest in the market – the research is focused on HOW to do something. This focus is essential, since much of our breakthrough science has come through research which was looking at something else. Also, in many cases, a breakthrough will create a market – when fusion power is achieved at a net power gain, then power generation by fusion will become feasible.

But if the new process does not create a market, where does it fit into the marketplace? What industries does it sell to? What is the product – equipment, parts, engineering, services, or some combination of these?

A systems-level view is required to answer these questions. It is important to understand the systems into which the new product will fit. In addition to an understanding of supply and value chain, there are higher level system issues on a global basis. This thesis takes this high-level system approach to developing the questions to ask for new product development of this type.

This thesis was initiated from a very interesting opportunity awarded the author through the Global Entrepreneurship Lab (G-Lab) course at the Massachusetts Institute of Technology. In this course, students are matched with entrepreneurs and start-up companies in a global setting. During January, 2002, a team of MIT students (Waqas Khan, Vishal Metha and the author) worked with EFMB in Coleraine, Northern Ireland (UK), to look at opportunities to exploit the intellectual property (IP) owned by EFMB. EFMB is exactly in the position where it needs to look at the system-level issues to determine how it should proceed, what type of company it should become.

The results of that study showed that there are many different ways in which new processes can be developed into products. A number of different potential value propositions were noted. This thesis continues that work, and discusses how the various factors can be taken into consideration when setting the value proposition for a new product. EFMB is used as a case study.

1.2 Product Development

The product development process (PDP) involves a series of activities to conceive, design, and commercialize a product. The typical product development stages are shown in Figure 1 (Ulrich and Eppinger, 2000).

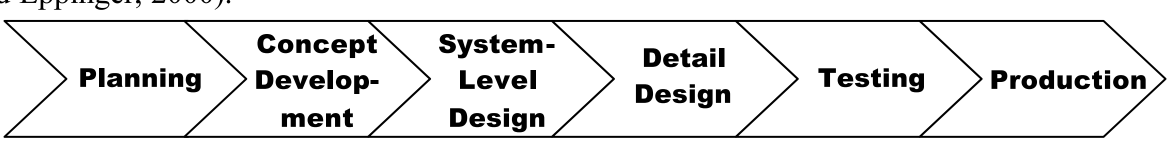

Figure 1: Generic product development process

In the concept development phase of the PDP, the development of the technical system architecture and the business case proceed in an interactive manner as illustrated in Figure 2[1].

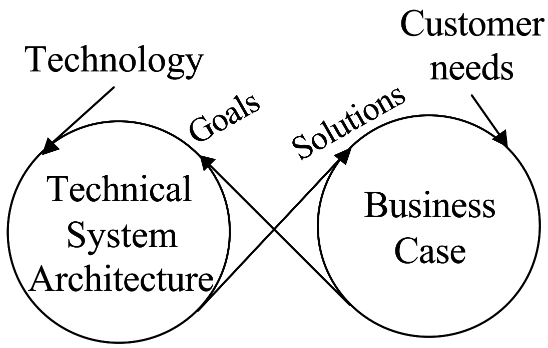

Figure 2: Relationship between product architecture and the business case

Practically speaking, this means that a new product idea can come from either a new technology (discovered by the technical side of the enterprise) or a new customer need (discovered by the business side). In either case, the technologists and business people work together to come up with technical solutions and goals. As the business side of the enterprise talks to customers, they come up with a list of goals for the new product. The technical people turn these goals into designed solutions, which are passed back to the business people as potential solutions to the customer needs.

The PDP in industries which are predominantly the domain of chemical engineers – bulk and specialty chemical production, mining, pulp & paper and environmental treatment technologies (actually multi-disciplinary) is different from the traditional approach. In these cases, the new products are actually new unit operations and new chemical processes, as opposed to manufactured goods. They are historically developed as shown in Figure 3.

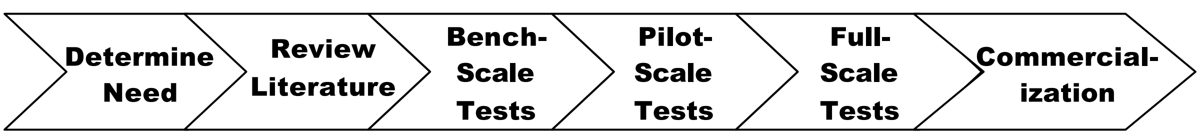

Figure 3. Industrial/chemical process development

Research and development on new chemical processes is primarily conducted by industry, academia, and for-profit technology developers. In the early stages, there is a known technical need – for example, removal of heavy metal pollutants from wastewater – but the marketing group typically play a small role in defining customer needs. The objective of the research is to develop a technical solution to a known processing problem. The ultimate customer does not play such a strong role in the product development at the early stages, because the challenges are

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[1] Dr. Ed Crawley, MIT Professor of Aeronautics and Astronautics, personal communication

the technical development of the product. At each stage of the development (bench, pilot and full scale) the enterprise evaluates whether the new technology will be able to accomplish the technical task in a cost effective manner. As more information is known about what can be accomplished with the new technology, the "customer" is more fully defined, as are the terms "cost effective" in light of that specific customer need. Once the new chemical process can demonstrably accomplish the required processing, with known capital and operating costs, then it is launched on the market.

1.3 EFMB

Research on the use of biomass to remove metals from wastewater and effluent streams has been conducted at the School of Biomedical Sciences at the University of Ulster, Coleraine. In 1998 they patented a process that would separate heavy metals from a wastewater stream using adsorption onto biomass (biosorption) and DC power. In the summer of 2001 EFMB was formed to commercialize this technology.

The process was initially developed from a known need to remove metals from water, and literature suggesting that biosorption could perform this chemical separation. The team at University of Ulster conducted bench-scale testing, which showed that biosorption was effective, and, further, that application of an electric current would speed up the process. A series of batch pilot-scale tests were also run for a specific wastewater application. This PDP follows that shown in Figure 3.

Heavy metals are pollutants that must be removed from industrial wastewaters before the water can be released to the environment. These contaminants are present in a number of industries, including mining and mineral processing, textiles and dyes, film and photoprocessing, nuclear fuels and contaminated sites. The advantage of the EFMB technology is that it can use either living or dead biomass – potentially increasing the market to include effluents that would normally be too toxic for living organisms. Also, the DC current significantly speeds up the process, making it more attractive for commercialization. (Khan *et al*, 2002)

In addition to wastewater treatment, there are some other potential markets for EFMB's intellectual property. Since the technology can specifically remove certain species of metals (for example silver and not copper), there are potential industrial needs inside a production process. Also, because the technology combines two existing processes, biosorption and electro-dialysis, it might be more cost effective for industries which use both of these processes in series. (Khan *et al*, 2002)

1.4 Objectives

The research objectives are:

- through a series of case studies, determine the value proposition and product development process of other non-traditional industrial/chemical processes.
- determine which industrial applications are most suited for the EFMB technology as it stands at present.
- evaluate the business models in these industries, concentrating on the purchaser-supplier relationships.

- develop a recommended product development process for this situation, using EFMB as an example case.
- determine if there are market concerns in these industries about suppliers located in Northern Ireland and attempt to evaluate how important these concerns might be in the purchasing decision.

1.5 Structure of Thesis

This thesis provides some background to the product development process and develops a framework for answering the question "What is the product?". In Chapter 2 the industrial and chemical process industry is described, including system considerations, the industry structure, and the value propositions used by a number of companies operating in this industry. Chapter 3 describes the company EFMB, which is used as a case study. In Chapter 4 a framework is developed, and is used to review information EFMB, culminating in conclusions about the next steps for EFMB, based on analysis of the information from the framework. Chapter 5 concludes with a discussion about the usefulness and applicability of the framework developed.

2.0 PRODUCT DEVELOPMENT IN THE INDUSTRIAL/ CHEMICAL PROCESS INDUSTRY

2.1 System Considerations

2.1.1 Economy and Access to Financing

For an enterprise looking to develop a new process for eventual sale in the marketplace (as opposed to situations where the new process is to be used internally as a source of competitive advantage), the traditional enterprise internal funding mechanisms are likely sufficient. Care must be taken that early stage projects are considered part of R&D funding and not subject to ROI-type analysis too early on, since this can lead management to make decisions which are based on vague values of the potential market. (Mitchell and Hamilton, 1988).

For a new enterprise, such as a start-up from technology spun-out of a university or technology incubator, there are a number of other issues such as the availability of venture capital, access to international markets, loans from commercial banks, funds provided by the government to hi-tech businesses, corporate ventures and partnerships, and potential exit strategies for investors (Locke and Johnston, 2001)

Access to financing can impact the product development. In many countries, government funding is available for new enterprises or new products from existing enterprises, in areas where that government would like to see growth. For example, Northern Ireland would like to encourage manufacturing, and so they provide financial support to companies developing products which will be manufactured locally. Various US government departments have specific needs, and will fund new product development where there is synergy. NASA specifically have a mandate to share and transfer technology to the marketplace, and will work with industries, providing financial and technical assistance, when there are joint needs (NASA briefing, 2002).

While in the early stages of trying to fund a new product it is tempting to focus the product such that it can access some funding initiatives, this can be a short-sighted approach. Other system-level issues should be taken into consideration, as noted below.

2.1.2 Regional/National Support and Stability

There are a number of factors associated with the enterprises location that can impact product development. In some cases, the national or regional government can provide support such as cluster/technology park initiatives, industry associations, networks, physical infrastructure such as power, telecom and transpiration (Locke and Johnston, 2001).

Physical infrastructure can play a major role in product development. The chemical industry developed around waterways because of access to water for cooling and processing needs, and because of shipping access for delivery of raw materials and shipment of product. These areas are typically near towns and cities, and industrial sites can be crowded. Space is often an important factor when installing a new process, while access to power is not a problem – many industries produce their own power, or have access to a grid.

The mining industry is exactly the opposite. Mine sites have very limited power, but almost no limitation on space. This industry would prefer a technology which does not use any power (water wheels are common), and retention times (which equates to equipment size) can be on the order of days if necessary.

The pulp and paper industry is a mixture of the two. The mill often has access to power at the plant site, but none at the effluent treatment area.

For product development, the infrastructure limitations of the ultimate customer can have a major impact on the process as it is being developed.

2.1.3 Regulatory Regime

In the industrial/chemical processing industries, there are two main regulatory issues. The first area of interest is at the enterprise level: number of clearances required to start a company, time to incorporate a company, corporate taxation levels, years of tax holiday for a new company, level of corruption, local legal environment (e.g., ability to enforce contracts), rules about corporate governance (do investors know what companies are doing?) (Simon and Locke, 2001). While these are important to the business, they have a limited impact on the product development decision.

The environmental regulations, however, often have a major impact on the product. It is true (according to the second law of thermodynamics) that you cannot make a product without waste. Regardless of the process, there will be some stream for disposal. Disposal of wastes must be taken into consideration when developing the product. This includes a number of issues such as:

- Will the waste be considered hazardous? – this depends on local jurisdictional issues (states in the US, provinces in Canada, the whole European Union).
- Can the eventual owner of the process dispose of the wastes at all (some wastes are so hazardous that storage in a secure facility on-site is the only option)?
- Can the wastes be recovered in some other process, or turned into a different product? – for example waste organics often have some fuel value if they can be burned.

- Can the process vendor agree to take back any wastes? This is becoming a popular option in Europe, and is legislated in some specific industries in both the US and Canada.
- Can disposal of the waste be arranged in nearby jurisdictions? Slight variations in hazardous waste regulations between Washington, Idaho, Alberta and British Columbia has resulted in a new industry – trucking waste around the various landfill sites because what is classified as hazardous waste in one state/province may not be hazardous in the neighbouring state/province. Often this provides a low-cost waste disposal option, making the process more attractive.

There are other situations in which environmental legislation can impact product development. Two very specific examples (below) can show how an understanding of the local environmental regulations can impact the product development.

In the 1980s there was significant advancement in the field of water treatment in the Czech Republic. Due to water shortages, some companies developed technology that would clean grey water (household water such as comes from sinks and showers) to such an extent that it could be recycled. When they developed the products, they measured the parameters that were important in their local regulatory regime. With the opening of eastern Europe and the opportunities of the North American market, a number of these companies tried to move these products to North America. However, the testing that they had done on the products was not sufficient for North American regulators, who regulate a completely different set of chemical parameters. Many of these companies found that the products they had developed did not quite meet the US regulations – had they planned in advance for the US market, a slight "tweaking" of the product would have make it acceptable. However, once they were into production for their home market, production of a whole new product for the North American market often proved too expensive.

The second example relates to a known (by local practitioners) quirk in environmental regulations. When British Columbia, Canada, first developed its hazardous waste (called special waste) regulation, it did not have provisions for removing the hazardous materials and "cleaning" the waste. Therefore there was no mechanism for declaring that a waste which was once hazardous was no longer so. As remediation technology advanced, there were now technical solutions and products for cleaning contaminated sites (among other hazardous wastes). Technology providers could provide processes to clean huge contaminated sites, but then the site owner would have invested millions of dollars to now have "clean" special waste – as far as the regulations were concerned, they had done nothing. These technology products were not of any value in this market, due to the regulatory system, despite the fact that they were effective processes. (The *special waste regulation* has since been amended to permit de-listing after remediation).

2.1.4 Protection of Intellectual Property/Rights

Protection of intellectual property is a key issue in the processing industry. If the technology is patentable, then it can be protected (if such protection is available where the enterprise is located). There are both product and process patents, and it is important to understand what is "key" about the product and the value proposition in order to know how to protect the product. In other circumstances, patenting might not be suitable. Protection of IP is discussed in more detail in the sections on Products and Value Propositions, below (Section 2.3).

2.1.5 Human Capital

On the enterprise level, the availability of people with the required education to run the new company or new product is important. Expertise tends to focus in specific geographic areas (Silicon valley for IT, around Boston for biotech, Vancouver for mining, etc.). Studies have shown that companies that are not physically located near the centers of expertise (human capital) do not fare as well as those that are (Utterback reference).

For the enterprise, the new process should be sustained by the in-house expertise. It will be difficult to sustain a new product which requires primarily chemical technicians if the enterprise typically have electrical technicians on staff. An enterprise which manufactures products and ships them to clients, with sales and service only, will have a difficult time with a new product which requires engineering consulting as part of the value proposition. Some additional issues associated with human capital are discussed in Section 2.3 below.

2.1.6 Industry Structure and Value Propositions

A recent example of the importance of the industry structure comes from the automotive industry. A supplier developed a new high-tech dashboard – one that included a CD player, GPS, air bags, all in one complete unit. When they approached an auto company with this new product, they ran into problems with the purchasing departments. The department that purchased dashboards did not purchase GPS units, the department that purchased GPS units did not purchase CD players. The product has to fit somehow into the existing industry structure, or be prepared to include stakeholders early in the product development process to anticipate their needs (A. Fyke, pers. comm.).

The value proposition of the product is also key. Is the product a manufactured good, consulting services, equipment, process design, or some combination of these?

Industry structure and value proposition are discussed in detail in Section 2.3.

2.2 Industry Definition and Structure

This thesis is concerned with the development of new chemical processing products for which the purchaser or end user will be involved in some form of chemical processing. Specifically, this end user will be interested in separating or combining chemicals, with or without chemical reactions. The products under consideration are chemical processes rather than manufactured goods. Manufactured goods such as tankage, pumps, mixers, diffusers, etc. are required, but the product, the key intellectual property, is the process. This process is like a recipe – if you mix these chemicals together in these quantities, under these conditions of temperature and pressure, you will get this result.

Both the Standard Industrial Codes (SIC) and the North American Industry Classification System (NAICS) break the users (potential customers) into mining and manufacturing, with manufacturing further divided to include a number of industries. In general, then, the two broad industries of interest are the mining industry and the chemical processing industry (CPI, which includes bulk and specialty chemicals, pharmaceuticals, oil and gas, water and wastewater treatment, plastics, and biotechnology, among others). However, in addition there are some final customers in the area of wastewater treatment who are outside these traditional industries. Many other manufacturing industries have water discharges which require treatment for regulatory purposes. These industries may not employ chemical engineers who typically make process selection, and the purchasing decisions in these industries may be based on different criteria.

An overview of the industry structure is given in Figure 4.

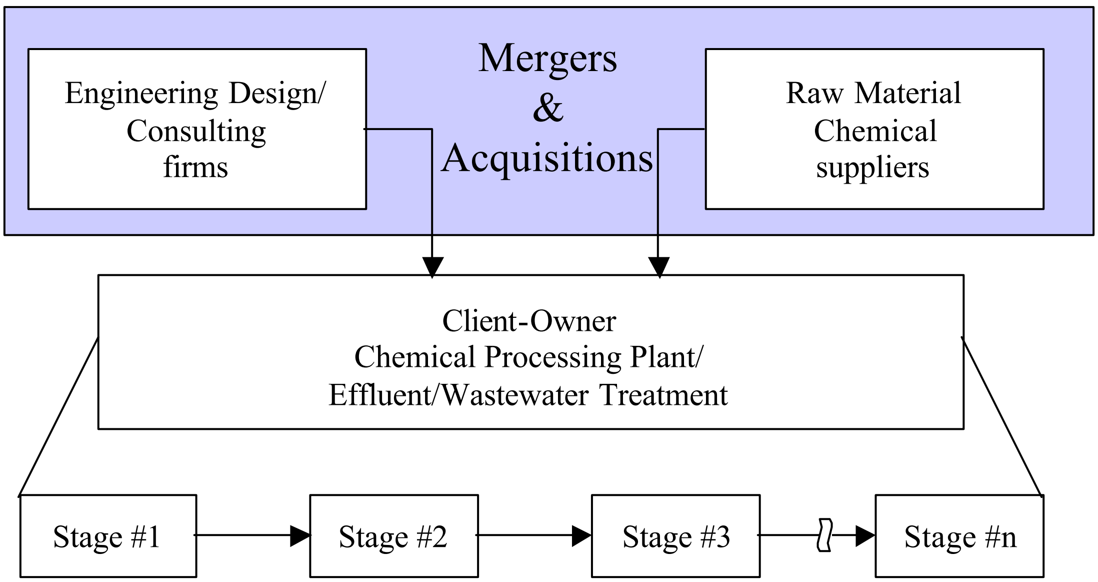

Figure 4. Indus try structure

When a new facility is being built, the engineering design, including the decision about which processes will be used, is completed by a design team. Some large companies have such design engineers in-house, while others will use the services of a consulting engineering company. Regardless, these teams will determine what process to use. In many cases there are very limited options. Once the facility design has been completed, these design engineers are no longer involved (although some designers may become part of the construction team). The facility is constructed, commissioned, and begins operation.

As shown in Figure 4, a chemical process and/or a wastewater treatment facility usually comprises a number of stages. A new process (product) will either be a complete series of these stages (for example, a new process to produce hydrogen from methane), or might include only one of these stages (for example, an oil-water separator).

In addition to the design engineers, there are companies which supply the raw materials used in the process. These chemicals are consumed during the process. This results in a continuous cash flow for the raw material provider, as opposed to a one-time fee obtained by the design engineers. Provision of treatment chemicals is a high margins business and often includes a service component. In the environmental industry, there has recently been M&A activity between plant engineering firms and chemicals suppliers. Many large chemical suppliers now have their own in-house engineering organizations. This gives these firms the opportunity to offer a larger menu of services where they can bundle services and provide a discount on plant engineering while retaining the high margin, long-term relationship for chemical supply.

When a new process is available on the market that has some advantages over an existing process, the facility owner may decide to replace the relevant stage in the process with the new process. This decision can come about for a number of cost reasons:

- lower maintenance costs
- lower raw materials or operating costs
- less waste produced, or lower waste disposal costs
- lower environmental liability due to waste, regardless of cost
- new regulations resulting in required changes (existing process cannot meet new regulatory standards)
- safer operation or use of less-hazardous chemicals or processes, often regardless of cost
- opportunities provided by the new process, for example if a usable by-product is produced

In these cases, the decision to evaluate a new process (potential purchaser for the new process) will be the facility operator.

For the company with a new process, it is important to understand the industry structure and other relevant factors to determine the best product offering and pricing model. These factors are discussed in the next section.

2.3 Products and Value Propositions

2.3.1 Manufactured Goods Supply - Zenon Environmental Inc.

Zenon Environmental Inc, based in Burlington, Ontario, Canada, was founded in 1980 and now has 17 offices in 11 countries. Revenues in 2001 were $124 million (CDN) and typical growth rates are over 20% (48% in 2001), with the current (March 2001) order backlog at $122 million. Founded by Dr. Benedek, previously a professor of chemical engineering, Zenon was created to commercialize membrane technology to treat water and wastewater. Membrane technology is a very specific water treatment technology, where water is passed through membranes with very small pores, which remove contaminants including bacteria and parasites. The company released its major technology in 1990, primarily for use in the municipal drinking water market.

Marketing is through regional sales and services offices, and through licensees in some jurisdictions. A typical water treatment system is sold for $2 million, and constructed over 6 months to two years. These large treatment systems are basically the same design, although there is some customization. (Wall Street Corporate Reporter, 2001).

Zenon consider their clients to be the municipalities and industries who will own and operate their membrane systems, regardless of the fact that the system might be designed by a consulting engineering company. These clients serve as models for other potential customers, and it is advertised throughout the industry when a municipality or industrial company choose a Zenon treatment plant. The use of case studies to promote the company is common in this industry, where the major players would have been asked for proposals and the winner selected in a competitive process.

For Zenon, the value is in their patent protected membranes. Zenon manufactures its membranes in Ontario, Canada. They sell the membranes as stand-alone goods (for systems designed by others), as well as "membrane systems" which include the related equipment (tankage, pumps, etc.). The membrane itself is reported to be the "competitive advantage" of the company [2], and higher margins are realized on membrane sales, although they realize additional revenues with the sales of the membrane systems. Typical margins are on the order of 35%

Since their value proposition is primarily based in their membrane product, a significant portion of the profits have been traditionally reinvested back into the company in the form of research and development, and growth infrastructure improvements. Membrane filtration was historically known as a high-cost water treatment technology, and only used where the obtainable purity was required. Zenon's investment in R&D has resulted in the development of a membrane which results in a system which is comparable in cost to other drinking water treatment competing technologies which do not deliver the additional purification of the membrane system, which likely explains the major company growth in the last few years.

Zenon also offer servicing to their clients, and the membrane lifecycle is approximately 10 years, after which they must be discarded and replaced.

Zenon has been funding the growth of the company in the traditional ways (public offerings, cash flow from operations and debt). They have also taken advantage of Canadian government Technology Partnerships Canada deferred technology credit, which has been used to develop and launch new membranes.

2.3.2 Process Design & Equipment - Noram Engineering and Constructors, Ltd.

Noram Engineering and Constructors, Ltd. (Noram) is a privately-held engineering firm founded in 1988 in Vancouver, British Columbia, Canada, which currently has approximately 100 employees. Since the firm is privately held, financial information is not available. In 1993 Noram became a major shareholder (1/3 ownership) in BC Research Inc., a contract R&D company and technology incubator, also located in Vancouver.

Noram develops and licenses process technologies and custom designed equipment worldwide for the chemical industry in three main business areas: production of nitric acid, production of sulphuric acid, and production of chemicals used in the pulp and paper industry. A recent acquisition has added an organic wastewater treatment technology to their process technologies, and a recent partnership shows them developing new electrochemical technologies. As a specific example of their product line:

> "Mononitrobenzene (MNB) is an important raw material in the production of polyurethane; a plastic used in many products and applications including automobiles, sports equipment, medical and aerospace systems. MNB, the first link in the polyurethane manufacturing chain, is converted to aniline, which is subsequently used to produce MDI. MDI is copolymerized with various polyols to form polyurethane. Since the introduction of its patented Electrophilic Reactor system in the late 1980s, Noram has become the world's leading supplier of

[2] Andrew Benedek, as interviewed in the Wall Street Corporate Reporter, December 3, 2001

> MNB plants. Today more than half of the world's polyurethane supply is produced from MNB manufactured in plants using Noram's patented process."[3]

As an engineering firm, Noram's clients are chemical manufacturers. Noram have developed over the years a number of specific process technologies, which they protect with US and European patents. The list of clients using technology developed by Noram includes many major players such as Monsanto, Rhone-Poulenc, Bayer and ICI (Newman, 1996).

Noram develops these technologies internally and through their access to BC Research Inc. Their value proposition is that they typically sell equipment and engineering packages to the end users' engineering and construction contractors. Since they are selling to the chemical industry, their purchasers have the technical expertise to take the design drawings and specifications in the engineering packages, order the equipment that might not be provided (off-the-shelf components, as opposed to process-specific components), and commission the facility. This value proposition results in a one-time fee, although process licensing fees can also be charged.

Noram has provided engineering, procurement and start-up services for specific projects, and is starting to add installation supervision, commissioning, operator training and project management to their initial services of process design & detailed engineering and equipment design and supply. With their most recent wastewater treatment acquisition, they are also offering on-going services which involve installation of some of the process monitoring equipment in Noram's Vancouver office so that Noram staff can assist customers with process troubleshooting.

As a privately-held company, Noram has been funding the growth internally, through project revenues.

2.3.3 Equipment Only – Hankin Atlas Ozone

Hankin Atlas Ozone manufacture and sell ozone generators for water and wastewater treatment. Ozone is more effective than chlorine for disinfecting water and removing organic contaminants. For example, Olympic-approved swimming pools must now have ozonation systems to purify the water instead of chlorination systems. Hankin is a privately-held company with offices in Canada, US and UK.

Hankin manufacture equipment that generates ozone, based on known technology. They produce a number of different sizes of generators, and these are purchased off-the-shelf by customers. If the customer needs some help determining the required size for their given treatment demand, then sales staff at Hankin can use a series of tables and charts to help the customer determine the best unit. However, if the ozone generator is to be used for an application outside of "standard" applications, or for some specific chemical need, then Hankin sales staff will put the customer in touch with a consulting engineer who can work with the customer on a fee-for-service basis to design the system using the Hankin equipment.

Hankin's profits come from the sale of the equipment and parts. They also provide servicing of their product. While Hankin will make some profit from the replacement parts, their value proposition is that the primary source of income will be from the sale of the units.

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[3] http://www.noram-eng.com/nitration.htm

2.3.4 Equipment (IP Protective) – Linde Group

There are primarily two ways to protect IP in these industries – patents and trade secrets. Trade secrets are challenging to protect, because once the product is sold it can be reverse engineered and copied.

The Linde Group had a unique way of protecting the technology inside their distillation columns. For certain specific processes, they were the only company who could design and construct a distillation column which could accomplish the required separation. Dow Chemical, Monsanto, and others in this industry all used this specific column from Linde, while all of their other separation equipment would have been custom designed by their own engineers. When these companies ordered a column from Linde, they specified the required flow rates, etc., and the column was delivered completely bolted up – the companies agreed not to open the column or to attempt to determine how it worked, for a set period of time. Thus Linde was able to protect the IP inside the column for the contract period, and was also able to secure maintenance agreements.

This type of business model would only be effective where the customer has limited or no options, because of the very restrictive contract requirements.

This model was encountered by the author in the early 1980s, but the Linde Group no longer seem to follow this model – they are primarily an engineering design and equipment supply company. They differ from Noram in that Noram design the chemical process and specify and supply the equipment for that design, while Linde design the equipment only, given the required inlet and outlet conditions. Noram would employ primarily chemical engineers, while Linde would employ primarily mechanical engineers.

2.3.5 Equipment and Parts – Printer and Cartridge Model (HP)

The printer and cartridge model refers to a business model followed by a variety of successful organizations in many industries, including Hewlett-Packard. The idea is to sell a relatively high-value item basic machine (the printer) at a low price while selling the consumable items (ink cartridges) associated with the machine at a high margin. This strategy does two things: locks-in customers and provides continuous cash flow from a high margin product.

The customer lock-in is created by the unique design of the printer (basic machine) and the cartridge (consumable item). By ensuring that the user will have to buy cartridges manufactured by the original machine manufacturer, the competition is kept out.

The continuous cash flow is generated when the customer runs out of ink and has to buy a new cartridge. Each cartridge does not cost too much so the customer does not feel that he is making a big purchase but he has to buy it quite frequently. Moreover, ink is basically a commodity but becomes a branded product by being enclosed in the cartridge and the seller can thus extract prices that are much higher than commodity prices. (Khan *et al*, 2002)

2.3.6 Sector-Limited Licenses – Millennium Pharmaceuticals Inc.

Millennium Pharmaceuticals Inc. started in 1993 with $8.5 million in venture capital funding, with a vision of using molecular biology coupled with automation and informatics to discover and process information about genes as potential targets for new drugs. This genomics-based approach reversed the traditional pharmaceutical process by first identifying and understanding the role of the gene in a disease and then selecting drug candidates based on their ability to target the root genetic basis of the illness. Their current market valuation is approximately $4 billion.

Using their technology platform, Millennium sought partnerships with drug companies. They granted select rights of high value to their partners, while retaining new knowledge and the remaining rights (Thomke and Nimgade, 1999). The most interesting of these partnership deals was with the agricultural arm of the large multi-national, Monsanto.

Millennium was focused on human therapeutics, while Monsanto was very interested in using biotech tools in its agricultural biotechnology. Through a technology transfer arrangement, Millennium agreed to replicate its technology platform in an agricultural setting and creating Cereon Genomics, a Monsanto subsidiary. The deal was structured such that Millennium received $118 million in an up-front fee and $20 million/year for 5 years on achievement of milestones that were set to be 80% achievable. Millennium achieved all milestones and was paid the full $218 million.

The value proposition in this specific deal is interesting because it provided a number of advantages to both players. Monsanto was one of the first to recognize the advantages that biotechnology and genomics advances could be used in their agricultural business, and this new technology put them ahead of their competition. In addition to the money it received for the technology, Millennium found that in the process of transferring the technology it was forced to more formally document its procedures, which was useful for them. Also when training the Cereon staff they sometimes found new techniques which could be used by Millennium. Millennium did not give up much in this deal, since it was not interested in the agribiotech industry and, in fact, needed to concentrate on human genomics. By selling the rights to their technology platform to Monsanto, they earned significant income while retaining the rights for their main business – human genomics.

2.3.7 Use of Equipment - Annapurna Conservation Area Project

In Nepal, the tourist trekking circuits are organized with the help of the government, NGOs and outside development monies. In these areas, tourist trekkers pay a fee to travel in the area, which covers infrastructure costs. All of the lodging and food prices and menus are standardized.

Into this business environment water treatment has recently been introduced. The Annapurna Conservation Area Project (ACAP) is a non-profit organization supported by various trusts and the fees collected from trekkers. ACAP has been responsible for getting a water purification business up and running for the Annapurna Circuit, Nepal's second busiest trek route (first is Kathmandu to Everest Base Camp). This route sees over 50,000 trekkers annually. Water Borne Technologies Ltd., of New Zealand have developed a small-scale water treatment system that purifies drinking water using ozone. This system can operate on DC power, and therefore can be used in remote locations in the Himalaya where there is no power. The units are serviced and supported under contract by a local company in Kathmandu. The units were purchased from Water Borne initially by ACAP, with money from the New Zealand Overseas Development Assistance Fund which funds the units as well as the training required for their operation.

Water treatment stations have been set up in local villages along the trekking circuit. The stations treat local surface waters for trekkers and local inhabitants on a per litre charge. It would be consistent with the existing business model on the Circuit that international trekkers would be charged substantially more than local inhabitants. Local women are employed to operate and run the water treatment. "Revenues generated firstly pay for the full cost of the equipment and are then used for local development projects as decided by individual communities."[4]

The value proposition for the operators and their communities is in the provision of the use of the equipment. The operators purchase the ozonation equipment and retain ownership of it. They have a fee-for-service model, where clients pay the operator to operate the equipment on behalf of the client.

2.3.8 Services in the Developing World – Multinationals

Most of the large multi-nationals rely on local service organizations to distribute and manage their treatment chemicals and process to customers in the developing world. Most large multi-nationals have licensing arrangements with service providers in various countries. The service providers provide the following functions:

- Identifying potential customers
- Establishing customer contact
- Obtaining and testing potential customer's effluent.
- Developing treatment solution in consultation with MNC
- Submitting bid and closing sales deal
- Providing customer service and maintaining customer relationship (including sale of consumables e.g. activated carbon, resins etc.)

(Khan *et al*, 2002)

3.0 CASE EXAMPLE – EFMB

3.1 The EFMB Technology

3.1.1 The Process

The IP held by EFMB is a process which uses biosorption to remove metals (the solute) from a solution (solvent). In this process, a liquid stream (typically water) which contains dissolved metal ions is contacted with a living or dead biomass in the presence of the electric circuit. The metals are sorbed into and onto the biomass, and therefore removed from the liquid solution. EFMB is currently conducting research to broaden the technology.

3.1.2 Adsorption

Sorption is a general term to encompass a number of processes such as adsorption, absorption, chemisorption. The process involves distribution of molecules between two phases.

Dealing with only solid-liquid sorption, adsorption is the diffusion of the molecules from the bulk of the liquid to the surface of a solid, forming a distinctly solid phase. Manufactured

[4] http://www.mpwr.co.nz/acap_safe_drinking_water_update.htm

adsorbents are highly porous, giving rise to a large internal surface. Absorption involves the diffusion of the solute from the bulk of the liquid to the bulk of the gas phase. Chemisorption is similar to adsorption with the exception that the solute chemically reacts with the surface. (Coulson and Richardson, 1990).

The mechanism of biosorption, ad/absorption onto a biological medium is less well studied than adsorption and absorption, although some of the principles are the same. A brief description of adsorption processes are provided here, for background.

Initially a single layer of molecules builds up over the surface of the solid, which may chemisorb to the surface. Second and third layers form, which are physically adsorbed. The number of layers which can build up is limited by the size of the pores in the sorbent. When the sorbent becomes saturated it cannot further adsorb the solute molecules. It must then be removed from service and either regenerated or disposed of. Ion exchange is a specific example of an adsorption process which is discussed further in the next section.

Much of the experimental data pertaining to adsorption represents equilibrium measurements, since the mechanisms are still not well understood. Data collected are plotted as adsorption isotherms, which show the apparent adsorption (wt. adsorbed/wt. adsorbent) versus the equilibrium concentration (lb solute/ft^3 solution).

Isotherms are generated by treating a known volume of solution with a known weight of adsorbent (*V* ft^3 solution/lb adsorbent). As the solute is preferentially adsorbed, the solute concentration of the liquid falls from the initial concentration to the final equilibrium value. The apparent adsorption can then be calculated (neglecting changes in volume):

$$\textbf{Apparent adsorption} = V(c_0 - c^*)$$

where: V = volume of solution/weight adsorbent, ft^3 solution/lb adsorbent

c_0 = initial solute concentration, lb solute/ft^3 liquid

c^* = equilibrium solute concentration, lb solute/ft^3 liquid

The apparent adsorption depends on the concentration of the solute, the temperature, the solvent and the type of adsorbent. (Treyball, 1968)

Commercially attractive adsorbents have the following features:

- be large internal surface area
- have pores big enough to admit the molecules to be adsorbed but small enough to exclude other molecules
- have the capability to be regenerated easily
- retain its adsorptive capacity through continual recycling (not age rapidly)
- have sufficient mechanical strength to withstand bulk handling and vibration

(Coulson and Richardson, 1990).

Adsorbent solids are usually used in granular form. They are usually very specific in their ability to adsorb certain molecules. (Treyball, 1968)

3.1.3 Applications

There are two primary markets for a technology which removes metals from a water stream – wastewater treatment and chemical processing. Water is extensively used in the chemical processing industry, the mining industry and in general manufacturing. Water which is taken into the facility from nearby surface water sources, or provided through local utility companies, is sometimes contaminated with metals in the process. These metals need to be removed prior to discharge of the water. This is accomplished in a wastewater treatment facility. The wastewater can be contaminated with a number of different chemicals, and wastewater treatment facilities can contain a number of unit operations such as clarification (to remove solids), settling (solids), oil/water separation (oils) and/or metals removal, and final polishing.

In chemical processing, which includes the mining industry, there are some very specific needs to separate ionic species. The EFMB technology might be able to accomplish some of these specific separations, and might find a market in this area.

Each of these potential markets is discussed below.

3.1.4 Wastewater treatment

The wastewater treatment industry is driven almost exclusively by the need for customers to meet regulatory requirements. Wastewater can be defined as water which has been used for something (usually in an industrial process, sometimes called effluent) and is no longer needed. In the industrial environment water comes into contact with some other chemical and gets contaminated with that chemical. There are three broad categories of these chemicals – organic, inorganic and nuclear. The EFMB technology can be used to remove some inorganic and nuclear ions.

Wastewater contaminated with inorganics is typically treated with technologies which remove the heavy and/or radioactive metals. The water is cleaned so it can be discharged, but the metals stay behind on something – differing technologies use different ways to trap the metals.

Industries install wastewater treatment in response to regulatory requirements. A secondary motivation might be to recover the metals for re-processing, but this is much less common because the high costs rarely result in their being an economic incentive to do so. Typically the treatment plant will be designed to meet the regulatory needs, and if metals can be recovered cost-effectively, this will be implemented.

Typically the treatment plant is operated as part of an industrial facility – part of the mine operation, or the chemical processing plant. These facilities are upgraded periodically, but a new one is not often built. Engineers in the company conduct optimization studies on the operation of these facilities, and there is on-going research with regard to various improvements – changes can be implemented in these large water treatment facilities. Facilities are typically custom designed. (Khan *et al*, 2002)

3.1.5 Chemical Processing

The process plant industry is another sector where EFMB's technology might find significant applications. In these industries, the EFMB technology might find application inside the processing plant, where the driving force will be cost savings and not regulations. There will also be effluent treatment opportunities. Some of the major industries located in the UK are: nuclear fuel processing, oil and gas production, petroleum refining, gas supply, electricity generation, steel, water & sewerage and food & drink industries. The challenge, however, might be that each one of these industries is effected by different forces so they all have different buying behaviors. (Khan *et al*, 2002)

3.2 The Competing Technologies

The main technologies used to separate metals from water or wastewater are shown in Table 1.

As indicated in Table 1, the EFMB technology would likely compete most closely with ion exchange resins. This technology removes metals by adsorption, and the metals remain on the resin, resulting in a waste disposal issue. The ion exchange resins are typically regenerated as part of the process, resulting in a liquid waste which is concentrated in metals. These can be recovered, if this is cost effective, or disposal must be arranged. The EFMB technology has not yet been developed to the stage where waste disposal has been finalized, but the technology will have to meet the same regulations. It also might compete with the use of electrodialysis, which removes metals through the use of an electric current and membranes.

In ion exchange, the dissolved ion is removed from the solvent (usually water) by adsorbing onto the surface of the resin (and releasing another ion from that site). In membrane processes, the dissolved ion is separated from the solvent because the solution is put in contact with a membrane which will selectively let the dissolved ion pass through. Semipermeable membranes are selective to specific species. The size of the openings in the membrane, as well as the charge, shape and size of the ion are the important parameters which determine the effectiveness of the process. Each of these technologies is discussed separately.

Table 1. Competing Technologies (based on Metcalf and Eddy, Inc., 1991)

TECHN-OLOGY	TYPE	DETAILS	ADVANTAGES	DISADVANTAGES	WASTE
Physical	Precipitation /Settling		inexpensive	only effective for particulates	solid sludge
	Filtration		inexpensive	only effective for particulates	solid filter cake
Chemical	Chemical Precipitation	alum, lime, iron salts, organic polymers	reasonably inexpensive	may be incompatible with anaerobic digestion of organics (if required), increased solids, increased and more toxic sludge	solid sludge
	Neutralization (used in mining)	lime, soda ash, caustic	very inexpensive, no power required		sludge (in mining is used as backfill)
	Evaporation (used in mining)	passive	no cost, no power required	large area required, climate dependent	concentrated sludge (process used only in mining)
	Adsorption/ Absorption	ion exchange	removes anions and cations	tends to plug if particulates, residual organics bind to resins reducing effectiveness	concentrated liquid from backwash for disposal
		EFMB	removes anions and cations	bench scale	contaminated solids or backwash
	Ultra-Filtration	low pressure membranes	removes colour	normally used for colloids and larger molecules	backwash (concentrated liquid)
	Reverse Osmosis (Hyper-Filtration)	high pressure membranes	removes dissolved salts	high cost	backwash (concentrated liquid)
	Electro-Dialysis	semi-permeable membranes + electric current	removes anions and cations	precipitation of salts	concentrated liquid solution
		EFMB	removes anions and cations	bench scale	contaminated solids or backwash
Biological	Natural Systems (used in mining)	wetlands	take up metals into plants	need lots of space	plants with high concentrations of metals
	Engineered Systems	biological	common treatment process	likely only effective if metals bound to organics	solid sludge

3.2.1 Ion Exchange

Theoretical background

Ion exchange is the term used for the unit operation which does literally that – ions (charged particles) are exchanged between an immobile phase (solid or a gel) and a liquid which surrounds it.

An example reaction is that of water softening which removes calcium ions from solution. The reaction can be written as:

$$\mathbf{Ca^{++} + 2Cl^{-} + 2Na^{+}\,R_c^{-} = 2Na^{+} + 2Cl^{-} + Ca^{++}(R_c^{-})_2}$$

This reaction describes a water solution which is "hard", meaning that it contains calcium chloride, CaCl. When CaCl is dissolved in water, it takes its ionic form, where the ions Ca^{++} and Cl^{-} are in the solution. In the reaction shown above, the resin R_c^{-} has a negative charge and has sodium ions (Na^{+}) on the resin. As the resin is contacted with the solution, the Na^{+} ions are replaced on the resin by the Ca^{++} ions, resulting in a solution which contains the resin (now with Ca^{++} ions attached) and salt water (Na^+ and Cl^- forms NaCl, table salt).

The general form of the equation is (Coulson and Richardson, 1990).:

$$\nu_B C_A + \nu_A C_{SB}(R_c)_{\nu B} = \nu_A C_B + \nu_B C_{SA}(R_c)_{\nu A}$$

Where: ν_A = valency of ion A in solution

ν_B = valency of ion B on a cationic resin

C_A = concentration of ion A in solution

C_B = concentration of ion B in solution

C_{SA} = concentration of ion A on the resin

C_{SB} = concentration of ion B on the resin

The thermodynamic equilibrium constant K is calculated (including the activity coefficients γ) as follows:

$$K = \frac{(\gamma_B C_B)^{\nu_A} (\gamma_{SA} C_{SA})^{\nu_B}}{(\gamma_A C_A)^{\nu_B} (\gamma_{SB} C_{SB})^{\nu_A}} = \frac{(\gamma_B)^{\nu_A} (\gamma_{SA})^{\nu_B}}{(\gamma_A)^{\nu_B} (\gamma_{SB})^{\nu_A}} K_C$$

K_c is used as a measure of preference of an ion exchange resin for one ionic species over another. It is calculated as:

$$K_C = \frac{(C_B)^{\nu_A} (C_{SA})^{\nu_B}}{(C_A)^{\nu_B} (C_{SB})^{\nu_A}}$$

$$= \frac{(y_A / x_A)^{\nu_B}}{(y_B / x_B)^{\nu_A}} \left(\frac{C_0}{C_{S\infty}} \right)^{\nu_A - \nu_B}$$

Where: C_0 = total ionic strength of the solution

$C_{S\infty}$ = exchangeable capacity of the resin

When K_c is greater than 1, the ion exchange resin takes up ion A in preference to ion B (Coulson and Richardson, 1990).

Another important performance metric is the separation factor, α

$$\alpha_B^A = \frac{(y_A / x_A)}{(y_B / x_B)}$$

Equilibrium relationships are plotted as y versus x diagrams, and those curves which are concave to the concentration axis for the mobile phase are termed favourable[5]

Equipment

Ion exchange resins are typically small, round and bead-like. The most common ion exchange unit operation is done in a continuous downward flow fixed bed column. The column has a screen near the bottom which acts as a support for the resin bed and a liquid distributor. The resin bed is typically 1 metre or more of resin beads or particles, ranging from 0.7 to 2 metres in typical wastewater applications (Metcalf and Eddy, 1991). Above that is the inlet liquid distributor, which ensures that the incoming liquid (at the top of the column) is distributed evenly across the column. Ion exchange in the wastewater treatment industry is typically used for flow rate ranges of 0.205 to 0.407 $m^3/m^2 \cdot min$ (Metcalf and Eddy). The column is typically pressurized, and may be lined depending on the liquids to be treated. If removal of both anions and cations is required, there are often two beds in series.

There are always at least two columns or series of columns in parallel equipped with piping and valves so that the incoming flow can be directed to one column or the other. When one bed is spent (the resin can no longer exchange ions with the incoming solution), the flow is switched to the other bed, and the spent bed is backwashed and regenerated.

Backwashing is typically done from the bottom of the column, counter-current to the regular flow. The column is first backwashed to remove any particles and to re-distribute the resin bed to remove any flow channels which might have developed. Backwash water may contain grit and particles, and low concentrations of contaminants, and is usually sent for treatment before disposal. After the column has been backwash, the resin is regenerated by running a regenerant solution through it. This solution is concentrated in the ions which have been removed from the resin bed, and by passing it through the bed, the ions which were removed from the inlet stream are now removed from the resin bed, and the original ions replaced. This results in a waste liquid stream which is very concentrated in the ions which were removed from the original solution, and this waste stream requires further processing or disposal. Once the bed is regenerated, it is rinsed of excess regenerant, and available for use when the other bed needs to be regenerated.

The equipment for this system is purchased once by the user, but resins are replaced on a more regular schedule. While the resins can be regenerated, eventually they lose this capacity and replacement is required. In addition, the resin particles will break down due to vibration and abrasion. The resin replacement cycle depends on the use factors and the resin itself, and can vary from a year to many years.

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[5] Coulson and Richardson. 1990. "Chemical Engineering Volume 2 – Particle Technology & Separation Processes", Butterworth Heinemann, Oxford, p826.

Design considerations

The design of the ion exchange column depends on the required flow rate, the size of the batch to be treated between regenerations, and the capacity of the resin under the operating conditions. The flow rate determines the minimum and maximum diameter, based on hydrodynamics. The depth of the resin bed is based on the required resin volume (which is based on the required separation), although there are minimum theoretical bed depths which are based on engineering constraints (it is more difficult to distribute the inflowing liquid across a shallow, wide area and ensure sufficient contact time).

In order to size the ion exchange equipment, it is necessary to have a complete analysis of the influent stream. In addition, the resin capacity must be known, as described in the section above. For many commercially available resins there are data in the literature and sales brochures. However, these data may not be sufficient for a specific application. For any process that has not been proven in a similar plants under similar conditions, laboratory and pilot plant work are recommended to determine the resin capacities, regenerant quantities, resin life and product quality (meets desired outlet conditions). It is usually feasible to scale up from results obtained in columns with 25 to 50 mm diameters. (Perry, 1984)

Operating parameters and costs

Ion exchange resins are designed to remove certain types of ions. Resins are chosen based on the specific resin selectivity and the concentration of the solute in the solution.

An important measure of resin capability is the exchange capacity, which can be measured through a simple procedure involving titration. The procedure is:[6]

1. Regenerate the resin with the appropriate acid or base.
2. Rinse the resin with distilled water or water that does not contain any ions that are exchangeable with the resin. This water may be prepared by passing it through an active resin. The rinse will remove any excess regenerating agent in the resin column.
3. Measure the resin volume
4. Titrate the resin with base or acid, as appropriate.

The exchange capacity of the resin is calculated from:

$$\textbf{Exchange capacity} = \mathbf{N_t V_t / (volume\ of\ resin)}$$

Where: $\mathbf{N_t}$ is the normality of the titrant

$\mathbf{V_t}$ is the volume of titrant used

[6] Droste, Ronald E. 1997. "Theory and Practice of Water and Wastewater Treatment", Wiley, New York, p478

The total exchange capacities for a number of commercial resins are reported to have ranged from 2.5 to 4.9 meq/g resin on a dry-weight basis, or 1.0 to 4.0 meq/mL on a volumentric basis (Droste, 1997). Perry (2002) lists a number of common ion exchange resin types and their shape, bulk wet density, moisture content, swelling due to exchange, maximum operating temperature, operating pH range and their exchange capacity on dry and wet basis. These are the important parameters for resin selection.

Downing (1965) and Prater (1960) offer formulae, nomograms and graphs for sizing and pricing ion exchange equipment. The results of these preliminary cost estimates must be corrected for inflation, most usefully using the Marshall and Stevens index which is published in *Chemical Engineering*) (Perry, 1984).

Cation exchangers range between $2100 and $3900/m3 ($60 – 110/ft3). The average price of anion exchangers is about three times higher than that of cation exchangers. Anion-exchange resin production requires more steps than cation exchangers, and the chemicals used in production of anion exchangers are more expensive. Replacement sales have become an ever increasing percentage of total sales.[7]

Primary uses

The primary uses of ion exchange, in order of most common, are provided in Table 2.

Table 2. Industrial uses of ion exchange resins (Kirk – Othmer, 2002)

INDUSTRY	USE
Water treatment	Softening, deionization, dealkylation, nitrate removal, condensate polishing, boron removal
Food processing	Removing organic and inorganic impurities from sucrose, deacidification of fruit juice, removal of acidity and potassium bitartrate in wine
Pharmaceutical	Removal of impurities in antibiotic production,
Catalysts	Substitute for catalysts
Chemical purification	Iron from hydrochloric acid, divalent cations from NaCl solutions,
Metal processing	Removal of impurities from plating, etching, anodizing, pickling, and galvanizing baths
Hydrometallurgy	Recovery of uranium from sulphuric acid leaching and bicarbonate leaching solutions (no longer much used due to downturn in uranium market)
Waste treatment	Removal of numerous toxic metals from wastewater
Gas adsorption	Few commercial uses
Analytical	Used in ion chromatography

[7] Kirk – Othmer Encyclopedia of Chemical Technology, on-line version (subscription only), Ion Exchange Section, Economic Aspects subsection

3.2.2 Electro-dialysis

Theoretical background

The use of membranes to separate ionic species can be accomplished under the driving force of pressure, electrical potential or concentration gradient. Electrodialysis is a form of membrane process where application of an electric current is used to enhance the separation. An important application of membrane technology in wastewater treatment is in the recovery of precious metals (Droste, 1997).

Membrane separation is a mass transfer phenomenon. A concentration gradient between the stream to be treated on one side of the membrane, and another liquid on the other side of the membrane is one of the driving forces. In electrodialysis, the application of the electric current provides an additional driving force. A voltage is created across an anode and a cathode, and membranes that are selective to the anion or cation to be removed are inserted between the anode and the cathode. When the current is applied, the ions migrate through the membrane to the electrode with the opposite charge. (Droste, 1997).

Electric current is carried through the system by the anions and cations. **t** is the transference number, the fraction of the total current carried by a given ion. The anion transference number is denoted by $\mathbf{t}^-$ and the cation transference number by $\mathbf{t}^+$. The transference number of anions through the anion membrane is denoted as $\mathbf{t_m}^-$, and of anions through the solution as $\mathbf{t_s}^-$.

If $\mathbf{t_s}^-$ is 0.5 and $\mathbf{t_m}^-$ is 1.0, then half as many ions will be transferred through the solution to the side of the membrane that the anions enter as will be transferred through the membrane. The solution at the membrane interface (in the boundary layer) will be depleted of anions, because more anions will transfer through the membrane than can get there through the solution. The other side of the membrane will accumulate anions, and the same effects can happen with the cations at the cation exchange membrane. In practical situations, $\mathbf{t^m} \geq 0.9$. This is shown in Figure 5.

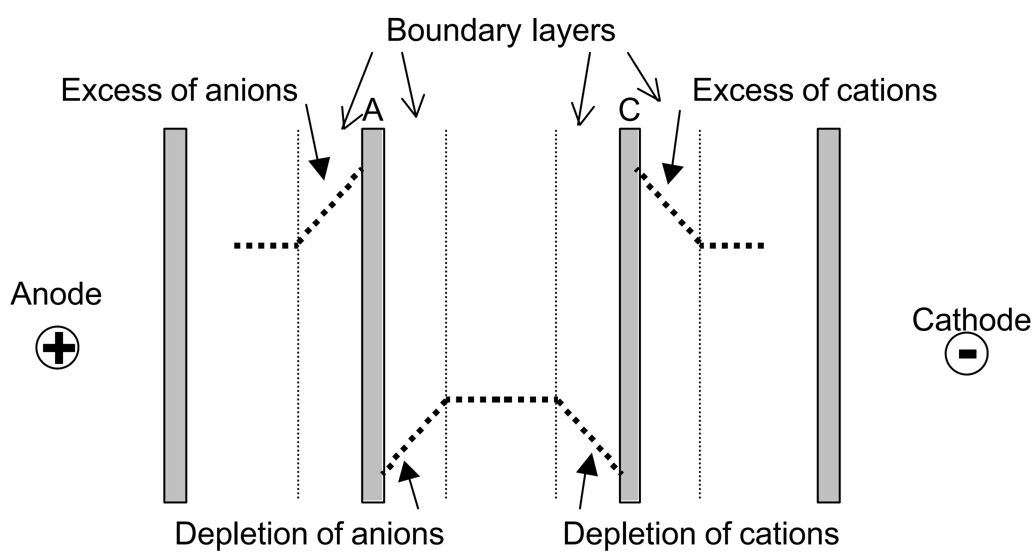

Figure 5. Schematic representation of concentration polarisation with demineralisation of central compartment (Coulson and Richardson)

The limiting current density is reached when the concentration of electrolytes at the membrane interfaces on the depleting sides approach zero. At this point, H^+ and OH^- ions from the ionization of the water (assuming a water solvent) begin to transfer through the membrane, causing a loss of efficiency, and can cause membrane fouling (Coulson and Richardson, 1990).

For an ideal situation, where the bulk of the liquid is completely mixed and the boundary layers are completely static, the polarisation parameter is defined as:

$$\frac{i_{\mathrm{lim}}}{zC_i} = \frac{D\mathrm{F}}{l(\mathrm{t_m} - \mathrm{t_s})}$$

Where: i_{lim} = limiting current density

D = diffusion coefficient

F = Faraday's constant

l = equivalent film thickness

C_i = ion concentration (kmol/m3)

$\mathbf{t_m}$ = transference number in the membrane

$\mathbf{t_s}$ = transference number in the solution

The value of i_{lim} is determined by the discontinuity noted when cell current is plotted versus applied cell voltage, and it occurs when the concentration at the interface approaches zero. The polarisation parameter is useful for scale-up, since it can easily be measured in small-scale stacks and a given bulk concentration and then used to predict limiting current density in larger stacks at other concentrations. Most commercial stacks operate with polarisation parameters between 50 and 70% of the limiting values. (Coulson and Richardson, 1990)

Equipment

Membrane stacks are a series of cation exchange membranes alternated with anion exchange membranes in a parallel array to form solution compartments. In ion exchange systems, membranes are highly swollen gels containing polymers with a fixed ionic charge (Perry, 2002). The anode and cathode form the ends of each stack, one on each end. The solution compartments are typically approximately 1 mm thick, and a single membrane stack will typically contain 100-400 membranes, each with an area of approximately 0.5-2.0 mm^2. The inlet solution is fed into each of the compartments. There are two outlet streams, one which is rich in the ion of interest, and one from which this ion has been removed. (Coulson and Richardson, 1990).

In addition to the membrane stack, there are peripheral equipment requirements such as power supply, pumps, instrumentation, and tanks, among other needs. Safety devices are mandatory because of the potential dangers of electricity and hydrogen (which can be produced in the membrane stack). The inlet water is usually pre-treated to remove particulates, which otherwise would clog membrane pores. (Perry, 2002).

Operating parameters and costs

"Typical DC voltages are ~ 0.5–1 volt per cell pair. Assuming an overall current efficiency of 90% this implies a DC electrical energy requirement of ~ 15 – 30 W · h/g · eq of electrolyte transferred. To this must be added the energy consumption of auxiliary equipment such as pumps and instrumentation, about 500 W · h/m^3, and energy losses during conversion of AC to DC. In the case of relatively concentrated electrolytes, for economic reasons, designers tend to choose DC voltages per cell pair from the low end of the range mentioned above."[8]

An example of typical unit costs is provided in Perry (2002). Operating costs for a unit which produces 1000 m^3 treated water are:

- $66 membrane replacement costs
- $32 power
- $16 filters and pretreatment chemicals
- $11 labou4
- $ 8 maintenance

for a total cost of $133 to provide 1000 m^3 treated water.

Primary uses

The primary uses of electro-dialysis are provided in Table 3.

Table 3. Industrial uses of electro-dialysis (Kirk – Othmer, 2002)

INDUSTRY	USE
High Purity Water	Production of pure and ultrapure water for use in high pressure boilers, and manufacture of electronics and pharmaceuticals
Desalination	Removal of salts from brackish water to produce potable water
Production of salt	Concentration of sea water to produce salt, although industrial applications are not justified on economic grounds
Industrial wastes	concentration of blowdown from cooling towers in power plants; concentration of reverse osmosis blowdown; and the processing of metal treatment wastes
Electrodeionization	Production of demineralized water, process is just starting to find commercial application
Miscellaneous	The largest miscellaneous application of electrodialysis is the demineralization of whey and nonfat milk for food and feed applications. Other applications include recovery of valuable components from metal plating or treating effluents

[8] Kirk – Othmer Encyclopedia of Chemical Technology, on-line version (subscription only), Electrodialysis Section, Apparatus subsection

3.3 Economy and Access to Financing

Northern Ireland is the fastest growing regional economy in the UK. The GDP per capita in Northern Ireland has increased by nearly 71% since 1989. Northern Ireland will record growth of 3.4% in 2002, ahead of the UK average of 2.6% according to a leading economic consultancy. Business strategies also predict Northern Ireland will be the UKs number one growth spot in 2002. Since 1997 and the Good Friday Agreement (1998 Peace agreement), manufacturing output has increased by almost 30% in Northern Ireland, compared to an increase of only 3% for the UK. Industrial production in Northern Ireland increased by nearly 17% throughout the 1990s, compared with 11.7% for the UK and 4.3% for the European Union.

Northern Ireland has the lowest cost of living in all the UK regions. Unemployment in Northern Ireland is 5.9%, the lowest ever recorded, and well below the European Union average of 8.1%. Total employment in Northern Ireland is expected to grow faster between 2001 and 2010 than the UK as a whole in each of these years. This growth rate is expected to result in an extra 40,000 jobs by the end of the decade.

Much of the funding for new enterprise in Northern Ireland is provided by funding from various government sources. The Department of Trade and Industry (DTI) in Northern Ireland support new ideas through the SMART Scheme. This is open to individuals and independent small businesses to carry out feasibility studies on innovative technologies. The core government programs for entrepreneurship are START and COMPETE, which provide funding for early-stage research through prototype production.

Between 1992 and 1997 UK venture capital investment rose by 145% from £1.25 billion to £3.07 billion; over the same period venture capital investment in Northern Ireland fell by 28% from £28m to £20m. Seventy-five percent of venture capital investment in Northern Ireland is in seed, start-up and early stage entrepreneurial businesses - higher than in other regions of the UK. Nevertheless, in 1997 the region still had 60% less venture capital investment of this type than expected. Some academics believe the continued deficit in venture capital investment in Northern Ireland is a constraint on the development of a dynamic entrepreneurial economy.

Until recently Northern Ireland had few locally-managed sources of venture capital. The absence of a local supply of venture capital has been a major constraint on investment in the region. This is changing, and there are new venture capital companies operating in the region. In addition, there has traditionally been a limited pool of 'deal makers' - business professionals (accountants, corporate financiers, and legal experts) - with extensive experience of putting together venture capital deals for clients.

Many businesses in the region are not seeking venture capital because they have low growth aspirations, are unwilling to share ownership of the business with an outside investor, have become used to relying on 'free' or subsidized capital from government sources, or are not sufficiently well prepared to convince a venture capitalist to invest. Simply increasing the availability of venture capital finance will not make a major difference to the development of an entrepreneurial economy. The entrepreneurs have to understand fully the needs of venture capitalists and how to prepare a winning business plan. In addition, the entrepreneurs need to understand how a venture capitalist can help the company grow through the contacts and other non-financial resources it can provide.

Various surveys have shown that venture capital funds are unique in that they provide both financing and experience to companies in which they invest, which helps the company to grow and develop more quickly and successfully than other types of companies. Northern Ireland has not yet enjoyed its pro-rata share of the UK's venture capital activity as the associated chart shows. It has been suggested in some studies that if Northern Ireland had obtained its 'fair share', venture capital investment in the region would have been £95 million in 1997.

3.4 Regional/National Support and Stability

The legislatures of Great Britain and Ireland were united in 1801, and the country officially adopted the name United Kingdom of Great Britain and Ireland. In 1921 Ireland was partitioned with the six northern Irish counties remaining part of the United Kingdom (now called the United Kingdom of Great Britain and Northern Ireland), and the formation of the Republic of Ireland (the remaining majority of the island of Ireland) (CIA factbook, 2002). Since that time there has been conflict in Northern Ireland between parties which believe that the island of Ireland should be one country, and those who want Northern Ireland to remain part of the UK. A historic peace agreement was signed on 10 April 1998 (Good Friday Agreement), and the conflict has decreased substantially since then. However there are still outbreaks of violence.

EFMB have the advantage of support from both the University of Ulster and the University of Ulster Science Research Parks (UUSRP Limited).

Because of its academic ties with the University of Ulster and its stake in EFMB, the company have access to the research and library facilities at the University of Ulster, Coleraine, and, through those ties, to other universities. In addition to the advantages of the infrastructure at the university, EFMB have access to a peer group of technical experts, for informal discussion and support.

UUSRP Limited operate a Science Research Park at Coleraine. Because of their involvement in the company, EFMB have access to facilities such as offices, conference rooms, and other such business infrastructure that they might need. The Science Research Park at Coleraine has just recently opened; however, as more companies move into the facility EFMB will have access to a peer group of other business entrepreneurs, which may also prove valuable.

The University of Ulster has campuses located in Belfast, Jordanstown, McGee and Coleraine. The University has the following faculties – Arts, Business, Engineering, Informatics, Life and Health Sciences and Social Sciences. While many of these faculties are spread across the campuses, there are some areas of specific focus: Life and Health sciences (EFMB origin) is at the Coleraine campus, and Engineering is primarily at the Jordanstown campus about an hour away.

3.5 Regulatory Regime

Most environmental standards and regulations inside the European Union are governed by the Directives and Regulations of the EU. Implementation of these regulations is enforced by local authorities in the member countries, and member countries in some cases have additional or more stringent regulations. Both solid and liquid (water) wastes are covered in the EU standards.

Because of this structure, effluent discharge characteristics (concentration of the various metals) should be standard throughout the EU. A more in-depth study of these regulations or a consultation with a local consultant could provide details about how these regulations are interpreted and enforced locally. The regulations themselves are quite complex. However, the fact that they are common for the EU is of benefit to EFMB, since this opens up the whole of the EU to a product designed for a specific application.

Disposal of the solid wastes from the EFMB process is also regulated inside the EU. If the resulting solid waste is classified as a hazardous waste (called Special Waste in Northern Ireland), then disposal at a hazardous waste facility will be required. There are very few permitted hazardous waste facilities in either the Republic of Ireland or Northern Ireland, and most hazardous waste on the island is exported through any of a number of brokerage services. Disposal of hazardous waste is more expensive than disposal to a local landfill, which would be permitted if the waste is not classified as hazardous. In Northern Ireland, landfill costs range from £20-40/ton + £13/ton tax. One of the few landfills in Northern Ireland that is permitted to handle special waste charges £100/ton + £12/ton tax. VAT is also charge on both regular and special waste total cost.

Wastes are classified as hazardous if they meet any one of a number of criteria. Solid waste can be hazardous if it contains metals above a certain concentration (concentration depends on the metal), regardless of whether the metal is bound to a substrate. If the concentration of the metal is below this regulated concentration, the waste might still be classified as hazardous if the metal can be made to leach from the substrate in specified tests. Again, these regulations are quite complex and consultation in this matter should be sought as the capabilities of the technology and resulting waste products are more firmly established.

3.6 Protection of Intellectual Property/Rights

The United Kingdom is a member of the European Patent Office (EPO). The EPO with its headquarters in Munich, Germany, officially came into existence in 1977 when ten European states banded together to form the EPO. It is regulated by a treaty known as the European Patent Convention (EPC). The EPO is very successful with about 100,000 patent applications currently being filed each year. In the biotech industry, patent protection is a very important consideration, due to the high initial investment costs. Protection from competitors for a period of time is necessary to be able to recover the investment costs. There are certain pitfalls in Europe with respect to the subject matter which can be protected and in European concepts of new matter. The procedure before the European Patent Office is different than that found in the United States. It is also much more expensive to file a European patent application than it is to file a similar U.S. application, yet the benefits of filing patent applications at the European Patent Office for most inventions outweighs (i) the costs of filing multiple independent applications before national patent offices and (ii) the pitfalls noted above.

Of the 142,942 patents applications made to the EPO in 2000, 4.3% of them came from the United Kingdom (GB in the chart). The growth in patent applications in Europe shows that biochemistry is second only to computing from 1999 to 2000. The United Kingdom is also a signatory to the Patent Co-Operation Treaty, administered by the World Intellectual Property Organization, a UN agency.

3.7 Human Capital

Northern Ireland comprises the six northeastern counties of the island of Ireland. It is part of the UK and, as such, is within the European Union of 373 million consumers. The region has a population of 1.7 million and 46% of the people are under 30 years old. The education system places a strong focus on mathematics and information technology and it has consistently out-performed the rest of the UK with over 60% of all high school graduates going on to universities or colleges that specialize in technical skills.

Northern Ireland has one of Europe's youngest populations - nearly 60% of the region's 1.7 million residents are under the age of 39. The workforce numbers 1,021,000 and about 40 percent of this employed population is young, educated, and under the age of 25, compared to 15% for the UK. (Khan *et al*, 2002)

At present EFMB is considering its staffing needs. The decision about the EFMB value proposition and product offering will determine the staffing needs in the short term.

3.8 Industry Structure

Two major trends of the environmental industry that are likely to continue for some time in the future are the consolidation of major companies through mergers and acquisitions (M&A) and a trend towards privatization. The failure of Enron was a major shock for the private water utilities in the US but this does not seem likely to change the trend towards privatization. Private systems probably will demand single-source supply and consulting companies.

Several large US-based companies have been acquired by French companies. Vivendi (the world's largest water company) bought US filters, and Suez Lyonnaise (world's second largest water company) bought Nalco chemical, United Water Resources and Calgon Corporation. There is also significant M&A activity in the water utilities in the US. (Khan *et al*, 2002).

3.9 Current Industry Value Propositions

Another trend in the environmental protection industry is expansion of services. The contaminated sites industry in the West is a sunset industry – the sins of the past have been cleaned up and the regulations are in place to ensure that there are no such problems in the future. Consequently, companies in this area looking to other markets for their products and services. Some companies have done this through mergers and acquisitions (described above) and some by internal R&D. There is a definite trend for suppliers to offer "complete solutions" rather than parts of a system. For example, Calgon Carbon, one of the world's best known suppliers of activated carbon (from household sink units to large industrial units) now also offer ion exchange and some other technologies in their "Solutions for Industry" portfolio.

Although the trend towards consolidation is continuing, there is an important role for the small and medium size companies. These firms can offer more customized services and are not subject to the bureaucratic processes inherent in larger organizations. (Khan, *et al*, 2002).

4.0 PRODUCT DEVELOPMENT PROCESS

4.1 Generic System-Level Framework

The thesis of this work is that in order to answer the question "What is the product?", the following system-level factors should be taken into consideration:

- economy and access to financing
- regional/national support and stability;
- regulatory regime
- protection of intellectual property/rights
- human capital
- industry structure
- industry value propositions

These factors should be evaluated inside a standard SWOT analysis framework, where the strengths and weakness of the enterprise are compared with the opportunities and threats posed by the marketplace.

This system-level framework is applied to the EFMB case, as an example, below.

4.2 Case Study – as applied to EFMB

4.2.1 Economy and Access to Financing

Economy and exports

In 2000 the UK expenditure on process plant equipment as estimated by Key Note Ltd. (2000) was 5.13 billion. This includes manufacturers of equipment, ranging from larger items of plant (such as distillation columns, evaporators, pressure vessels and dryers); to smaller items (such as pipework components, pumps, filters and valves); to control gear items (such as sensors, instrumentation and control computers). The main end users for process plant include chemicals, pharmaceuticals and biotechnology product manufacturers etc.

A report to the Directorate-General for the Environment on the EU eco-industry's export potential concludes that there is considerable scope for export to developing countries (European Commission, 1999). This report cites forecasted expansion on environmental markets in Central and Eastern Europe, SE Asia, China and South America. The growth will depend on economic circumstances and availability of investment finance, but is expected to come in the areas of water, waste, resource management and energy infrastructures, environmental pollution control and more sophisticated environmental technologies and services.

The same report finds that export to developed nations are more limited, due to the fact that these countries, particularly the US, already have a well-developed industry in the environmental sector. Technologies developed for this sector must have a significant value proposition to entice clients to switch from well-known technologies to a newer technology, since the wastewater treatment industry is quite conservative.

Access to financing

The Industrial Research and Technology Unit, an agency within the Department of Enterprise, Trade and Investment for Northern Ireland, has as its stated role the encouragement and support local companies to become more competitive through innovation and investment in industrial research and development. They offer two programs which might be useful for EFMB – START and COMPETE.

The START programme offers financial assistance for technology-based, industrially focused, pre-competitive research and development. Discretionary investment support is provided to the successful companies, normally not exceeding 40% of project costs, up to a maximum level of £2 million per project over a three-year time period.

COMPETE supports market-led innovative products and manufacturing processes. The programme has two parts, Phase I (Project Definition) and Phase II (Project Development). Phase I is optional and provides a maximum grant of £15,000. Phase II projects can receive funding assistance of up to £250,000 total per project (i.e. £250,000 less any Phase I assistance).

These funding initiatives encourage companies which are developing technology-based, industrially focused products and manufacturing process. If EFMB were to need to access this funding, it would limit the value proposition to those where goods or equipment are produced, since this type of funding could not be used for setting up a consulting or process design firm, for example. For other reasons, it is unlikely that EFMB would find their best value proposition in the provision of services only (discussed below), so access to these government sources of support will probably be feasible.

4.2.2 Regional/National Support and Stability

The fact that EFMB is located at the University of Ulster and has access to the Science Research Park are both advantages. These facilities should provide the company with access to both scientific and business peers.

The entry of both the UK and the Republic of Ireland into the European Union has had a significant impact on the relationship between the counties in Northern Ireland, where EFMB is based, and the Republic of Ireland. Both Northern Ireland and the Republic of Ireland have benefited economically from membership of the EU. From 1989 through 1993, the EU contributed £600 million to Northern Ireland, which is still very small compared to the £2.4 billion which was typically transferred each year from the UK (Ingraham).

“Since funding will inevitably decrease, the status of North / South relations in a European context faces some uncertainty. Commenting on the "chiefly economic" benefits of EU membership, Peter Bell of the Northern Ireland Office concluded it was doubtful the EU "could play a significant political role in the Province for the time being" (Bell, 1993; p32). Although economic benefits will decrease in the future, European integrationists believe it will be EU structures which help transform relationships between Northern Ireland and the Republic of Ireland.”[9]

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[9] Ingraham, Jeson. 1998. “The European Union and Relationships Within Ireland”, INitiative on Conflict Resolution and Ethnicity (INCORE), http://cain.ulst.ac.uk/issues/europe/euireland.htm

The trading relationships between Northern Ireland and the Republic have been traditionally poor. In the last 40 years, the Republic has been continuously decreasing its trade with the UK, while Northern Ireland historically is heavily dependent on trade with the rest of the UK and very little with the Republic. Efforts are being made to increase trade between these two areas, in part due to their membership in the EU and in part locally. The ending of economic custom controls between Northern Ireland and the Republic is part of this initiative, which should encourage trade. (Ingraham, 1998)

Increased trading relationships with the Republic of Ireland and between Northern Ireland and the rest of the EU are favourable for EFMB. The consistency of the regulatory regime in the EU is also favourable for EFMB, as discussed in Section 4.2.3 (below). While these are positive issues, they do not at this point limit or help to describe the type of product EFMB can offer. Both goods and services, and other value propositions that can be envisioned, would be equally possible under these situations.

It is possible to suggest that the instability in Northern Ireland, specifically the fact that bombing is one of the more common ways that hostilities have been expressed in the past, might suggest that an infrastructure-limited approach might be better. It could be argued that the outside world might be more comfortable purchasing services, which are dependent on qualified staff, rather than goods, which are dependent on equipment and facilities which could be bombed. However, these concerns can be mitigated with purchasers through performance guarantees and other such instruments. The instability in Northern Ireland should be kept in mind, but is likely not a major deciding factor in the "What is the product?" decision.

4.2.3 Regulatory Regime

Environmental regulations are standardized across the EU, although the specific applications are country dependent. This shows some advantages to EFMB in the development of a product in the area of wastewater treatment, because the one product could be designed to meet the environmental regulations throughout the EU. A specific potential market is the countries which have applied to join the EU – Estonia, Latvia, Lithuania, Poland, Czech Republic, Slovakia, Hungary, Slovenia, Romania, Bulgaria, Malta and Cyprus. These countries must conform to EU regulations, including environmental regulations. Since wastewater and effluent treatment in eastern Europe lags behind the West, there will be some business opportunities in this new market, although these will be aggressively pursued by existing practitioners.

There are also some potential advantages to a process that removes metals in the processing and manufacturing industries. If metals can be recovered from liquid hazardous waste, there might be two advantages to the potential customer – the waste might no longer be hazardous and therefore their disposal costs would be reduced, and the recovered metal could be reprocessed, resulting in an income stream or at the least a cost reduction. The hazardous waste regulations in the EU are written in such a way that removal of the metals which cause the waste to be classified as hazardous could result in the waste being re-classified as non-hazardous, or not being classified hazardous in the first place.

The regulations in the EU and the UK must be understood as product development progresses. Regardless of the final product, there will be a waste stream requiring disposal. This opportunity afforded EFMB by the stringent regulations has some impact on the product development decision. If EFMB can mange the waste stream from their process, through either metal recovery or managed disposal options, they can offer addional products and/or services to their customers.

4.2.4 Protection of Intellectual Property/Rights

It is outside the scope of this thesis to discuss the legal details of IP with respect to EFMB. However there are a number of IP issues that are relevant to the PDP.

The final product decision should be taken in light of the patent opportunities. Patents are protected through the European Patent Office, as well as the US Patent office. In the US, an "invention" must be a new and useful process, machine, manufacture or composition of matter. The term manufacture is used to describe a product and a the term composition is used for such entities as a new chemical or bacteria. There are also, process, or method patents.

The protection that EFMB will require will depend on the value proposition decision. It might be necessary to patent the actual "device" that is manufactured, if it is to be sold for use in equipment designed for others, like the Zenon membranes. It might be better to patent the process they develop, like Noram, and license this to customers. Finally, it might be possible to patent the specific use, for example the use of biosorbents to remove uranium from sulphuric acid leachate in hydrometallurgical applications, much as MIT patented various uses of technology in digital TV (MIT Tech Talk, 1997).

4.2.5 Human Capital

The issue of human capital is important to EFMB at this stage, since it will need to hire additional staff to move the company further towards product launch. While Northern Ireland has a young, educated workforce, there are some disadvantages faced by EFMB based on their specific location. At the University of Ulster, they have good access to business and scientific literature and peers, but limited access to engineering skills since these are located at another campus. The local area around Coleraine is also not very industrial, meaning that there is not a local pool of talent. However, there are some geographic advantages – located on the north Irish coast, Coleraine and the neighbouring triangle of Portstewart and Port Rush are beautiful holiday areas with affordable housing and other amenities. Recruiting personnel to re-locate to the area is definitely feasible.

Since EFMB does not have an existing staff base, the human capital issue is not as important in the product development decision. Since EFMB will have to hire staff, the decision about the product and the value proposition will determine what staff are required.

4.2.6 Industry Structure

Wastewater treatment

A report to the Directorate-General for the Environment on the EU eco-industry's export potential concludes that there is considerable scope for export to developing countries (European Commission, 1999). This report cites forecasted expansion on environmental markets in Central and Eastern Europe, SE Asia, China and South America. The growth will depend on economic circumstances and availability of investment finance, but is expected to come in the areas of water, waste, resource management and energy infrastructures, environmental pollution control and more sophisticated environmental technologies and services.

The same report finds that export to developed nations are more limited, due to the fact that these countries, particularly the US, already have a well-developed industry in the environmental sector. Technologies developed for this sector must have a significant value proposition to entice clients to switch from well-known technologies to a newer technology, since the wastewater treatment industry is quite conservative.

According to Environmental Business International Inc.(not dated) the world market of the environmental industry will be about $854 billion by the end of 2002. The value of water and wastewater utilities market is estimated at $142 billion[10] of which $52 billion lies in the US. The water and wastewater industry can be divided into four sub sectors: water supply, wastewater treatment, water equipment and chemicals and water consulting.

The industry can be considered in four main sub-sectors:

- The water supply sub sector includes government-owned and investor owned utilities and distribute purified water to consumers.
- The wastewater treatment sub sector consists of government-owned and investor owned facilities that treat municipal and industrial sewage and effluents.
- The water equipment and chemicals sub sector includes companies that make pumps, filters and chemicals for water purification.
- The water-consulting sub sector consists of firms that provide consulting and engineering services for water treatment projects and processes.

The wastewater industry is a mature marketplace with intense competition, slim profits and slow demand drivers. Historically, environmental regulations were the main driving force in the development of environmental technologies in most of the industrialized nations. The growth seems to have tapered off and the primary reason for this seems to be the limited enforcement of existing regulations in some jurisdictions and few new incremental regulations.

In terms of spending for water and wastewater treatment, the biggest industrial wastewater markets are chemicals, electric utilities, pulp and paper, petroleum refining, food processing, primary metals and other types of manufacturing. Among these markets, the chemicals sector accounts for 25% of spending (Khan, 2002).

Processing plants

The process plant industry is another sector where EFMB's technology might find significant applications. In these industries, the EFMB technology might find application inside the processing plant, where the driving force will be cost savings and not regulations. There will also be effluent treatment opportunities. Some of the major industries located in the UK are: nuclear fuel processing, oil and gas production, petroleum refining, gas supply, electricity generation, steel, water & sewerage and food & drink industries. The challenge, however, might be that each one of these industries is effected by different forces so they all have different buying behaviors.

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[10] © Environmental Business International, Inc. 2000

In 2000 the UK expenditure on process plant equipment as estimated by Key Note Ltd. (2000) was 5.13 billion. This includes manufacturers of equipment, ranging from larger items of plant (such as distillation columns, evaporators, pressure vessels and dryers); to smaller items (such as pipework components, pumps, filters and valves); to control gear items (such as sensors, instrumentation and control computers). The main end users for process plant include chemicals, pharmaceuticals and biotechnology product manufacturers etc.

The chemical industry is the second most important sector for process plant sales in 2000. It accounts for more than 20% of all process plant sales in that year. The chemicals industry, however, has been affected by declining sales and a global over-capacity in several of its sub sectors. These factors are likely to lead to short term falls in capital expenditure.

The nuclear fuel processing industry is shrinking due to a total absence of plans to build new stations. Consultancy services for decommissioning of nuclear power plants and on waste disposal are the only areas where there seems to be growth in the future.

Oil and gas production is an important sector for new process plant sales and accounts for more than 26% of the total expenditure in 2000. A related industry, petroleum refining industry is the largest customer of process plant equipment. This industry, however, is plagued by overcapacity in UK and would have limited needs for metals removal.

Gas supply, electricity generation and steel are all small buyers of process plant equipment.

The water & sewerage industry has become the largest customer for process plant equipment. This has primarily been triggered by the need to comply with EU drinking water quality directives. The industry has had strong investment in the last few years and this trend is likely to continue for some time.

Food and drink industry is likely to be a major customer of new process plant and equipment. The problem, however, might be the current capacity glut and the price pressure from big retailers.

The market trend for the purchasing of process plant equipment exhibits long lags from economic influences, due to the considerable delay between the purchase decision and the final commissioning of the plant. The delay can be as long as 5 years and is rarely less than a year, even for small projects. As a result of the time lag the process industry is the last industry to go into a recession and the last to come out of it.

The total UK expenditure on process plant equipment is forecasted to be 5.27 billion in 2005 (Key Note, 2000). This reflects the static expectations for the total market over the next few years, although some sectors, such as electricity generation are expected to do well due to increased market demand. To some extent, the low investment in process plant and automation has been caused by a move to production by low wage economies rather than the installation of modern machinery to reduce labor costs in the UK and European factories. (Khan, 2002)

4.2.7 Industry Value Propositions

The potential value propositions for EFMB will be discussed in light of the examples provided in Chapter 2.

Manufactured Good Supply – Zenon Environment

With this value proposition, EFMB would develop their biosorbent as the primary product. It could be installed in equipment either designed and specified by EFMB, or in equipment provided by others. If the technology turns out to be a good replacement for ion exchange resins, then this value proposition might be quite viable. Engineering studies comparing ion exchange resins and a contained biosorbent would have to be completed to determine if this is feasible. Two types of studies are required to answer this question – technical and economic. It will be necessary to determine if the biosorbent can replace the same volume of resin or less and perform the required separation. Next, it is important to determine if this can be done economically, if it would be cheaper for the end consumer. If resins can be replaced with some form of biosorbent, then the market for the biosorbent as a replacement of ion exchange resins is quite large.

This value proposition is not as feasible with biosorbents as a replacement for electrodialysis, because that equipment is always specifically designed for a given application, and there is no opportunity to offer to this industry a manufactured good without providing them with a complete replacement for the electrodialysis process.

Process Design and Equipment – Noram Engineering and Constructors, Ltd.

If the whole process has some competitive advantages, then EFMB might offer the whole package. EFMB would have to be prepared to bid competitively with other well-established companies, and would have to be able to demonstrate advantages to their process. In this scenario, the technology is developed so that a custom designed and specified system can be provided for each customer.

While this is certainly feasible for EFMB (assuming that they hire personnel with a record and contacts in the industry, to increase the chance of a successful bid), it does not fit well into the value propositions of their primary competitors. Engineers who are designing either ion exchange or electrodialysis systems make the decision based on the technology that is best suited for the separation need. That is, they would be choosing a technology, not a specific vendor. It would be harder to sell a new process in this market because it is hard to contact the decision-makers (the individual engineers inside each chemical or industrial company, or consulting firm).

Equipment Only- Hankin Atlas Ozone

It is feasible for EFMB to develop a platform of products which remove specific constituents from water or wastewater streams, for example. These would then be constructed locally (eventually in local markets wherever these are) and sold off-the shelf. In this case, the primary market would be for manufacturing industries where they do not have technical expertise and where they would make decisions based on sales literature and sales presentations. The IP protection would have to be strong, since EFMB have no manufacturing expertise which could result in them launching a product which is lower cost than any competitor could make it after reverse-engineering the technology. It might be possible to obtain such expertise and partner with a manufacturing company, but the manufacturing company would have to have significant experience with very similar manufacturing.

Equipment (IP Protective) – Linde Group

EFMB could follow the Linde model and produce equipment which is guaranteed to meet the required outlet conditions, while requiring that the customer not look inside the equipment.

However, this business model will not likely be very effective given that there are other competing technologies that can also perform the separation. If the only advantage of the EFMB technology over electrodialysis or ion exchange were cost, then customers might be suspicious that the costs would increase over time. Given technology options, customers are less likely to choose a technology that restricts them so severely.

Equipment and Parts – Printer and Cartridge Model (HP)

With this business model, EFMB would provide customers with the equipment to perform the separation and would contract with them to provide the biosorbent on an on-going basis. EFMB would have to manufacture both the equipment (although this could be contracted out) and the biosorbent. The equipment could either be custom designed for each use, with the quantity and type of biosorbent depending on the use. Market prices for competing technologies would determine if EFMB would have to follow a true printer and cartridge model and sell the equipment at a loss, or if profits could be made in both cases.

In this case, the business model favours thinking of the EFMB technology as a competitor for electrodialysis. In electrodialysis, the equipment design is based on lab studies and engineering calculations and is custom designed for each application. The purchaser is comparing technologies which will be suitable to perform the required separation, knowing that off-the-shelf technologies will not work.

Sector-Limited Licenses – Millennium Pharmaceuticals Inc.

As EFMB goes forward, it may will need partners to use its technology so that it can construct pilot flow-through and full scale systems. One mechanism for this might be granting a sector-limited license which would be profitable for the licensee yet is not an area in which EFMB wants to pursue. One such example comes to mind: Recovery of uranium from sulphuric acid leaching and bicarbonate leaching solutions. This is a short term market, due to the downturn in the uranium market because of the lack of construction of new nuclear power plants. It would not be advisable for EFMB to target this market, but companies already in this area might be interested in the potential quick profits which could be made with the introduction of a new technology. This is substantial nuclear decommissioning work in the UK and around the world, and a practitioner in this industry might be able to exploit the EFMB technology. It would also give EFMB a potential initial customer for larger scale trials.

In the long term, using sector-limited licenses might be feasible, and doesn't specifically limit the product definition at this stage.

Use of Equipment – Annapurna Conservation Area Project

The business model where EFMB would retain ownership of their process and operate it for others is not feasible in this situation.

However, there is the potential that customers might prefer to ship their waste back to an EFMB facility for metal recovery or reprocessing, which would result in a continuous income stream for EFMB. EFMB could also offer brokering services to help customers find either disposal or re-use options for their waste. For waste processing, it might suit EFMB to follow the APAC use-of-equipment model, where EFMB builds and owns the waste processing facility, and others pay a fee to have EFMB treat or handle their waste. This is feasible for the waste stream as opposed to the influent, because of the relative volumes and the fact that the customer traditionally has to ship the waste somewhere for disposal.

4.2.8 Conclusion

The primary conclusion from the above is that engineering studies are required before EFMB can determine its best value proposition.

If the technology can be cost competitive with and as effective as ion exchange, then the best option for them seems to be as a supplier of manufactured goods. Research would focus on broadening the types of separation that can be accomplished, making the product as robust as possible for customers, and reducing manufacturing costs. The staff required would be scientists, engineers and technicians with a background in manufacturing, and possibly some experience with ion exchange. Sales would be to known ion exchange customers, probably through advertising in trade journals and direct sales.

If the technology's cost is more in line with electrodialysis (more costly than ion exchange), then the printer and cartridge model might be a better fit. Technical expertise required will be based on the need for cost reduction, which will likely focus on reducing electrical requirements.

In both cases, the revenue stream from the customer is continuous and not a fee-for-service model. Also, the use-of-equipment model might be feasible for the waste stream, certainly in markets in Northern Ireland and the Republic of Ireland.

The final conclusion for EFMB is that limited licensing might be an effective way to proceed from here, to find a partner which offers an opportunity to pilot test the technology and who has the necessary industry contacts to get such a venture up and running quickly.

5.0 CONCLUSIONS

The framework developed for analysing the system-level factors involved in the very early stages of product development shows some interesting applications for products which are process-based. It highlights the importance of the regional economy and regional/national support and stability. In the case study presented, use of the framework allowed for the discussion of how the political situation in Northern Ireland might affect the product development, which would not have been the case in the traditional concept development stage. Framework introduced the importance of the regulatory regime into the product development decision, which raised an additional potential value proposition. The discussions around IP and human capital were the same as those that would traditionally be held, and therefore not much insight was gained using this specific framework in those areas. However, the importance of the industry structure and value propositions was very enlightening, showing that two different value propositions and products are viable, with additional insights about other possibilities.

This framework is presented for the situation where a specific market for the product is not yet known, because the product offering has not yet been fully developed. The framework could be applied in similar situations which attempt to address a certain market, but of course the market information would have to be included for completeness.

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