Pulsed Power Technology and Applications–Scandinavia

TR-112566

Final Report, April 1999

EPRI Project Manager
C. Mansson

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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CITATIONS

This report was prepared by

Vattenfall AB
Jämtlandsgatan 99
SE-162 87 Stockholm
Sweden

Principal Investigators
K. Ahlfont
H. Sandborgh
D. Sundén

Authors
K. Ahlfont
H. Sandborgh

This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Pulsed Power Technology and Applications–Scandinavia, EPRI, Palo Alto, CA: 1999. TR-112566.

REPORT SUMMARY

Pulsed power is a new and promising technology with a large number of potential applications. In addition to existing and future pulsed power supply and technology in Scandinavia, this report also describes present and future applications.

Background

Recent advances in pulsed power technology have made it possible to apply the technology to commercial and industrial environments. Today, many facilities are unaware of pulsed power systems or find themselves struggling with applications that are not perfectly adapted to its operating conditions. To obtain a better understanding and characterization of the pulsed power supply and its end-use applications, it is necessary to apply pulsed power technology in an appropriate and efficient manner. This study's main goal is to facilitate better technology transfer.

Objectives

- To investigate and characterize the status of existing pulsed power supply and technology in Scandinavia.
- To identify and characterize present and future areas of pulsed power applications in commercial and industrial end-use sectors in Scandinavia.
- To perform a market assessment in Scandinavia for the pulsed power applications defined and prioritized in this study.
- To facilitate technology transfer by arranging a workshop in Scandinavia where study results will be presented.

Approach

Analysts conducted this market assessment through searches on the Internet and through contacts with a number of institutions, universities, and companies. They focused on Scandinavia (Sweden, Norway, and Denmark). To some extent, they also surveyed the status of pulsed power technologies and applications in the rest of Europe, mainly through a database maintained by COST (European Cooperation in the field of Scientific and Technical Research). When identifying present and future end-use applications, they covered the following sectors: food, materials fabrication, mining and minerals, pulp and paper, iron and steel, the chemical industry, residential and

institutional buildings, water and waste water treatment, packaging processes, and production of pharmaceutical products.

Results

The study concluded with the following recommendations:

- Start the proposed marketing strategy with a limited range of applications to a limited target group. Begin with applications that have the shortest time to commercialization—water treatment for the pharmaceutical industry and gas treatment for the plastic industry.
- Initiate demonstration projects in Scandinavia that demonstrate the efficiency of large-scale gas and water treatment by pulsed power.

EPRI Perspective

This assessment indicates that gas treatment and water treatment have interesting market opportunities as pulsed power applications in the surveyed market segments. The total potential appears adequate and the responses from customers are promising. The study also confirms the importance of demonstrating full-scale test results to customers. If pulsed power technology is to be successfully introduced into Scandinavia, demonstration projects are necessary.

TR-112566

Keywords

Pulsed power
Power supply
Industrial application
Energy services

ABSTRACT

The application of pulsed power is a new and promising technology with a large number of potential applications. The report describes existing and future pulsed power supply and technology in Scandinavia as well as present and future areas of pulsed power applications. A prioritization is made with the selection of the pulsed power applications assessed to be the most interesting on the Scandinavian market. A market assessment is performed for Scandinavia for the defined and prioritized pulsed power applications and a business plan is discussed in general terms.

The awareness of pulsed power technology and applications is generally very low in Scandinavia. Only in certain limited areas, primarily food, is there any activity or knowledge about pulsed power.

The market assessment showed some interesting marketing opportunities. The total potential seems large enough and the responses from customers are promising. As a result of the study, the final recommendations in this report is to start the introduction of pulsed power applications with a limited range of applications to a limited target group. It is also recommended that demonstration projects are started in Scandinavia to show the efficiency of gas and water treatment by pulsed power.

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INTRODUCTION

Pulsed power in general, in the sense of stored energy that is released in an intense pulse or pulses, is not a new concept in itself. Explosives are, in a sense, a pulsed power technology with several applications, both for military and for civil use. Energy, that is stored in the explosives, is released as a short and intense "pulse" which gives the characteristic effect, in short: an explosion.

Pulsed power technologies in general, are characterized by the concentration of energy, both in time and space, to pulses of high intensity. The pulsation of energy augments power efficiency and enables new applications that are not possible with conventional continuous flow of energy. Chemical and physical processes are often characterized by being non-linear, where a critical threshold, such as activation energy, has to be exceeded before the reaction or process takes place. By supplying the energy in pulses, the peak power of the pulses can well exceed the critical threshold while maintaining a moderate average power demand. The high flux of energy into the treated object is also often much faster than the energy transport away from the treated area, preventing the energy from being "diluted" in the workpiece. This phenomena, often called adiabatic heating, concentrates the energy in the treated object so that the critical threshold can be exceeded and that the treatment can be concentrated, for example only on the surface of the object.

Recent advances in numerous components of pulsed power systems – batteries, capacitors, inductors, and charging systems – have made it possible to economically apply pulsed power technology to the commercial and industrial environment. Today, many commercial and industrial facilities do not take advantage of pulsed power systems because they are unaware of their existence. At the same time, some end users find themselves struggling with pulsed power applications that are not perfectly tuned to the operating conditions. It is, therefore, necessary to obtain a better understanding and characterization of the pulsed power supply as well as end-use applications in order to apply pulsed power technology in appropriate and efficient manner. The main goal of this study is to facilitate for better technology transfer.

The study is divided in four parts where the objectives are:

- To investigate and characterize the status of existing pulsed power supply and technology in Scandinavia.

- To identify and characterize present and future areas of pulsed power applications in commercial and industrial end-use sectors in Scandinavia.
- To perform a market assessment for Scandinavia for the pulsed power applications defined and prioritized in this study.
- Finally, facilitate technology transfer by arranging a workshop in Scandinavia where the results of the study shall be presented.

Vattenfall's interest is also to define markets that are attractive to enter with pulsed power applications; especially the possibility of outsourcing of energy related services. Thus enabling the end-users to concentrate on their main process while Vattenfall can offer a complete solution for the problem, including hardware and know-how.

The study has mainly been focusing on Scandinavia, i.e. Sweden, Norway, and Denmark. Also, to some extent, the status of pulsed power technologies and applications has been surveyed in the rest of Europe, mainly through a database maintained by COST (European Cooperation in the field of Scientific and Technical Research). In the work of identifying present and future end-use applications, the following sectors were covered:

- Food
- Materials Fabrication
- Mining and Minerals
- Pulp and Paper
- Iron and Steel
- Chemicals and Petroleum
- Residential and Institutional Buildings
- Water and Waste Water Treatment
- Packaging Processes
- Production of Pharmaceutical Products

For some sectors it has not been possible to find any activities or knowledge about pulsed power technologies in Scandinavia.

The number of applications where pulse technology is used in some way is almost unlimited. In order to restrict the extent of this study, it has been limited to:

- Pulses where the rise time is much shorter than the pulse length
- The pulse generators are capable of giving repetitive pulses
- The pulse application gives advantages similar to those described in the opening of this chapter, i.e. augmentation of power efficiency and/or enabling new applications that are not possible with conventional continuous flow of energy.

The survey has been performed through searches on the Internet and through contacts with a number of institutions, universities, and companies.

2

EXISTING PULSED POWER SUPPLY AND TECHNOLOGY

Pulse Technology

A general pulsed power system can be described as the figure below.

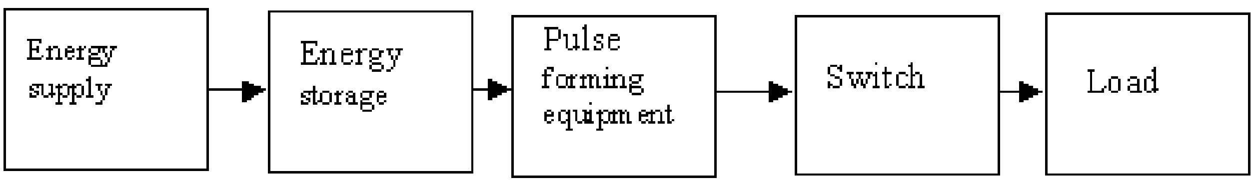

Figure 2-1
Principal layout of a pulsed power system with energy storage.

The energy supply, in most cases the ordinary power network, is connected to the energy storage system which, in turn, is connected to the pulse forming equipment. The energy storage is usually either of capacitive or inductive type, i.e. the energy is stored electrostatically or magnetically. The pulse forming equipment, which is charged from the energy storage, is used to give the right shape of the pulse for the intended application. To allow the energy pulse to reach the load, a fast switch is connected between the pulse generator and the load. The end-user defines the load characteristic.

In the past, the absence of pulsed power technology was ascribed to the limitation in the energy storage components and the switching components. With the development of these components, some of the problems to achieve high-energy pulses to an acceptable cost are eliminated. Better capacitors, inductors, and switches make new application of pulse technology possible.

Examples of pulse technologies are:

- Impulse generators for testing isolation withstand of electrical power equipment (will not be discussed in this study)
- Cyclotrons

- Ion-accelerators
- Pulsed laser

Pulsed power devices are usually turn-on devices to discharge a capacitor or capacitor bank, through a load. However, certain cases will require turn-off of the current, which involves opening of the switch.

Repetition Rate

A high repetition rate results in that the gate unit must be re-charged quickly to give a consistent turn-on performance with each pulse. The thyristor must be turned off quickly so that it may recover in time for the next pulse, and in the case of energy recovery circuits, the device may have to withstand the voltage a short time after the conditioning pulse.

Switches

In electrical power systems, switches are used to make it possible to control the electrical power. The characteristics of the switch, such as voltage standoff, current carrying capability, switching time, and leakage current, decide which application it is most suitable for.

Switching technology today can be divided in three groups:

- Mechanical switches
- Semiconductors
- Other electrically controlled switches

Mechanical Switches

Conventional switches are used in non time-critical pulsed power applications.

Semi-Conductors

The choice of semiconductor is mainly decided by two parameters:

- Power versus frequency
- Voltage versus current

For low power but high switching frequency, MOSFET-transistors are used. They can handle some hundred Volts and some hundred Amps. For medium power applications (100 kW) and higher switching frequencies (10-100 kHz), IGBT-transistors are used. They can handle some kilo-Volts and some kilo-Amps. In high power applications GTO-thyristors are used. These thyristors are able to carry several kilo-Amps at several kilo-Volts. The disadvantage with the GTO is the low switching frequency, which make it slow.

Thyristor Limitations

Thyristors are normally used as a switch in conventional pulse generators. The thyristors have limitations in maximum blocking voltage, maximum average current, and minimum current rise time. Typical maximum values are 5 kV blocking voltage and pulse current of 80 kA during 250 ms. The ability for the thyristor to manage fast switching is basically a function of its silicon thickness, its gate geometry, gate construction, and its gate drive system. A typical thyristor is limited to about 500A/ms; however, minor modifications can be made to the standard devices to get up to 10 kA/ms.

Other Electrically Controlled Switches

Other electrical controlled switches, such as vacuum tubes etc. are used in special cases. They are not discussed in this report.

Capacitors

The ability to store a large amount of energy, is an essential part of pulsed power systems. In capacitors the energy is stored as charge, which is a product of the voltage and the capacitance of the capacitor. The capacitance is decided of the geometry of the plates, and of the dielectric medium. The problem is to create a capacitor with high capacitance *and* high voltage. Common capacitors for power applications are manufactured up to approximately 25 kV at a capacitance of 10-20 μF. At really low voltage, capacitors with a capacitance of several Farads are available.

The Blumlein Circuit

A Blumlein circuit can be used to create a square pulse. The circuit consists of capacitances and inductances connected in a network. The major advantage is that the full charge voltage appears across the load while other pulse forming circuits produce a pulse with merely half the charge voltage across the load. To get a well-suited circuit the load (end user) shall be twice the characteristic impedance. The pulse-forming network can be used to form pulses up to 50 MW with voltage stability within 0.03%.

The circuit can form pulses in microsecond scale but the repetition rate can be low in case of high voltages or high power.

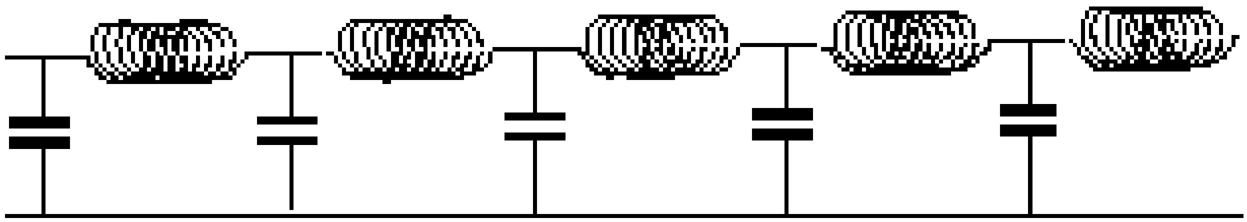

Figure 2-2
Blumlein circuit with lumped inductors and capacitors

Manufacturers

Scanditronix and Siemens Elema are manufacturing cyclotrons and ion-accelerators for hospitals. They are generally used for X-ray generators for medical purpose.

Scanditronix Pulse Modulator

An electron beam with electrons accelerated to very high energy levels is a well-established method for the treatment of cancer. The e-beam has to be formed as very accurate pulses in order to be used for medical applications. Scanditronix has developed a new modulator for the purpose. In the modulator, microwaves are formed with high accuracy, and then transferred into an accelerator. The microwave pulses make the electrons to accelerate to exactly the right speed before they hit the patient. The modulator is built with new semi-conductor devices, such as IGBT-transistors. In the secondary circuit, a high voltage transformer is used to increase the voltage up to 100 kV. The modulator can produce pulses of 5-10 μs and 6 MW power at a frequency of more than 300 Hz.

3

EXPECTED FUTURE COMPONENTS AND EQUIPMENT

Basic Considerations

The limitations for the components of today depend very much on the application they are intended for. Normally the objective is to generate intense (MW) and narrow (μs) pulses at a frequency of 100's to 1000's of Hz. This, in turn, sets the demands for the components to be used in the pulse supplying equipment. Generally there is a need for switches and capacitances that can handle higher voltages than today. Also, the capacitances must meet the demand for high capacitance and high voltage as well as the ability of a short discharging time.

The pulse equipment and the load characteristic must be electrically adapted to each other. In many cases the load characteristic may vary with time, e.g. due to temperature variations. If possible the application can be designed so that load characteristic is maintained at a constant level. As an alternative the characteristic impedance of the pulse equipment must be adjustable in accordance with the variations of the load.

Super Capacitors

The energy storage system is an essential subsystem in a pulsed power supply assembly. Superfarad, a Scandinavian company, is currently developing super capacitors. A super capacitor has higher energy storage capacity than an ordinary capacitor but still has the same good discharge characteristic as a conventional capacitor. The fundamental criteria for a powerful capacitor is to find an insulation material with the combination of highest possible dielectric constant and highest possible electrical withstand.

Technical data for the capacitors of Superfarad:

- Voltage: 48 V
- Capacitance: 250 F
- Maximum current: 2.3 kA during 100 ms.

- Energy density: 10 Wh/kg

The super capacitors of Superfarad will be in commercial production very soon.

Silicon-carbide Semiconductors

The Royal Institute of Technology in Stockholm (KTH) is currently doing research on silicon-carbide semiconductors (SiC) that can operate at voltages up to 20 kV per unit and with a much higher switching frequency than ordinary semiconductors. The SiC also has lower losses, can withstand higher temperature (up to 400 °C), and even has better heat-leading ability than copper. The distribution triggering pulses limits the possibility of having semiconductors connected in series.

The MINOS Switch

MINOS (**M**agnetically **IN**sulated **O**pening **S**witch concept) is a novel switching concept of interest for industrial applications where high voltages, high currents, and short switching times are requested. The concept was studied, both theoretically and experimentally[i], in a Ph.D. thesis at EKC, KTH[1]. In the Ph.D. studies, a functioning prototype of the MINOS switch was designed and built.

In pulsed power systems, the switch shall be able to transfer high power level during a short time and a longer recovery time is used for energy storing in the circuit (i.e. charging of capacitors). Today, the only commercially available high power switches for advanced industrial applications that are true type switches are GTO (Gate Turn-Off thyristor) and CMS (Crossatron® Modulator switch). Technical specifications of these components compared with MINOS are shown in the table below:

[1] Department of Industrial Electrotechnology, Royal Institute of Technology, Stockholm

Table 3-1
Technical specifications of some high power true opening switches as single device. Devices can be connected in series or in parallel to reach other data. The table shows the potential of the MINOS concept.

Operational parameter		GTO (1994)	CMS (1990)	MINOS
Voltage standoff	kV	7	50	>100
Current carrying capability	kA	6,6	2,5	>10
Min current falltime.	ìs	100	0,05	<0,1
Max repetition rate	kHz	10	100	>1000
Max. power (pulse)	MW	50	100	>1000
Max. power (RMS)	kW	10	100	>1000
Max current (RMS)	A	2	2	1000

In the MINOS-concept, the current in a thermionic vacuum diode is controlled by a magnetic field. The diode can then be used as a switch, closed when operating as a conventional vacuum diode, and opened by magnetic insulation of the electron flow. In the presence of a magnetic field, the electron trajectories are bent and for sufficiently high field, electron flow through the diode is prevented. Without a magnetic field the electrons flow radially to the anode.

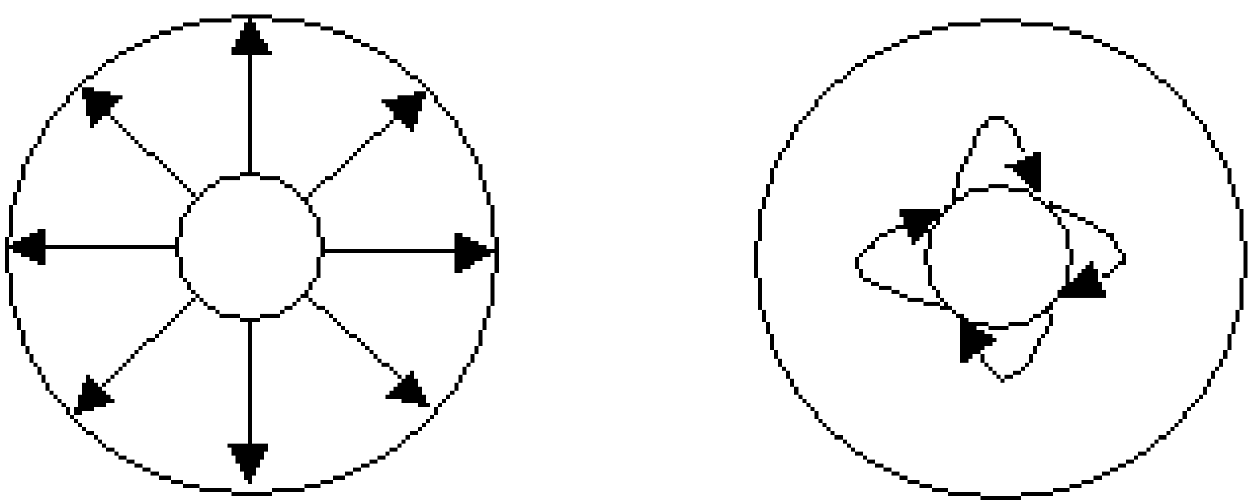

Figure 3-1
Electron flow in MINOS at no magnetic field (left) and high magnetic field (right)

The MINOS switch has several advantages. High voltage standoff capability is reached by reducing the probability of voltage breakdown induced by cathode phenomena. It is robust against transient over-voltages, since voltage breakdown is not destructive in this construction. Switch losses are distributed along the anode surface, efficiently cooled since it is made of copper. The recovery time is very short since no ions are involved in the switching process and capacitive effects are negligible.

The switch is suitable mainly for high power applications, 100 kW and more. The main disadvantage with MINOS is the high leakage currents. The MINOS was aimed for the power distribution companies and they did not accept these high leakage currents.

4

ADAPTATION TO EMC-CRITERIA AND PERSONAL SAFETY REGULATIONS

Electromagnetic Compatibility

In most cases the pulsed power applications are sources of electromagnetic radiation that need to be shielded off. Reported results show that this is not a major obstacle, although one has to be aware of the need of proper design and shielding when designing the pulsed power unit. M. A. van Houten at Eindhoven University of Technology in Holland developed methods for effectively suppressing interference in a Ph.D. thesis[ii]. Heesch et al., at the same university, designed and built a pulsed corona pilot unit where the electromagnetic radiation was suppressed so that adequate electromagnetic compatibility (EMC) was achieved[iii]. The capacity of the unit was 1,5 kW average power with 50 MW pulses at 1 kHz. Sensitive apparatus for chemical analysis that operated close to the pulse source as well as computers and networks in close vicinity were not disturbed.

Personal Safety Regulations

Besides meeting adequate electrical safety standards it depends very much on the type of pulsed power application to determine what is needed in order to comply with personal safety regulations. In most cases this is not an insurmountable obstacle and involves limiting electromagnetic fields (EMF), UV-light radiation, and so forth.

5

IDENTIFICATION OF END-USE APPLICATIONS

EU RTD Framework Programs

Since very few applications were found in Scandinavia, a search was performed in the EU CORDIS database. CORDIS, the Community Research and Development Information Service, is a searchable database covering the EU Research and Technical Development (RTD) activities. The European Union activities in the area of RTD are driven by the need to improve the scientific and technological basis of Community businesses to enable them to compete in the global market. The principal role of EU action is to extend, complement, and enhance the research activities of the member states.

Established Effects on Microorganisms

There are several different pulsed power applications for the treatment of microorganisms. Generally, there is mainly one biological objective in focus, inactivation of the microorganism. Basically, all pulsed power applications achieve the inactivation by exposing the microorganisms to energy levels that disrupt the cell membrane or damage large molecules, such as proteins or the DNA. The underlying mechanisms that cause death are less discussed and not known. In general, pulsed electric field and pressure shockwaves damages the cell membrane, which leads to cell inactivation. Energetic radiation, such as light or ionizing radiation damages and/or inactivates biomolecules.

In laboratory use, pulsed electric field is sometimes also used for the transportation of foreign matter in and out of the cell. UV radiation can also be used for promoting mutations since the energetic radiation damages the DNA molecule.

Mustafa Fincan, Ph.D. student at Food Engineering Department at Lund University studied the general effects of treating microorganisms with Pulsed Electric Field (PEF)[iv]. It is well known that this application results in pore formation or complete breakdown of cell membranes although the precise mechanism remains unclear. According to the most accepted breakdown theory, an externally applied electric field induces an electric potential difference across the membrane, known as transmembrane potential, which in turn causes accumulation of opposite charges on the inner and the outer surface of cell membrane. When the transmembrane potential (or the external electric field) exceeds a critical value, the repulsion between charge-carrying molecules initiates the formation of pores in the weak areas of the cell membrane.

A consequence of this is that pulsed electric field has effect mainly on vegetative cells, while spores and viruses are not affected to the same extent. Grahl et al. investigated the lethal effects of pulsed electric fields (PEF) on suspensions of various bacteria, yeast, and spores in buffer solutions and liquid foodstuffs[v]. Living-cell counts of vegetative cell types were reduced by PEF treatment by up to more than four orders of magnitude (> 99.99%). Endo- and ascospores were not inactivated or killed to any great extent. The killing of vegetative cell types depends on the electrical field strength of the pulses and on the treatment time. Above critical values of electric field strength and specific treatment time, the fractions of surviving cells were reduced drastically.

Food

High Electric Pulse (HELP) for Food Production

Description

The main objective in the development of pulsed power technologies for the treatment of food is developing alternative, non-thermal methods of pasteurization. Treating food with High Intensity Pulsed Electric Field (HIPEF) is a non-thermal physical process evolving as a potential alternative to traditional pasteurization in food processing. It can be defined as a process by which high electric field strength is delivered as a series of pulses of direct current to a piece of food for a very short period of time while the food is held in between anode and cathode. The treatment disrupts and/or affects the membrane permeability of the cell membranes of microorganisms and of plant tissue. This outcome can be used both in extraction processes to increase the juice yield and in microbial inactivation of food.

The HIPEF technology is known under different names and acronyms, such as “Pulsed Electric Field” (PEF) as well as “High Electric Pulse” (HELP).

Benefits

The HELP technology is being developed in response to the consumer demands for fresher foods, with improved quality in comparison to heat pasteurized foods. HELP processed fruit juices show only limited effects on their nutritional and sensory quality thus maintaining the fresh properties of the raw materials. The HELP technology is also developed to meet the customer demands for increased safety of our food supply system, where the HELP processing can add safety during handling and distribution to previously unprocessed foods.

Since the treatment with Pulsed Electric Field affects the permeability of the cell membrane it can also be used for facilitating the drying or increase the yield of fruit juice from plants and fruits.

Obstacles

Obstacles of different kinds have to be overcome before the technology can be successfully introduced on a large scale. The obstacles can be summarized in three categories:

- **Technology**
  - The underlying mechanisms of inactivation of microorganisms are not yet fully understood.
  - Problems will arise when upscaling the technologies from lab- or pilot-scale to full-scale applications.
  - At present, HELP processing is limited primarily to liquid foods, since the uniformity of the applied electrical field is distorted by e.g. air bubbles and suspended solids that usually exist in solid foods. This distortion leads to the risk of dielectric breakdown of the foodstuff.
  - The inactivation of bacterial spores requires extensively high electrical field strength.
- **Knowledge and acceptance among end-users**
  - It is necessary to demonstrate the technical viability and the product quality and microbiological safety advantages of HELP processed food before it can be successfully introduced on the food market.
- **Approval by authorities that are supervising the food market**
  - The consumer related safety of the HELP processed foods must be demonstrated in aspects that are required by, for instance, the EU Novel Food Legislation as well as the U.S. Food and Drug Administration.

Key Players

LiFT – Future Technologies for Food Production

LiFT is a national Swedish research program for future technologies in food production. Most of the major Swedish universities are members of the program[2] and work in close collaboration with industry. The program is financially supported by the Swedish Foundation for Strategic Research. In the research program, the use of pulsed electric field will be studied as a method for mild treatment of animal cells as well as for mass transport of cellular plant tissues by the use of HELP permeabilization. SIK, The Swedish Institute for Food and Biotechnology, a member of the LiFT program, possesses a PEF unit for laboratory research with a capacity of 5-10 l/h, 1 MW peak power and 1,6-2 kW average power. Tetra Pak, the owner of the unit, procured the unit from Ohio State University, United States.

EU HELP Program

SIK is also participating in a research project coordinated by FAIR; *High Electric Field Pulses: Food Safety, Quality, and Critical Process Parameters*[3]. The general objective with the study is to address and overcome scientific and technological hurdles and to make an informed judgement on the relevance of HELP technologies. The project members come from six research institutions, three major European food manufacturers, and one European supplier of processing equipment[4]. Costs are shared by cost-sharing contracts. Start date: November 1, 1997, end date: October 31, 2000.

As part of the research project, a continuous treatment chamber (100 l/h) will be designed, optimized, and implemented for pumpable food products.

EU-demonstration Project of PEF Technology

Tetra Pak and SIK are planning to design and build a mobile PEF demonstration unit with a capacity of up to 1000 l/h and will apply for EU funding of the project[vi].

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[2] Lund University, Chalmers University of Technology, the Swedish University of Agricultural Sciences, Uppsala University, and SIK - the Swedish Institute for Food and Biotechnology.

[3] Program Acronym: FAIR, Project Reference: FAIR963044.

[4] Berlin University Of Technology (Prime Contractor), Pernod-Ricard S.A., Unilever Nederland B.V., CPC Europe Consumer Foods Ltd., SIK, Universidad De Zaragoza, Universite Montpellier II : Sciences Et Techniques Du Languedoc, Katholieke Universiteit Leuven, Tetra Pak

The objectives of the project are:

- To speed up and facilitate the introduction of the HELP processing technology on the European food market.
- To design a semi-industrial scale HELP treatment unit built up as a modular, mobile, flexible fruit juice treatment unit.
- To develop the documentation needed for the approval of the HELP processing by the EC Novel Food Legislation.

Apart from Tetra Pak and SIK, fruit juice producers, analytical laboratories and pulsed power supply manufacturers will participate in the project. The budget comprises a total of U.S. $1.8 million of which EU is expected to supply 35-49%. The demonstration project is planned for two years; final date for application is September 1, 1999.

Materials Fabrication

Pulse Plating

Description

In electrolytic surface treatment processes it is often advantageous to pulse the electrolytic current. It is not well known what makes this improvement; a common theory is that the mass transport through the stagnant layer around the workpiece is improved.

The shape, frequency, and intensity of the pulses depend on the application. In most cases the pulse is unipolar, but bipolar pulses are used in some cases. The pulsing is often changed during the process in order to control and vary the formation of the protective surface. Chrome plating, for example, can be initiated with pulsed current, which gives a dense but tarnished surface, and is finished off with direct current. Normal process parameters are 5-15 V and 10 kA (the current depends on the area of the material). The pulse generators for pulse plating are based on conventional technology for rectifiers with GTO, IGBT, and transistors. The pulse length can be less than 1 ms and the rise time $\Delta I/\Delta t$ = 400 A/ms. Some pulse generators could have a current up to 25 kA.

There are about 300 companies in Sweden that use electrolysis in their production. Approximately 2000 tons of metal per year is consumed for plating of which about 50% are zinc. Approximately 1% of all the plating and anodizing in Sweden is performed with pulse technology.

Benefits

Advantages mentioned with pulse plating are increased productivity (aluminite process), enhanced protection against corrosion, improved material distribution, and reduced consumption of chemicals (mainly surfactants).

Obstacles

Pulse plating is an established technology where commercially available power electronics components are used. The obstacles for a wider use of the technology on the Scandinavian market are primarily lack of knowledge among the end-users about the benefits of pulse plating and, since many of these companies are small, problems with financing the necessary investment in new rectifiers.

Key Players

The leading countries are mainly the United States, Japan, Germany and Italy. Many believe the use of pulse plating will increase in the future.

Pulse plating is an established technology and there are several suppliers, all around the world. Some examples:

- Kraftelektronik, Sweden
- Axel Åkerström, Denmark
- Elca, Italy
- JB Technology, Denmark
- Rapid Power Technologies, United States

Pretreatment of Wood by Laser Pulses

Description

When sawing and planing wood, the fibres in the surface are bruised by the treatment leading to the wood surface being covered with partly loose fragments of wood. The debris on the surface prevents color and adhesives to be absorbed and attach properly to the wood. With the use of high intense laser pulses[vii] the damaged surface of the wood can be removed, thus enhancing the attachment of color and adhesives.

The method has been developed at KTH[5], partly in collaboration with a laser laboratory in Göttingen, Germany. The underlying mechanisms are still not revealed, but the theory is that the wood molecules evaporate and react with the air oxygen. The method is patented but has only been evaluated on a laboratory scale basis.

Energy demand for wood treatment is in the range 40 Wh/m^2, depending on the type of wood treated and the effect that shall be obtained.

The pulse generator produces a 4 ns, 25 kV, 10 kA pulse generating an UV-light pulse at 248 nm wavelength and a pulse power of 250 MW. Total energy in the pulse is 1 J. The low energy content in the pulse does not cause any temperature rise in the wood, in spite of the high intensity. The pulse generator consists of conventional capacitors for energy storage and a tyratron tube acting as a switch, making the generator capable of frequencies up to 300 Hz. The tyratron tube is an electron tube with only a turn-on function and no turn-off function.

Benefits

By removing the debris on the surface, the attachment of color and adhesives is greatly improved. The method makes it possible for a color coating to last much longer than is the normal case, maybe up to 30 years.

Obstacles

The technology has been evaluated only on a laboratory scale. Currently there is no research or development being done in this field. Further development and pilot-scale tests are necessary to prove the potential of the technology.

Key Players

Except for KTH, there are no other key players.

[5] Royal Institute of Technology, Department of Manufacturing Systems, Wood Technology and Processing

Hard Coating Deposition

Description

A breakthrough of high tech coating technology on low cost or large size industrial wear parts is highly hindered by the dimension (and therefore the price) of today's Physical Vapor Deposition (PVD) and Plasma Assisted Chemical Vapor Deposition (PACVD) technology. Ionic nitriding of engineering substrates in industrial sizes is already achieved routinely.

Benefits

The combination of plasma nitriding and hard coatings in one process would, besides the improvement in the lifetime of engineering components, also reduce the process duration and therefore the process costs. The bipolar pulsed PACVD technology allows depositing conductive and insulating coatings in one reactor. This is favorable for upscaling to large areas and volumes.

Key Players

EU RTD Project

EU has started a research and development project in the program for Industrial and Materials Technologies, BRITE/EURAM 3, "Industrial Upscaling of Pulsed Plasma Processes for Economic Hard Coating Deposition"[6]. The main objective of the project is to expand current PACVD technology to an industrial scale (m^3 size). The goal is to implement the deposition of high quality diamond like carbon and TiN coatings with excellent adhesion in commercial plasma nitriding systems ($2m^3$) using bipolar pulsed DC technology. High power bipolar pulsed DC power supplies will be developed and tested in the second phase of the project.

The consortium comprises a plasma nitriding company (Nitruvid, France), a manufacturer of bipolar pulsed power supplies (Magtron, Germany, prime contractor), two research organizations (VITO, Belgium, and FhG IPA, Germany) that contribute their know-how for the deposition of TiN and DLC hard coatings. Two end users (STC, Belgium and Renault, France), active in important European industrial sectors, have a great interest in low cost hard coating technology. Start date: May 1, 1997, end date: April 30, 2001.

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[6] Programme acronym: BRITE/EURAM 3, Project Reference: BRPR970416

Metal Forming at High Velocity

Description

When applying the forming energy as short and intense pulses the energy is concentrated in the workpiece. This results in high temperature and softening locally in the material, a phenomena known as adiabatic softening or adiabatic heating.

Energy can be applied to the workpiece mechanically, hydraulically, or electromagnetically. When applying the energy mechanically the application has similarities to conventional forging.

Hydraulic forming, or hydroforming, is a forming method where the workpiece is placed between a press tool and a chamber that is filled with water (or some other suitable liquid). Pressure is applied to the water in the chamber, which, in turn, presses the workpiece against the press tool. When ElectroHydraulic Discharges (EHD) is used, an underwater electric discharge creates a pressure shockwave that shapes the workpiece by pressing it against the tool. The pressure in the shockwave is in the range of 1 000 to 10 000 bars.

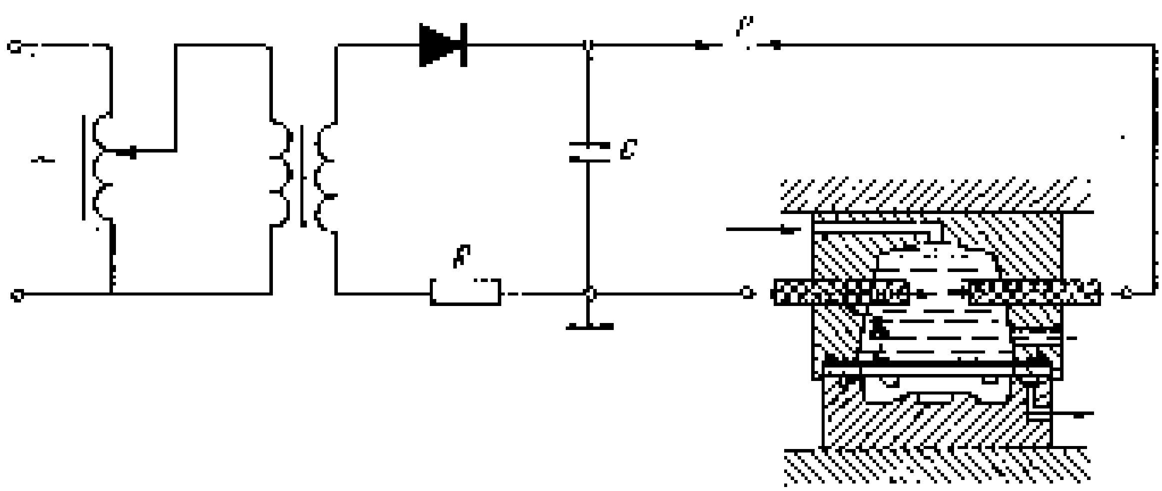

Figure 5-1
Outline of equipment for electrohydraulic forming. The plate (black) is placed on the tool. The chamber above the plate is filled with water. The electric discharge creates a pressure shockwave in the liquid.

When applying the energy electromechanically as an ElectroMagnetic Discharge (EMD) the workpiece is forced against the tool by an electromagnetic pulse.

Benefits

By forming material with very high velocity, compared to conventional technique, several advantages can be achieved. The ductility of the material is improved drastically and material that otherwise would not be formable can be shaped.

Adiabatic heating is also advantageous for cutting where the workpieces are cut off by a short impact. Loss of material is reduced, the workpiece requires less finishing, heating is not required, and the pieces are cut with high accuracy.

Obstacles

For applications with mechanically applied force the problem is to design tools that can sustain the energy. For forming by EHD or EMD the pulse capacitors (and pulse switches) are the most critical components of the device that need further development.

Key Players

Hydropulsor

Hydropulsor, a Swedish company, has developed an impact unit with hydraulic drive for cutting wires, rods, and the like. They have commercially available machines and have delivered a total of 7 units.

Table 5-1
Capacity of Hydropulsor's cutting machines

Diameter: 1-100 mm	
50-600 pcs per minute	*Depending on size*
Pulse time 0,5 to 2 ms	*Depending on behavior of the material*
5 kJ per blow	

Hydropulsor is developing the forming technique in collaboration with Dalarna University in Sweden.

VTT Finland

VTT, the Technical Research Center of Finland, have been studying hydroforming with ElectroHydraulic Discharges (EHD). They have built an electrohydraulic-forming device in cooperation with St. Petersburg Technical University, Russia, in a publicly funded project. The capacity is 40 kV and 48 kJ per pulse and pulse frequency 0.2 Hz.

Some Finnish companies were participating in the project, but are currently not using the technology. The results of the project have been published in seminars and in journals (in Finnish). There are no companies in Scandinavia currently using this technology in their production, although the published results have got some attention.

VTT has also had some contacts with Prof. Glenn S. Daehn, at the Ohio State University.

There are manufacturers of EHD equipment both in the United States and in Russia.

As a further development, VTT is now doing research on high speed forming with electromagnetic pulses, EMD technology. The research is done in collaboration with Finnish companies and a research laboratory in Russia. At present the EMD technology is not in industrial use in Finland. The equipment at has a capacity of 30-50 kJ pulses with less than 200 μs pulse time and corresponding peak power of 150-250 MW.

Mining and Minerals

Neither application nor development of pulsed power applications have been found in Scandinavia.

Pulp and Paper

Neither application nor development of pulsed power applications have been found in Scandinavia.

Iron and Steel

Neither application nor development of pulsed power applications have been found in Scandinavia.

Chemicals and Petroleum

Pulsed Volume Discharges for Generation of Ozone

Description

In a Ph.D. thesis from EKC at KTH[7] the potential for an industrial application of a novel concept for ozone generation was investigated[viii]. In the thesis a numerical model was developed for generating ozone in a pulsed electric volume discharge. The numerical model was verified and supported by experimental results for ozone production in a pulsed electric volume discharge by a research group in the former Soviet Union.

As part of the thesis an electric circuit was designed and simulated with the magnetically insulated MINOS switch showing that good matching for efficient power transfer can be obtained.

Based on the results, a 100 kg O_3/h unit could be realized in a compact pulsed volume discharge cell powered by a 100 kV, 500 kW power supply using existing preionized discharge and pulsed power technology. Before this is possible, further experimental and theoretical investigations are needed. Time to commercialization is probably more than 2 years, unless some company already is developing the technology.

Benefits

The model indicates that by generating ozone in a homogenous pulsed electrical volume discharge at low temperature (130 K) the energy efficiency would increase substantially. It is shown that ozone with 10% concentration can be produced on a commercial scale with an efficiency of 200-300 g O_3/kWh, depending on production parameters. The energy required for oxygen production and for cooling to 130 K is not included in the specified efficiency. A conventional dielectric barrier discharge method for the production of ozone normally has an efficiency of less than 100 g O_3/kWh.

Obstacles

To the author's knowledge the method is currently not being developed further. It has to be verified both in laboratory and pilot-scale tests. Also, a complete system needs to be developed before the method can be commercially introduced.

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[7] Department of Industrial Electrotechnology, Royal Institute of Technology, Stockholm

Key Players

At the moment there are no activities in the field.

Breaking Crude Oil Emulsions with Pulsed High Voltage Fields

Description

A technical problem facing the oil industry is the need to remove the co-produced saline water from the crude oil at the wellhead. One method of achieving this separation is by applying an electric field to the mixture. The effect of the electric field is to promote coalescence between water droplets, so that the small droplets quickly grow to a size where they can gravitate out of the mixture.

It has been discovered that the process can be made more efficient if a high-voltage pulsed DC rather than the more conventional AC equipment produce the electrostatic field. Several novel equipment designs have been developed and tested. Amongst the innovations is the coating of the high-voltage electrode with a layer of insulating material.

Normal operating parameters are pulses of 15-25 kV, pulsed with a mark:space ratio of unity (that is the pulse length is equal to the time between pulses), and frequencies in the range 0.1-60.0 Hz.

Benefits

The insulation of the electrodes enables the process to be used efficiently even on mixtures with a very high water content. The technology is capable of treating crude oil emulsions with water contents of 60% or more. The new equipment offers savings in space and weight and is, therefore, particularly important for offshore applications.

The technology is also applicable to solvent extraction operations where the natural rate of phase separation may be very slow.

Obstacles

An obstacle, or rather limitation, is that the application can only operate on a dispersion of water-in-oil, i.e. that the oil is the continuous phase.

Key Players

The application was originally developed at the Department of Chemical Engineering at the University of Bradford, England. Today, it is being developed commercially under the name of EPIC (Electro-Pulse Inductive Coalescer) by NATCO, an American manufacturer of process equipment for the oil and gas industries.

Several prototype EPIC models have been built and are being tested by oil companies like BP, ARCO (Atlantic Richfield Company), NAM (Nederlandse Aardolie Maatschappij BV) and SIPM (Shell Internationale Petroleum Maatschappij BV) at various sites, including the North Sea, Rotterdam and the United States. So far the technology has been installed commercially at two sites[ix].

Residential and Institutional Buildings

Neither application nor development of pulsed power applications have been found in Scandinavia.

Gas Treatment

Both treatment of flue gases from energy conversion as well as treatment of contaminated air are included here.

Description

Non-thermal plasmas produce reactive chemical species for the destruction of gaseous pollutants. The application has a potential for treatment of flue gases and other gaseous emissions containing harmful or odorous compounds, e.g. SOx, NOx, or VOC (volatile organic compounds). Two common devices to produce non-thermal plasma are the pulsed corona reactor (PCR) and the dielectric discharge reactor, also referred to as a silent discharge plasma reactor (SDP). Another way of producing non-thermal plasma is by submitting the gas to energetic pulses of electron beams. The destruction of the pollutants is achieved by reactions with the highly reactive chemical species – ions, electrons, and free radicals – produced in the plasma.

Benefits

There are a number of benefits of non-thermal plasma applications and they are expected to have some distinct advantages over conventional methods. For instance[x,xi]:

- High destruction efficiency

- Simultaneous removal of several pollutants
- In most cases no by-products are produced, and if they are, further treatment is facilitated
- No demands on pressure and temperature
- No catalyst is needed
- Potential for the abatement of dilute concentration of VOC
- Not vulnerable
- Widely applicable

Obstacles

When upscaling to full-scale applications problems arises with increasing capacity of the load, thus making it more difficult to produce narrow high-power pulses and high frequencies. With increasing duct sizes arises also the difficulty of exposing the entire gas stream of the non-thermal plasma.

Key Players

A number of European research institutes and companies are involved in the development or testing of gas treatment systems.

EU RTD Activities, Pulsed Corona Discharge Tar Cracker

Institut für Solare Energieversorgungstechnik e.V. is the prime contractor in an EU research project for a pulsed corona discharge tar cracker for thermally generated biogas[8]. The project goal is to offer a specific gas treatment method for thermally generated biogas. Contaminants such as tar, ammonia, hydrogen sulfide, and alkalis are detrimental to machine components and will strongly affect maintenance costs. The proposed method would avoid mechanical filters. It can operate at the high temperature of a gasifier (900°C) and it is adaptable to varying compositions of input gases and various sizes of biogas plants. It needs no gas conditioning, has a multiple cleaning effect, and avoids any further waste. In particular expected achievements of the project are:

[8] Program Acronym: NNE-JOULE C, Project Reference : JOR3980213

- Development of a compact high temperature purifier for treatment of biogas from high temperature gasifiers in a temperature range of 600-900°C.
- Integration of a gas purifier prototype into an existing lab-scale thermal 80 kW gasifier in Almelo, the Netherlands, and into a MW range gasifier being manufactured in end of the 2nd third of the project.
- The key point will be the reduction of tar to 10% per stage, so that the gas purifier is applicable for combustion engines and turbines.

Exploitation of the project results will be possible also at many other gas cleaning applications. Start date: June 1, 1998, end date: May 31, 2001.

EU RTD activities, Catalytic plasma process to limit combustion emissions affecting the environment

ENEL SpA of Italy was the prime contractor of a project for the development of a catalytic plasma process to limit combustion emissions affecting the environment[9]. The objective was to investigate principal aspects of flue gas cleaning by pulsed corona energization process. The goal was also to find design rules to reduce energy consumption and increase removal efficiency up to 70% for NOx and 80% for SO_2 for this combined DeNOx/DeSOx method. Start date: July 1, 1990, end date: June 30, 1993.

Water and Wastewater treatment

Description

Pulsed power technologies can be used for the treatment of water and wastewater, both for the reduction of microorganisms as well as for the destruction of chemical compounds. For the reduction of microorganisms the methods are similar as for sterilization/pasteurization of food, for example by pulsed electric field, UV/white light and non-thermal plasma.

For the degradation of chemicals in water, the mechanisms are similar of those for degradation of gas pollutants; i.e. highly reactive species – ions, electrons, and free radicals – react with the chemical compounds in the water. Pulsed UV catalyses reactions by the high photon flux.

[9] Program Acronym: JOULE 1, Project Reference: JOUF0053

Benefits

The benefits of pulsed power applications for water treatment are similar of those for gas treatment, i.e.:

- High destruction efficiency
- Simultaneous removal of several pollutants
- In most cases no by-products are produced, and if they are, further treatment is facilitated
- No demands on pressure and temperature
- Not vulnerable
- Widely applicable

An electrohydraulic discharge (EHD) emits UV-light as well as producing plasma. The emission of UV-light can be used in the same manner as an ordinary UV-light with the advantage of not needing any protective glass. The transparency of the protective glass needed for UV-light applications normally decreases after some time, which affects the efficiency of the installation.

Key Players

Wek-Tek

Wek-Tek, a German company, is developing and building pulsed power units for the treatment of both water and gas. They market equipment both for pulsed UV, pulsed electric field (PEF) and pulsed corona. Wek-Tek has a number of collaboration partners:

- Pulsed UV: Fraunhofer Institut Lasertechnik (ILT), Aachen, Germany, Rheinisch-Westfälische Technische Hochschule, Aachen, Germany.
- Pulsed HV technologies, PEF and "Quasi-Corona": High-Voltage and EMC-group, Eindhoven University of Technology, the Netherlands.
- Flashlamp physics and applications: Université P. et M. Curie, Laboratoire des Plasma Denses, Paris, France.
- CW high-pressure lamps and applications: Center de Physique des Plasmas et Applications de Toulouse, France.

- Photo-chemistry with flashlamps and with continuous wave lamps: Institute For Bio- & Chemical Physics, Moscow, Russia.

Packaging Processes

Neither application nor development of pulsed power applications have been found in Scandinavia

Production of Pharmaceutical Products

Neither application nor development of pulsed power applications have been found in Scandinavia.

6

PRIORITIZATION

The results of the North American study, that was done by EPRI in parallel to this study, are included in the prioritization since the results of this process will decide what applications will be investigated in the market assessment. The primary objective for the market assessment is to determine the available market for an application, regardless of where the application is being developed.

Summary of Applications

A total of 12 different applications or categories of applications were found in the Scandinavian and North American reports (some applications were put together in order to facilitate the prioritization).

Table 6-1
Applications with comments

Application	*Methods of operation*	*Comments*
Gas treatment	Pulsed Electric Discharge – plasma, corona	Flue gases (SOx, NOx), industrial emissions (VOC), odor abatement, indoor air quality
Water treatment	Pulsed Light, PEF, Pulsed Electric Discharge	Disinfection, decomposing hazardous and/or halogen compounds, prevention of biofouling
Generation of ozone	Pulsed Volume Discharges	
Non-thermal pasteurization/ sterilization	PEF, Pulsed (white or UV) light, e-beam	Liquid food (PEF), surface treatment (light) of bread, beef etceteras. Sanitation in connection with biogas production. Medical products, pharmaceuticals
Surface treatment	Pulsed plasma, ion beams, e-beams	Improved corrosion and wear resistance, surface alloying (combined with thin-film technology), adherence improvement.
Surface layer removal, cleaning/scouring	Pulsed laser, pulsed electric discharges, pulsed plasma	Paint removal, concrete removal, removal of damaged surface material, cleaning/scouring of plastics, composites, metals, surface preparation (for instance gluing operations)
Metal forming at high velocity	EHD, EMD, DMC, mechanical pulse	Forging, sheet metal forming, cutting, powder compacting
Breaking oil emulsions	PEF	Offshore technology; petrochemical technology, solvent extraction operations
Hard coating deposition, film deposition	Ion beam evaporation, plasma technology, evaporation by pulsed e-beam	Thin film coating for enhanced resistance to wear, low friction, transparent barrier layer on (polymer) packaging material
Pulse plating, anodizing		Increased productivity (aluminite process), enhanced protection against corrosion, improved material distribution, and reduced consumption of chemicals
Joining of ceramic components	E-beam	
Fragmentation of solids	E-beam, pulsed electric discharge, wire induced shockwaves, Electroblast (electronically controlled chemical reaction)	Nanocrystalline powders. Mining and minerals – no contamination, low disturbance of surroundings. Destruction of materials

Grading of Applications

The applications where judged by three criteria in a scale of marks of 1 to 3, with 3 being the best mark, i.e. the best connection to Vattenfall's line of business or shortest time to commercialization.

The three criteria:

- Market potential

  1. Small number of special applications and/or demanding expertise and adaptation of each application.
  2. Market potential not well established, market segment, or branch with difficulties of rising capital for investments.
  3. The possibility for a large number of installations of a standardized product.

- Strategic Value

  — The strategic value has been judged from the connection of the application to Vattenfall's line of business and Vattenfall's mission statement. Vattenfall's mission is to enhance customers' competitiveness, environment, and quality of life through a unique combination of efficient energy solutions and world-class service.

  1. No particular connection to Vattenfall.
  2. Being an efficient energy solution is a strong advantage of the application.
  3. Very high connection to Vattenfall's core business or within a field of high interest for Vattenfall.

- Time to commercialization

  1. More than 5 years to commercialization
  2. 1-3 years to commercialization
  3. Already commercially available.

The criteria were also prioritized so that the market potential had the highest priority, connection to Vattenfall's line of business the second highest, and time to commercialization the third highest priority.

Table 6-2
Prioritization of applications

	Market potential	*Connection to Vattenfall*	*Time to commercialization*
Gas treatment	3	3	2
Water treatment	3	3	2
Non thermal pasteurization/sterilization	3	3	2
Generation of ozone	3	3	1
Surface treatment	3	2	2
Surface layer removal, cleaning/scouring	2	2	2
Metal forming at high velocity	2	1	3
Breaking oil emulsions	2	1	2
Hard coating deposition, film deposition	2	1	1
Pulse plating, anodizing	1	2	3
Joining of ceramic components	1	1	2
Fragmentation of solids	1	1	1

The applications with the highest priority are those that are well suited for outsourcing by the customers, and in many cases do not belong to the customer's main process.

Comments

Gas Treatment

The treatment of flue gases connects directly to Vattenfall's field of action since the company owns and operates several heat and power plants. It is essential that Vattenfall have access to the best available technology for the reduction of emissions. For NOx abatement the established technologies (SCR and SNCR) are well suited for larger installations like power plants. For smaller installations, such as heating furnaces in the steel industry where the authorities are beginning to set tougher limits, there is currently no “end-of-the-pipe technology” that is established on the market.

The reduction of dilute concentrations of VOC’s is costly and energy consuming. Pulsed power applications can have a tremendous potential if it is proven to work on high gas flows.

Water Treatment

The treatment of water is necessary in almost all industrial activities, both for pretreatment of water to be used in an industrial process and for wastewater treatment. If function, capacity, and economics are at least as good as existing methods, pulsed power technology opens up a number of possibilities.

Non-thermal Pasteurization/sterilization

The food industry can be difficult and connected with certain risks for Vattenfall to enter. But apart from the food industry there are several other applications where pasteurization or sterilization is performed on a regular basis (see *comments* in Table 6-1).

A comment by the author; It seems to be well established that pulsed electric field kills the microorganisms by rupturing the cell membranes, thereby allowing for the internal fluid in the cell to come out. In many cases, such as dewatering of sludge, this would be advantageous since the water content could be further reduced. (As a consequence, the water from the dewatering step would contain much more COD that will demand further treatment before being released to the recipient).

Also, in other cases, for example the production of fruit juices, it would be advantageous and increase the yield if the cells were disrupted.

Surface Treatment

The applications for surface treatment opens up for the possibility of a more widespread use of new high-performing materials. It would be a difficult area for Vattenfall to enter since it requires specialist knowledge and networks in areas where Vattenfall has no activities today.

Generation of Ozone

Oxidation of organic material or sanitation/sterilization with ozone is an application with great potential that so far has been inhibited by high costs of investments and operation. If the costs can be reduced the use of ozone can be increased in the future.

Surface Layer Removal, Cleaning/Scouring

There are many areas where this application could be of interest, from removing graffiti to repainting airplanes. It would require expertise and adaptation of each application, depending on what is to be removed or cleaned.

Metal Forming at High Velocity

This technology is already in use today in special applications, and mainly in small scale. It has no particular connection to Vattenfall and there are many international competitors specialized in the field of metal forming.

Breaking Oil Emulsions

This application is of interest mainly for the offshore oil industry. It is close to commercialization by a company that is well established in the field. The business segment has no particular connection to Vattenfall.

Hard Coating Deposition, Film Deposition

Like surface treatment, this opens up for the possibility of a more widespread use of new high-performing materials. It requires skilled expertise in areas of cold vapor deposition (CVD) and materials research.

Pulse Plating, Anodizing

Pulse plating and anodizing is an established application and it does not require any high performing power electronics. There are major international suppliers that have worked with the application for a long time.

Joining of Ceramic Components

Ceramics is expected to be a material with growing importance in the future, for example in new high-performing combustion engines for the car industry. The potential number of units is limited and each unit would need a high degree of adaptation. It also requires skilled expertise in material technologies.

Fragmentation of Solids

Fragmentation can be used for producing nanocrystalline powders, which is required when producing special materials. The potential number of units is limited and each unit would need a high degree of adaptation. It also requires skilled expertise in material technologies.

7

MARKET ASSESSMENT – SCOPE AND METHODOLOGY

Executive Summary

Recent advances in pulsed power technology have made it possible to apply the technology to a commercial and industrial environment. Today, many facilities are unaware of the existence of pulsed power systems or find themselves struggling with applications that are not perfectly adapted to the operating conditions. It is, therefore, necessary to obtain a better understanding and characterization of the pulsed power supply as well as end-use applications in order to apply pulsed power technology in appropriate and efficient manner. The main goal of this study is to facilitate for better technology transfer.

The objective of the third part of this study was to perform a market assessment for the pulsed power applications defined and prioritized earlier in this study, i.e. gas and water treatment. The focus of the market assessment was to:

- define the most interesting markets to enter
- estimate the total market potential and market share
- propose possible business concepts and business plan

The market assessment was performed for two market segments per end-use application. The steel and metal industry and the plastic industry were investigated regarding gas treatment and the pulp and paper industry and the pharmaceutical industry were investigated regarding water treatment. Since the technology is under development a qualitative study was chosen. Deep interviews with customers were conducted and available statistics were collected.

The overall opinion among the customers was positive, although they thought it hard to say anything specific with the information given. Important aspects mentioned was:

- the need of full backup, the supplier must be reliable and represented in Scandinavia/Europe
- references, demonstration plants
- the cost-benefit analysis must be favorable in comparison to the customer's alternatives

The market assessment showed that there are interesting marketing opportunities. The total potential seems large enough and the responses from customers are promising.

As a result of this study, the final recommendations of this study are summarized as:

1. The proposed marketing strategy is to start with a limited range of applications to a limited target group. The strategy should be to start with applications with the shortest time to commercialization, i.e. water treatment for the pharmaceutical industry and gas treatment for the plastic industry.
2. The next recommended step for EPRI is to start demonstration projects in Scandinavia. The aim should be to demonstrate the efficiency of large-scale gas and water treatment by pulsed power.

Objective

The objective of the Market Evaluation was to perform a market assessment for Scandinavia for the pulsed power applications defined and prioritized in this study. The market research was performed in order to:

- define the most interesting markets for Vattenfall to enter
- estimate the market potential and market share in prioritized market segments
- propose possible business concepts and business plan

Methodology

The first step in the market evaluation was to define the most interesting markets to enter. This was done in two steps:

1. Market segmentation
2. Market targeting

The market potential and market share in the target markets was then analyzed. Finally, the last step was to develop possible business concepts and business plans. The methodology used in each step is described in the following.

Market Segmentation and Market Targeting

Market Segmentation

A market can be segmented in many different ways. Different segmentation variables can be used singly or in combination. Some major segmentation variables are

- Geographic segmentation
- Behavior segmentation
- Customer size
- Line of business

In this study the main segmentation variable chosen was “Line of business”. The reason for choosing this variable was measurability. When choosing this variable it was made possible to get information from statistics etc.

Market Targeting

Among the identified market segments we chose to prioritize two segments per end-use application. This was done in order to make the market research possible within the limits of this study.

The identification of the most attractive segments was done in discussions with business specialists within Vattenfall. The identification was based on existing statistics and knowledge of the market segments.

Estimating Total Market Potential and Market Share

The total market potential or market share is not a fixed number but a function of specified conditions. One of these conditions is the time level (short-range, medium-range and long range). Other conditions are geographical conditions or the overall environment (economical, political, or regulatory). This study is focusing on the Scandinavian market in the next few years. The overall environment is assumed to follow the same trend as in the last years. The following definitions were made:

The *total market potential* was defined as the amount of customers in Scandinavia who in the next couple of years will have a need for the function this application is fulfilling. They must not necessary want this particular application.

The *estimated market share* was defined as the amount of those customers who would be willing to make a demand of this particular application in order to satisfy their need of this function.

Total Market Potential

The total market potential was estimated with the help of interviews with business specialists and available statistics.

The information needed to estimate the total market potential was:

- Number of customers
- Their need of the function in question in terms of capacity (flow and concentration) and number

The latter was not always easy to find in available statistics. What could be found are the total number of customers and their present total discharges of water or air/gas to the environment. This does not directly show the total potential of our application since these figures do not show the discharges of water or gas before the existing treatment facilities or the number of units needed per customer.

Interviews with Business Specialists

An interview guide was developed, see Appendix A. The guide was used during the interviews with the business specialists. The same person performed all interviews. The purpose of the interviews was to get a picture of the market segment; the customer's competitive situation, needs, product forecast etc.

Available Statistics

Statistiska Centralbyrån (Statistics Sweden), SCB, was asked to provide us with information about the number of customers and their total discharges today for the four prioritized market segments in each country.

This information was complemented with information obtained from different business organizations and government agencies, for example the Swedish Environmental Protection Agency. These telephone contacts were performed without specific interview guides.

Estimated Market Share

To be able to estimate the market share the following information is necessary:

- The characteristics of the investigated product (cost, capacity, performance, reliability etc)
- The characteristics of the competitive products
- The customers' preferences, intentions and behavior

Since, in many cases, only pilot studies are conducted, information about the applications in full scale was not accessible. Therefore no hard facts about the characteristics of the prioritized end-use applications were available.

Within the limits of this study no survey of existing or coming products fulfilling the same function as the studied applications was made although some information about competitive products was possible to obtain during the line of the study.

Since the information about the applications' characteristics as well as information about competitive products was incomplete, we decided that it would not be relevant to try to quantify the market share. Instead a qualitative study was conducted. The methodology used was deep interviews with a few customers. Deep interviews give answers to questions like What?, How? and Why?, which is different to a quantitative study which gives answers to questions like How many?, How often? and How much?

Out of cost reasons we decided to interview only Swedish customers. This should not present a problem since our questions are not directly connected with cultural issues. We assumed that the cultural differences between the Scandinavian countries are of the sort that they only affect the consumer market and not the business to business market.

The selection of customers to include in the study was done solemnly by the sales staff at Vattenfall and the business specialists. The goal was to interview eight customers, two within each prioritized application and market segment. Due to time limit reasons and other practical reasons we only managed to perform five interviews. The respondents were persons who had an insight in the technical and environmental problem and who in some way participated in the purchasing process. All interviews were personal.

Developing Business Concepts and Business Plan

Outlines to business concepts and business plan were developed within this study. The means for doing this were brainstorming sessions with product development specialists within Vattenfall.

8

MARKET OPPORTUNITIES

Prioritizing Market Segments

In this study water treatment and gas treatment were identified as the two most interesting end-use applications. For each of these two applications there are a number of applicable market segments, see Table 8-1.

Table 8-1
Illustration of possible market segments for gas treatment and water treatment

Markets	Applications	
	Water Treatment	**Gas Treatment**
Pulp and Paper	X	X
Food	X	
Energy Conversion		X
Iron and Steel		X
Graphic Industry		X
Pharmaceutical Industry	X	
Mining and Minerals		
Chemicals and Petroleum	X	X
Municipal Waste Water	X	
Manufacturing Industry		X

To be able to perform a relevant market research within the given budget the market assessment had to be narrowed. It was therefore decided to concentrate on two market segments per end-use application. When prioritizing market segments there were two principal criteria that were taken into consideration:

1. Our estimation of the customers' need of water treatment or gas treatment and their desire for this particular application

2. Our estimation of Vattenfall's possibility to penetrate the market segment with this application

According to these criteria the following four market segments were chosen for the market assessment. For each market segment the reasons for prioritizing the segment are briefly described.

Water treatment:

- *Pharmaceutical Industry* – The pharmaceutical industry was believed to have an identified problem with COD in discharged waste water. Water treatment with pulsed power could be an interesting option as pretreatment prior to the conventional treatment facilities.

- *Pulp and Paper Industry* – This industry is focusing on environmental matters including waste water treatment. The market segment is believed to be large and possible to penetrate with new technology.

Gas Treatment:

- *Steel and Metal Industry* - The steel and metal industry is beginning to focus on these problems but have not come as far as for example the pulp and paper industry. The possibility to penetrate the market with a new technology is therefore believed to be greater than in other segments.

- *Plastics Industry* – This industry has a problem with discharges of VOC. Gas treatment with pulsed power is believed to be able to solve this problem in a satisfying way. The size of the normal production plants makes it suitable for the introduction of new technology. In the following an overview of the market segments that were not prioritized will be presented.

Water Treatment

Food Industry

In Sweden the food industry consists of approximately 800 companies with more than 10 employees. Many small companies but only a few large ones characterize the industry. In Table 8-2 the total number of companies within the food industry (NACE[10] code 15-16) and their turnover are presented for each country.

Table 8-2
Number of companies within the food industry (in 1996). Exchange rates used: 1 USD = 6.70 SEK, 1 USD = 6.40 NOK, 1 USD = 5.80 DKK[xii]

	Sweden		Denmark		Norway	
	Number of companies (1998)	Turnover Mill USD	Number of companies	Turnover Mill USD	Establish-ments	Gross value of production Mill USD
15-16 Food	2 697	20 500	2 665	23 900	1 729	15 100

The food industry is generating a large amount of waste water. The waste water is in principal dealt with in three different ways:

1. Directly discharged to municipal waste water plants

2. Treated in some way and then discharged to municipal waste water plants

3. Somehow treated and then discharged directly to the recipient

Despite the large amount of waste water generated in the food industry the focus on waste water treatment is not very strong. As long as the authorities will not set more strict limits on what is allowed to be discharged, the industry will not be interested enough in this kind of waste water treatment applications. In the future though, if the authorities set more strict limits, this may be a very interesting market segment.

Municipal Waste Water

In Sweden there are 2,000 public waste water treatment plants with about 7.8 million people connected. In 1995 1 360 Mm^3 water was treated in these plants[xiii].

Today, in Sweden, the most used treatment method is biological-chemical treatment with or without special nitrogen treatment. Plants corresponding to 7.3 million connected persons use this kind of treatment. The rest use biological treatment without chemical treatment or other methods[xiii].

[10] Nomenclature générale des activités économiques dans les Communautés Européennes, NACE.

In Sweden municipal waste water plants do not generally disinfect the waste water with chlorine. In specific cases this can be done, but in total the need for disinfection is not very large.

That, together with the fact that hazardous and/or halogen compounds do not present a general problem in Swedish municipal waste water treatment plants, gives us reason to believe that this should not be a prioritized market segment.

Chemical Industry

The chemical industry in Sweden is mainly concentrated to 50 plants located in the south and west parts of Sweden. Some plants are located in the north in connection with the pulp and paper industry, which provide useful by-products as well as a market for process chemicals. The number of companies in the chemical industry, defined as NACE Rev 1, chapter 24, is presented for the three Scandinavian countries in Table 8-3.

Table 8-3
Number of companies within the chemical industry (in 1996)[xii].

	Sweden (1998)	Denmark	Norway
24 Chemical industry	796	606	177

The different plants often belong to major company groups with production sites on many places in Sweden. Large foreign companies mostly own the basic chemical industries. The remaining large Swedish owned companies are AGA, Astra, Beckers, and Perstorp. In Norway large chemical companies are Norsk Hydro, Statoil and Dyno. In Denmark Novo Nordisk, Shell, Statoil, and Kemira are among the largest companies within the chemical industry.

In 1998 about 35 500 persons were employed in the chemical industry in Sweden. In 1997 the market value of chemical production reached approximately 71 000 million SEK, out of which 81% was exported[xiv].

In Sweden, many chemical industries are preparing for the introduction of environmental management programs according to ISO standard 14000 and/or to the EMAS system.

In the 1980s there were a number of mergers and acquisitions within the chemical industry. Since then there is normally only one main manufacturer of each high volume chemical in Sweden.

Pulp and Paper Industry

The industry is more thoroughly described in chapter “Market analysis”.

In 1997 the discharges of NO_x from electricity, heat and steam production within the pulp and paper industry amounted to 6 000 ton in Sweden. The industrial processes discharged around 11 000 tons of NO_x[xv]. Today the industry has solved this problem with well-established technologies such as SNCR and SCR. Because of this it is believed to be very difficult to get market shares with a new, unproven technology.

Energy Conversion

In Sweden there are about 2 300 electricity, gas, or heating plants of which 320 are heating plants. About 30 companies in Sweden generate 95% of the total electricity demand.

The discharges of NO_x from electricity, gas and heating plants in 1997 were 12 000 tons. The discharges of SO_2 were 11 000 tons in the same year[xv].

In the energy conversion industry the NO_x problems are well known and dealt with. Well-established technologies as SNCR and SCR are used. Therefore we believe it to be very hard to penetrate the market with a new, not yet fully developed or proven technology.

Graphic Industry

The graphic industry (defined as NACE code 22.2) consists of about 800 companies with a total turnover of 45 000-50 000 MSEK in Scandinavia[xii]. In 1994, the industry in Sweden discharged around 5800 ton of VOC[xvi]. According to the Swedish Environmental Protection Agency and The Swedish Graphic Company Federation the discharges of VOC have diminished considerably since 1994. Some discharges remain though, especially among companies that use mixed solvents.

Due to the information about diminishing amounts of discharged VOC this segment was not prioritized.

Manufacturing Industry

In Swedish manufacturing industry there are about 30 000 companies with a total of 400 000 employees. The presence of many small and only a few large companies characterize the industry. More than half of the companies have less than five employees and approximately 30 companies have more than 1000 employees. The value of production in 1996 was approximately 500 billion SEK[xvii].

The businesses are very differentiated, containing everything from electronics to means of transport and metal goods. Some large Swedish companies are Volvo, Saab Scania, Alfa-Laval, ABB, Electrolux, Atlas Copco, and Ericsson.

The production values in the different Nordic countries are shown in Table 8-4.

Table 8-4
Production values in the manufacturing industry in 1996. Exchange rate used: 1 USD = 0.80 ECU.[xviii]

	Production value, Mill USD
Denmark	21 500
Norway	15 500
Sweden	75 400

In 1994 the discharges of VOC in Sweden were 18 000 tons[xvi]. Since then the discharges have diminished considerably according to the Vattenfall business specialist. This is mostly due to the diminishing use of trichloroethylene when degreasing and the transition to water based colors when painting. Because of this the manufacturing industry was not prioritized.

9

MARKET ANALYSIS

In this chapter each prioritized market segment will be briefly described. The total market potential within each segment will also be discussed. Finally, a general discussion about the possible market share will be conducted.

Pulp and Paper – Water Treatment

Description of the Pulp and Paper Industry

The dominating companies in Sweden are MoDo, SCA, Stora, and Assi Domän. The industry is characterized by large investments, large fluctuations in demand, low profitability and heavy international competition. In Sweden the industry is growing with approximately 3% per year[xix].

The pulp and paper industry is focusing on the environment where also water treatment is included. The environmental work is often following the principal strategy to handle the problems at the source. That is, they are trying to improve the processes in order to minimize the generation of contaminated water. Waste water treatment is also installed as “end of the pipe”-facilities or as local “kidneys” within the processes.

Here follows a few examples of how the environmental work is performed[xx]:

- Assi Domän Kartongfabrik in Frövi have reduced their discharges of BOD from 6 tons/24 hours in the 1970’s to less than 0.3 tons/24 hours in 1996. At the same time the production has increased with 50%. At Frövi a number of different treatment technologies have been tested. Finally they decided on aerated dams with active sludge.

- In the late 1980´s Stora Skoghall believed that reaching AOX discharges of 1.5 kg/tons bleached pulp was impossible to achieve. Today, their discharge amount is 0.05 kg/tons bleached pulp, which is far below the limits set by the authorities.

- Closing the processes might give rise to new problems. At Mönsterås Bruk (Stora Cell AB) the processes at the bleaching plant were closed. The general opinion was that no external treatment was necessary. Closing the processes however, did not work out very well and the mill did not manage to reach the limits for discharges of Chemical Oxygen Demand, COD. Today, an external treatment facility with active sludge has been installed. This has reduced the COD discharges to almost 20 tons/24 hours. This can be compared with the limits set by the authorities of 23 tons/24 hours. Earlier the discharges amounted to 30 tons/24 hours, which damaged the company's credibility.

Total Market Potential

In Sweden the pulp and paper industry (NACE-code 21) consists of approximately 400 companies with a turnover of approximately 96 000 million SEK. The number of pulp and paper mills amounts to approximately 50 in Sweden and 10 in Norway. The number of companies and their total revenues in the pulp and paper industry in Sweden, Norway, and Denmark are shown in Table 9-1.

Table 9-1
Number of companies within the pulp and paper industry (in 1996)[xii]

	Sweden		Denmark		Norway	
	Number of companies (1998)	Turnover Mill USD	Number of companies	Turnover Mill USD	Establish-ments	Gross value of production Mill USD
21 Pulp and Paper	399	14 300	278	1 840	108	3 030

The waste water treatment application can be applicable in three ways in the pulp and paper industry:

1. Treatment of raw water prior to be used in the process

2. As pretreatment before the final conventional water treatment

3. As preventing biofouling within the processes

Information about the Swedish pulp and paper industry's total discharge of waste water and total amount of COD and BOD in the wastewater discharge is used to quantify the total market potential. See Figure 9-1 and Figure 9-2.

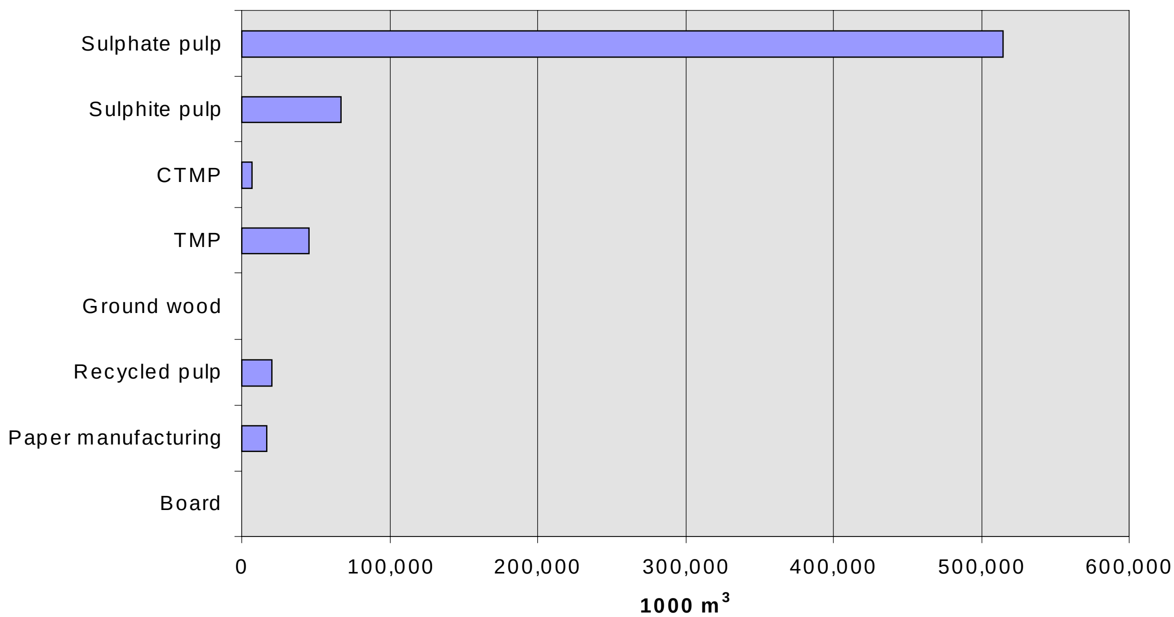

Figure 9-1
Total process outlet to water in Sweden in 1996[xx]

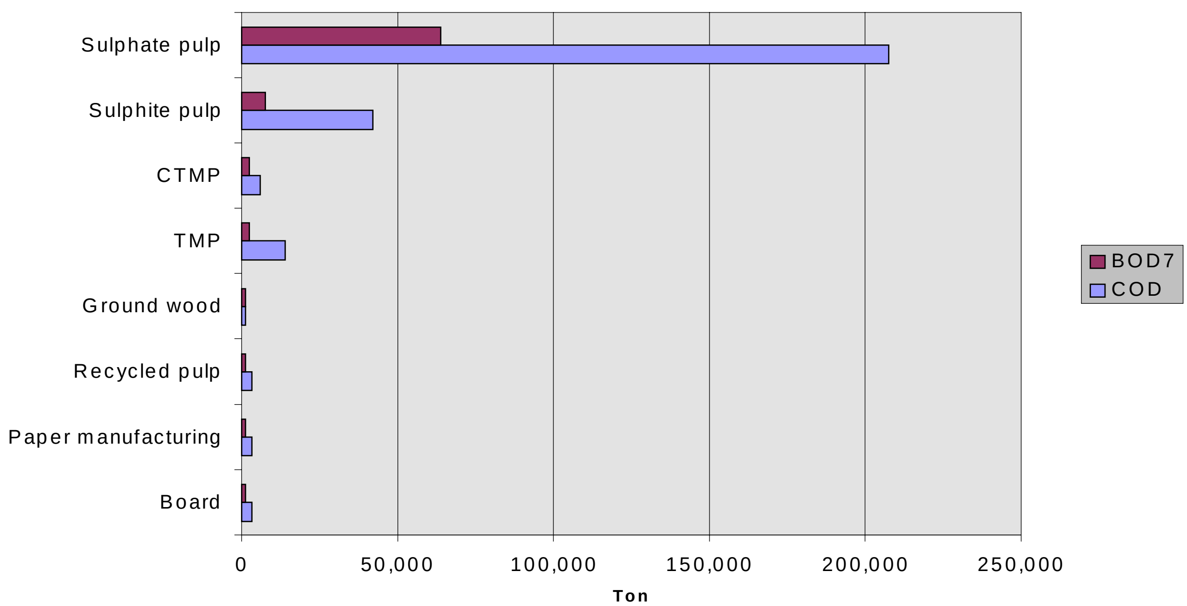

Figure 9-2
Total outlet of COD and BOD to water in Sweden in 1996[xx]

The outlet from pulp manufacturing refers to the total outlet from industries (pulp or integrated manufacturing of paper). Manufacturing of paper refers to non-integrated manufacturing. Chemical pulp industry has the largest outlet, total as well as specific. Manufacturing of sulfite pulp causes the largest specific outlets, but higher production of sulfate pulp make that this has the largest total outlet.

The number of possible units of this kind of treatment facility that could in theory be installed is not known. Some of the almost 800 companies in this segment may be too small or are in no need of this type of application while others might need more than one unit.

Pharmaceutical Industry – Water Treatment

Description of the Pharmaceutical Industry

The pharmaceutical industry in Sweden is employing approximately 15 300 persons. Another 1 000 persons are employed by the pharma industry, producing chemicals for the pharmaceutical industry. The industry is characterized by the large amounts of money spent on research and development. The resources allocated to research and development within the industry have increased from approximately 500 MSEK in 1981 to almost 6 200 MSEK in 1995. Another characteristic is the large exports, now representing approximately 80% of total sales. The export value in 1997 amounted to approximately 24 000 MSEK, equal to almost 4% of the total Swedish export[xiv].

The largest companies in Sweden are Astra AB, Pharmacia & Upjohn AB and Ferring AB.

Astra AB has since the early days had success with medicines for treatment of certain cardiovascular diseases, namely Seloken ZOC and Plendil. A rather new area for Astra is the treatment of asthma with products such as Pulmicort and Bricanyl. The largest success so far though is Losec for treatment of gastric ulcers, the world's most sold pharmaceutical product in 1996. The main part of Astra's production is located in Södertälje southwest of Stockholm. An increasing part of the production is also done in Japan and France. There are four main research centers in Sweden, one in the U.S. and one in U.K.

Important products of *Pharmacia & Upjohn* are Gentropin (a growth hormone), product for treatment of ocular diseases, and Nicorette, a nicotine chewing gum aiming at substituting smoking. The main production and research sites are in Italy, Sweden, and the U.S., where the head office is also located.

Ferring AB is a smaller pharmaceutical company in Malmö. Ferring is mainly concentrating on production of peptide hormones.

A trend in the industry is mergers between companies. One example of that is Pharmacia & Upjohn, a merger that took place in 1995. At the moment another merger is under discussion between Astra and the British company Zeneca.

Total Market Potential

In Sweden the pharmaceutical industry (NACE-code 24.4) consists of 121 companies with a turnover of approximately 13 100 million SEK. The number of companies and their total revenues in the pharmaceutical industry in Sweden, Norway, and Denmark are shown in Table 9-2.

Table 9-2
Number of companies within the pharmaceutical industry (in 1996)[xii]

	Sweden		**Denmark**		Norway	
	Number of companies (1998)	**Turnover Mill USD**	**Number of companies**	**Turnover Mill USD**	**Establish-ments**	**Gross value of production Mill USD**
24.4 Pharmaceutical industry	121	1 950	107	3 180	23	1 490

The waste water from the pharmaceutical industry is characterized by a high degree of persistent organic material, i.e. the contaminants can only be partially reduced by biological methods. The pulsed power application would serve as a pretreatment step that facilitates further degradation in the conventional waste water treatment facility.

Information about the Swedish pharmaceutical industry's concentration of COD and BOD in waste water discharge is used to quantify the total market potential in terms of waste water flow or degree of contamination. The figures represent six large manufacturing units located in the central and southern part of Sweden.

Table 9-3
Concentration of organic or oxygen-demanding material in composite samples[xxi]

Industry	**COD_{cr}** mg/l		**BOD_7** mg/l	
	Median	min-max	Median	Min-max
Pharmaceutical plants	1450	740-2700	405	240-2000

Table 9-4
Concentration of persistent organic oxygen-demanding material, stabilised composite samples.

(The term “persistent substances” refers to organic substances that have not been reduced after at least 28 days biological degradation under uniform temperature and aeration conditions and with addition of nutrients and trace substances).[xxi]

Industry COD_{cr} mg/l	COD_{cr} mg/l		BOD_7 mg/l	
	Median	min-max	median	min-max
Pharmaceutical plants	445	78-1300	<18	<10-380

The total flow or number of possible units that could be installed is not known.

Steel and Metal Industry – Gas Treatment

Description of the Steel and Metal Industry

The Swedish steel industry accounts for about 4% of the total added value of Swedish industry and employs approximately 24 000 people. More than 80% of the produced steel is exported with a net income of about 14 billion SEK. In 1997 the Swedish steel industry produced 4.7 Mtons of finished steels[xxii].

In Sweden there are 13 steel-smelting plants out of which 11 are based on scrap. The locations of the steelworks are mainly in central Sweden. All companies are privately owned.

Specialty steel, i.e. alloy and high-carbon steels amount to half of Sweden’s total crude steel production. Manufacturers of specialty steels are often concentrating their production to a limited range of grades and types and they often assume a prominent position on the international markets. The largest manufacturers of specialty steels are Avesta Sheffield, Sandvik Steel, Ovako Steel, and Uddeholm.

- *Avesta Sheffield* is a large producer of stainless steel. The company’s sales in 1997 were 19 billion SEK.

- *Sandvik Steel* is one of the leading companies within product ranges as stainless strip steel and stainless seamless tubing. The company’s sales were about than 10 billion SEK in 1997.

- *Ovako Steel* has an annual crude steel production of 0.6 million metric tons. The most important products are roller bearing steels and engineering steels.

- *Uddeholm Tooling AB* is one of the leading producers of tool steels. The most important products are cold-rolled strip of high carbon, stainless and other alloy steels.

The largest steel producer in Scandinavia is SSAB. SSAB operates two steel production units in Luleå and Oxelösund with a total annual raw steel production capacity of about 3.7 Mtons. The main products are coils, galvanized and organic coated strip and heavy plate.

In Norway Fundia and Norsk Hydro are two important companies and in Denmark there is only one producer, namely Det Danske Stålvalsverk (DDS).

Total Market Potential

In Sweden the steel and metal industry (NACE-code 27) consists of 338 companies with a total revenue of approximately 46 000 million SEK. The number of companies and their turnover in the steel and metal industry in Sweden, Norway, and Denmark are shown in Table 9-5.

Table 9-5
Number of companies within the steel and metal industry (in 1996)[xii]

	Sweden		Denmark		Norway	
	Number of companies (1998)	Turnover Mill USD	Number of companies	Turnover Mill USD	Establish-ments	Gross value of production Mill USD
27 Steel and metal	338	6 860	244	1 360	121	5 550

In 1997 the steel and metal industry discharged about 1 Mton NO_x from heat and steam generation in Sweden. The industry also discharged about 3 Mton NO_x due to the processes within the industry. The discharges of SO_2 were at the same time 1Mton and 5 Mton respectively[xv].

The amount of emission points or number of units that in theory could be installed is not known.

Plastic and Rubber Industry – Gas Treatment

Description of the Plastic and Rubber Industry

In Sweden the plastic and rubber industry employs approximately 20 000 people (14 000 people in the plastic industry and 6 000 in the rubber industry)[xxiii]. The Swedish petrochemical industry is mostly concentrated to the west of Sweden, Stenungsund. Examples of companies are Borealis and Hydro polymer. Heröya is the equivalent to Stenungsund in Norway. Large companies in Norway are Borealis and Norsk Hydro.

The companies within the plastic and rubber industry can be divided into:

- Companies producing raw materials used in the plastic industry; ethylene, propylene, cracked gasoline, butene etceteras.
- Companies refining the raw materials to basic plastics or intermediary products such as polyethylene, polyvinyl chloride, ethylene oxide etcetera.
- Companies refining intermediary products to final products, such as carrier bags, crates, cables etc.

In 1993, the production volumes of basic plastics were[xxiii]:

- 782 kton in Sweden
- 425 kton in Norway
- almost none in Denmark

There are four common production methods for working basic plastics into intermediary products or final products:

1. Casting
2. Continuous casting
3. Injection molding
4. Molding

Plastics are mostly used in products such as packages, building material, vehicles, nursing requisites, electronical components and textiles or clothes.

The rubber industry consists of a few large companies such as Trelleborg Industri and Gislaved. Rubber can for example be used in tires and bicycle inner tubes.

Total Market Potential

In Sweden the plastic and rubber industry (NACE-code 25) consists of 1 478 companies with a turnover of approximately 28 000 MSEK. The number of companies and their turnover in the plastic and rubber industry in Sweden, Norway, and Denmark are shown in Table 9-6

Table 9-6
Number of companies within the plastic and rubber industry (in 1996) [xii]

	Sweden		Denmark		Norway	
	Number of companies (1998)	Turnover Mill USD	Number of companies	Turnover Mill USD	Establish-ments	Gross value of production Mill USD
25 Plastic and rubber industry	1 478	4 150	944	3 020	356	1 100

Production of products containing unsaturated polyester generates emissions of volatile organic compounds, VOC. The total discharges of VOC from the plastic industry[11] in Sweden in 1994 were approximately 2 200 tons[xiv].

The amount of gas flow or number of units that could in theory be installed is not known.

Market Share

The market share is very difficult to estimate for both applications. Therefore it is only possible to discuss this in very general terms. Here the customers' answers regarding their existing equipment, their requirements and finally their general opinion will be commented.

Since the future market share for both applications will be affected by the authorities' decisions regarding discharges to air and water this will also be briefly described.

[11] Does not contain the rubber industry.

Authorities' Decisions

In Sweden the businesses that are comprised by The Environmental Code are given by The Decree of ecologically harmful activity and health protection (1988:899). Ecologically harmful activities refer to outlet of wastewater, solid material, or gas from ground, buildings, or constructions on ground, water areas, or ground water. If the type of construction or enterprise is mentioned in the decree, it is forbidden to build or operate the factory without permission according to The Environmental Code. The following types of constructions are for example mentioned in the decree:

- Pharmaceutical factories
- Pulp and paper manufacturing, and graphical production
- Metal production
- Production of chemical products, petroleum products, rubber and plastic goods

Permission is given by The Environmental Court for enterprises with the notation A according to the decree. The County Government Board gives the permissions to environmentally dangerous enterprises with the notation B according to the decree. The permissions are given for an individual plant, but sometimes a common practice is established for some lines of businesses.

The limits set have gradually become stricter. For example, electrostatic filters have become a common request for treatment of flue gases from combustion plants. Since, when setting limits, economics as well as best available technology, and environment is taken into consideration the electrostatic filters have become standard when it is economically justifiable.

Looking at the applications studied here this means that the pulsed power technology can become common practice if it is a good economical alternative and considerably improves the outlets to water or air. When new plants are built or when old plants are seeking a new permission the authority in question can demand that the company investigate the possibility to apply this specific technology.

The regulatory conditions in Norway and Denmark have not been investigated.

The Customers' Opinion of Water Treatment

Three customers were interviewed regarding water treatment. Their existing equipment consisted of advanced treatment of water as well as air. Some customers used aerated active sludge plants with adherent sedimentation basins for the treatment of water. Lime was sometimes used as precipitate chemical. One customer collected the process waste water in specific tanks. The water was then pumped, neutralized, and brought to a biological treatment facility. Another customer mentioned that they were trying to improve the processes and thereby lessen their discharges of COD even further.

The required waste water flows differed from about 800 m^3/day to 80 000 m^3/day. The waste water flow in the pulp and paper companies was much larger than in the pharmaceutical company.

The existing concentrations of COD in the waste water differed between 0.2-0.5 kg/m^3 in the pulp and paper industry to more than 10 kg/m^3 in the pharmaceutical industry. The requirements regarding decomposing COD were 60-80%.

The customers in question did not believe that the limits set by the authorities were going to change in the near future. They did say however that with new technology the limits might be set stricter.

The overall opinion was positive but they thought it was hard to say anything specific with the information given. More than one customer stressed the importance of the applications being able to cope with the amount of water flows that are mentioned above.

If the technology were to be applicable and economically justifiable the customers thought it might be an interesting solution to their problems. One customer thought that this product could be applicable in more than one place within their production plant. Comments like “It would fit, it does” and “This sounds very interesting” were said during the interviews. More than one customer wanted to be able to follow the future technical development of these applications.

The Customers’ Opinion of Gas Treatment

Two customers were interviewed regarding gas treatment. Both customers are within the steel and metal industry. Their main gas treatment problem consisted of dealing with dust, which was handled with different types of filters.

One customer did not see NO_x as a prioritized issue. The other however thought that reducing NO_x could be a “great thing” within their industry.

Both customers could see applications for decomposing of VOC or other industrial emissions. One customer mentioned that this could be applicable at 25 places within their plant. Operations where this could be applicable are extinction of coke, painting lines, (step) rolling mills and tempering operations.

The overall opinion was slightly positive, but they thought it hard to say anything specific with the information given.

10

PURCHASE DECISION PROCESS

Purchase Decision Processes in General

When discussing the customers' purchase decision process questions arise like

- Who participates in the buying process?
- Who makes the decisions?
- What decisions are made in the purchase decision process?
- What are the major influences on buyers?

In this chapter these questions will be discussed in general terms. In the next chapter the answers from the customers interviewed in this study will be discussed.

Participants in the Buying Process

The persons who are participating in the purchasing decision process are often called the "buying center". The members of the buying center can play different roles. Three important roles are described in the following:

Users – The persons who will use the product after it is purchased

Influencers – Persons who affect the buying process by defining specifications, providing information and evaluating alternatives

Buyers or *deciders* – Persons who have the authority to select or approve of the final supplier

Decisions Made in the Purchase Decision Process

When purchasing new equipment you have to make a whole set of decisions. The number and type of decisions however, depends on the type of purchase. There are at least three different types of purchases:

New purchase – This is when a company is buying a product or a service for the first time.

Modified rebuy – This is when a company are replacing an existing product or service with a similar but not exactly the same product or service.

Straight rebuy – This is when a company are replacing an existing product or service without modifications.

The new purchase situation is probably the best situation to face when trying to sell a completely new product such as the applications studied here. This is also the type of purchase situation we have focused on when prioritizing the market segments. The modified rebuy can also be an opportunity for new products. A straight rebuy however, does not offer an opportunity for a new product.

The buyers make their decisions when moving through a purchasing process. This process generally consists of a number of phases. Each phase will be more or less penetrated by the customer depending on what type of purchase situation they have. The different purchase phases are:

1. Recognition of a problem

2. A general description of the needs

3. Product specification

4. Supplier search

5. Proposal solicitation – Qualified suppliers are invited to submit proposals

6. Supplier selection

7. Final order

Major Influences on Buyers

The customer is subject to many influences when making their buying decisions. Some of these influences are briefly discussed here:

The environment – The economic environment such as cost of money, political and regulatory developments, rate of technological change etc will affect the decision process.

The customer organization – The organization's objectives, policies, systems, organizational structure etc will also influence the purchase decision process.

Interpersonal factors – between persons in the buying center or between supplier and customer will have an impact on the decisions made.

Individual factors – The participants in the purchase decision process have their own motivations and preferences depending on their age, education, personality etc which will also influence the buying process.

Results from Customer Interviews

Purchasing Process

Firstly the customers need to believe in the technology. They have to be convinced that this kind of technology can work with the requirements given by their processes. One customer has a development department, which the new technology must pass. Another customer wants to have test equipment installed where he can see exactly what happens in their processes and that the product functions satisfactorily.

When convinced that this technology might work most customers start a project group that evaluates the product. The decisions are made within the project group but must be approved of by the authorities.

One customer mentions that a purchasing process often starts with new directives from the authorities. The environmental department then starts to translate the authorities' requirements to the people working with the industrial processes. Thereafter a project group is put together with a constructor as project leader.

Requirements

Most of the customers stress the importance of the applications working all the time. Backup and service are of major importance. The availability must be 100% according to more than one customer. If the application should not work this means large economical losses for the companies.

Another important requirement is the capacity regarding flows and concentrations. Especially in the pulp and paper industry the customers comment on the importance of the applications being able to cope with very large flows. The product efficiency and the type of residues that arise are also important issues. One customer mentions the need of 100% guarantee of the treatment results.

The product must consist of material that can cope with almost anything, i.e. steel of some kind. Most customers expect their equipment to last 20 years.

The country of origin for the product does not matter to most of the interviewed customers. What is more important is that the supplier are represented not too far away from the customer since they regard backup and service as very important.

Many of the customers regard themselves as friendly towards new technology. One customer, however, claim that they are rather restrictive when it comes to new technology.

When discussing price many customers become rather silent and do not want to answer those questions. The answers given range between a couple of hundred thousand Swedish crowns to a couple of million SEK. These answers depend naturally on the believed customer benefit.

One customer mentions that being able to lease the equipment is a great benefit. They want the supplier to build the facility and then themselves to lease it. Another customer however, does not see leasing as a great opportunity. In practice they want to buy the facility.

11

KEY TECHNICAL, MARKETING AND STRATEGIC ISSUES

In this chapter we will discuss the key technical, marketing and strategic issues found in this study. These issues are essential for the applications' future in the studied market segments. The key issues are:

- The need of tests in full scale – references
- Cost-benefit analysis in comparison to the customer's alternatives
- Suppliers
- Time to commercialization
- Marketing - information

Each key issue will be described in the following.

Need of Tests in Full Scale – References

Today, the applications have only been tested in pilot scale. No test in full scale has been conducted. It is however, out of most importance, that such tests are performed for technical as well as marketing reasons.

Tests in full scale are a necessary step in the technical development. Now there are pilot tests that point at very interesting results. But it is not uncommon that problems arise when trying to extend the possible flow range.

Tests in full scale are also very important as references for potential customers. Many of the customers interviewed in this study have said that this seems to be an interesting application, but it has to be able to cope with much larger flows if it should be of any interest to them. It is therefore utterly important to be able to show potential customers that this application is capable of handling the flows and concentrations that are common in the industry.

Cost-benefit Analysis in Comparison to the Customer's Alternatives

Another important issue is the relationship between these applications' costs and benefits for the customer in comparison with the other customer alternatives.

One example could be a customer in the steel and metal industry that wants to lessen his discharges of NO_x. Doing this he has more than one alternative. One alternative is buying this application based on pulsed power technology. Other alternatives could be to change fuel, i.e. converting to electricity, or to try to improve the combustion process. The customer will then value the different alternatives according to their costs and benefits.

Suppliers

The suppliers of equipment found in this study are relatively small and are only in exceptional cases represented in Scandinavia. In the customer interviews many of the customers stressed that 100% availability, good service and back up is essential. It is therefore important to be able to show the customers that the suppliers are reliable, close and have a good reputation. If the supplier is a Scandinavian or foreign company seems not to be important however.

Time to Commercialization

The time to commercialization for these two applications is estimated to 0-2 years. Since time to commercialization is very hard to estimate and it is not uncommon that development processes take more time than estimated, this is a key issue. The risk is that other products will be developed and able to penetrate these markets before the pulsed power applications are commercialized. This means that other products might capture important market shares. These market shares will then be very hard to regain.

Marketing – Information

If these applications are to be successful they have to be known to the customers. If the customers have recognized a problem they need to get hold of information about these applications in order to be able to buy them, therefore this is a key issue.

To improve the customers' knowledge about these applications the supplier has to be visible. This can for example be done by participating at trade fairs or by appearing in trade press.

12

BUSINESS PLAN

In this chapter possible business concepts and plans will be generally discussed. No thoroughly developed concepts and plan will be presented since the information and resources available are not sufficient.

The general strategy proposed is to start to offer only a limited range of applications to a limited target market. When this has been successfully established new applications can be offered and new markets can be served.

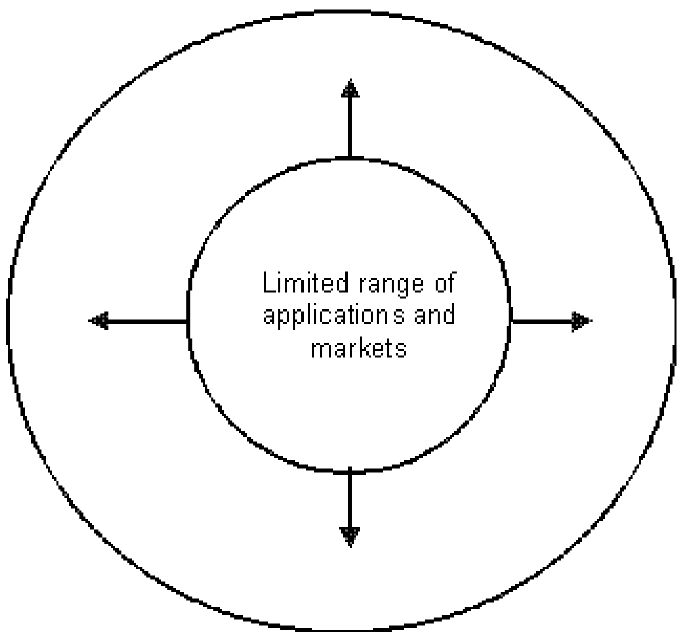

Figure 12-1
An illustration of the strategy to start with a limited range of applications and markets and then expand with new market segments and applications

Based on the information gathered in this study a plan has been developed that shows in which order different market segments should be penetrated with different applications. The plan is illustrated in Table 12-1. The number ones are the segments that should be penetrated first and number twos the applications and segments that should follow. The underlying criterion for this plan is to start with applications and market segments where the time to commercialization is believed to be the shortest.

Thereafter the strategy is to follow up with new market segments and applications in a natural order so that the most interesting business opportunities are made available.

Table 12-1
The table illustrates the order to put new applications on the market

Market segments	Applications	
	Water treatment	
	Decomposing of hazardous and/or halogen compounds	*Prevention of biofouling*
Pulp and Paper Industry	2	2
Pharmaceutical Industry	1	
Food Industry	3	
	Gas treatment	
	Reduction of NO_x	*Decomposing of VOC*
Steel and Metal Industry	2	(1-2)
Plastics and Rubber Industry		1
Other businesses	3	2

The offer made to the customer can take different proportions depending on the customer's needs and wants and what the supplier wants to deliver. Possible business concepts are for example:

1. Equipment sales
2. Equipment sales with service contract
3. Equipment leasing (with service contract)
4. Function sales

When moving from number one to number four the commitment between supplier and customer will increase. The supplier risk will also increase as well as the potential profit margin. Number four, Function sales, will in some form involve outsourcing. Not all customers are ready for that kind of business concept. The strategy proposed is however to strive to reach concept number four if possible.

When discussing business concepts an interesting issue is the different actors that are involved. Eleven different actors or roles have been identified.

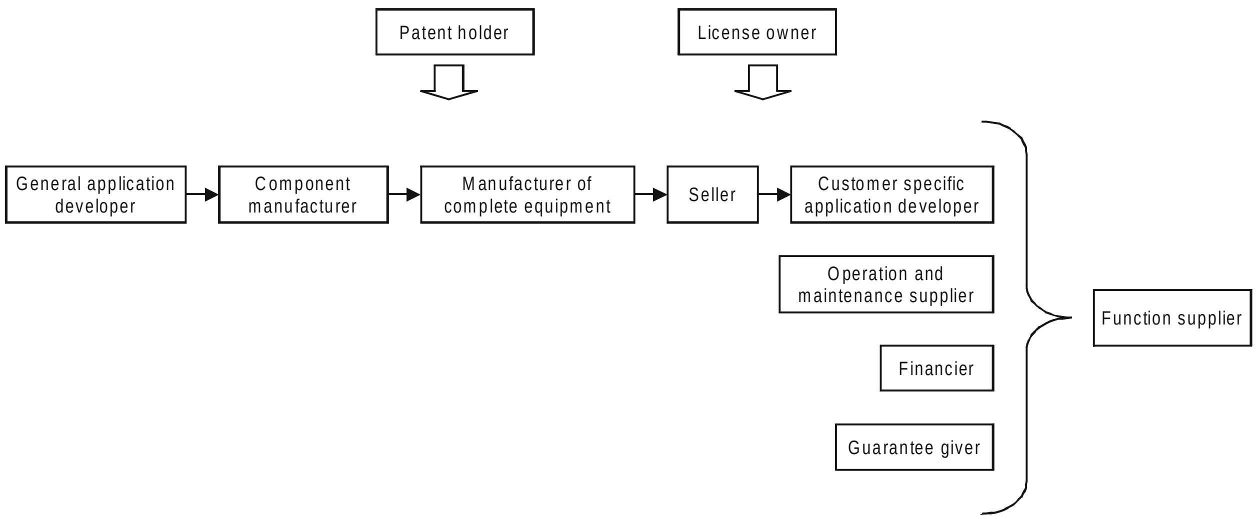

Figure 12-2
The different actors or roles identified.

1. General application developer – The actor who participates in the development from pilot tests to commercialized products.
2. Component manufacturer – The manufacturer of components needed.
3. Manufacturer of complete equipment – The supplier of the complete equipment.
4. Seller – The one who acts as seller towards the customer.
5. Customer specific application developer – The one who installs and adjusts the equipment for each customer.
6. Operation and maintenance supplier – The one who supplies the customer with service and maintenance.
7. Financier – The one who offers the customer some kind of financial service.
8. Guarantee giver – The actor that gives the customer a guarantee of the function.
9. Patent holder
10. License owner
11. Function supplier – The one who supplies a complete function to the customer.

All actors are not necessary in all of the four above business concepts. If the customer only wants business concept number one, Equipment sales, actor number 6-8 and 11 are not necessary. All actors are only necessary when supplying business concept number four, Function sales.

When deciding on a business concept and business plan it is important to have an idea of who are going to play the different roles. Questions like who are to supply the necessary components or who are to act as seller towards the customer are necessary to answer. It is important to note though, that the different actors not necessarily are different companies. One company can act as more than one actor.

13

SUMMARY AND RECOMMENDATIONS

The market assessment has shown that there are interesting market opportunities for the pulsed power applications gas treatment and water treatment in the market segments studied here. The total potential seems large enough and the responses from customers are promising.

The study has also shown the importance of being able to show the customers results from tests in full scale. If the technology is to be successfully introduced in Scandinavia demonstration projects must be conducted.

Therefore, the next step recommended is to start a demonstration project in Scandinavia. The demonstration project should be performed together with a Scandinavian partner and a potential customer. EPRI's contribution could be to provide the equipment and the technological know-how. The Scandinavian partner, together with the customer, should then evaluate the project from technical and economical perspectives. The project result should be an EPRI report and perhaps a customer workshop.

To be able to start a demonstration project however, a suitable customer has to be found. This means that some kind of marketing effort must take place. The workshops in May 1999 are one way of marketing the technology. Another way is to invite Scandinavian customers to demonstration sites in North America. The latter, if possible, is believed to be a more effective way to introduce the technology.

A

QUESTIONNAIRE – BUSINESS SPECIALISTS

Estimating Total Market Potential

- Useful statistics (Turnover, number of companies, discharges of water or gas, production etc)
- General assessment

Estimating the Market Share

- Existing technology
- New investment or replacement of existing equipment
- Competitors

The Potential Customers

- Competitive situation
- Needs
- Process requirements
- Environmental policy

The Customers' Purchasing Process

What is important when buying new equipment?

- Product performance
- Product specifications
- Size

- Price
- Marketing
- Distribution/Suppliers

Are there any cost or quality thresholds?

B

QUESTIONNAIRE – CUSTOMERS

Introduction

Presentation, introduction with a short description of the outline

How would you like to describe your company's line of business? What are your major products?

What is your position within the company?

What are your main tasks?

Analysis of the Situation Today

How would you like to describe your company's situation today? Conditions? Opportunities?

What strengths and weaknesses do you see within your company?

Are their any consequences on your environmental work?

Can you describe your competitive situation?

What will the future look like for your company?

What will change and how will it change?

What future opportunities and threats do you see for your company?

Introduction to Water/Gas Treatment

How do you treat gas/water today?

What are your requirements of these functions?

Does treatment of water/gas present a problem for your line of business today? Destruction problems, residues, problem with expansion?

What are your quality requirements on the treatment equipment?

What volumes do you treat today?

What concentrations?

Looking forward, will the need of treatment of gas/water change?

What is your opinion of how the customers' or other organizations' requirements or demands will develop?

How will your volumes change in the future?

How does this affect your demands on this function?

Description of the Applications

A description is read to the customers.

What is your opinion?

How does this fit into your requirements?

What advantages do you see with this application?

What disadvantages do you see with this application?

What opportunities or limitations do you see with this application?

Their requirements and wants regarding the following properties are discussed:

- Capacity
- Range of concentration
- Investment
- Energy consumption
- Operating expenses

- Suppliers
- Residues
- Additives

Decision Process when Purchasing

When a need arise, what is your course of action?

How are you handling the following aspects when making a decision about purchasing new treatment equipment?

Working environment

Function, performance

Quality

Environmental aspects

Size

Appearance

Average length of time used

Supplier – geographical

Is there a cost limit? What is the cost limit today? How will this change in the future?

Is there a quality/performance limit? What are they?

Who makes the final decisions? Who participates in the decision making process?

How do you feel about using new technology? Are you usually the first to use new technology or do you wait and see the results from others?

How do you usually “buy” new equipment of this kind? Outsourcing, leasing, buying, service agreements?

What could a supplier do to make your purchase decisions easier?

C

REFERENCES

General references to the methodology used for the market evaluation:

Philip Cotler, “Marketing Management, analysis, planning, implementation and control”, seventh edition, Prentice-Hall International Editions, 1991.

i Bo H. Vanderberg, “Experimental and Analytical Study of a Magnetically Controlled Thermionic Vacuum Switch Concept” Ph.D. thesis, Royal Institute of Technology, 1994.

ii M. A. van Houten, “Electromagnetic Compatibility in High-Voltage Engineering”, Ph.D. thesis, Eindhoven Institute of Technology, 1996.

iii E. J. M. van Heesch et al., “Pulsed Corona for Gas and Water Treatment”, 11th IEEE International Pulsed Power Conference. [conference paper, 4 or more authors]

iv Mustafa Fincan, “Processing Fluid Foods with High Intensity Pulsed Electric Field”, M.Sc. thesis, Lund Institute of Technology, 1998

v T. Grahl and H. Markl, “Killing of microorganisms by pulsed electric fields”, *Appl Microbiol Biotechnol,* March 1996 45(1-2) pp 148-157. [magazine article, 2 authors]

vi Thomas Ohlsson, SIK, “Help for Fruit Juice”. [Draft for EU-demonstration project, partly funded by EU]

vii “Laserchock mot virket får färgen att fästa bättre” Ny Teknik 1996:12 [magazine article]

viii J. O. Nilsson, “Numerical Modeling of Pulsed Volume Discharges for the Generation of Ozone”, Ph.D. thesis, Royal Institute of Technology, 1997.

ix Correspondence with Prof. Bailes, November 11, 1998.

x B.M. Penetrante et al., “Power Consumption and Byproducts in Electron Beam and Electrical Discharge Processing of Volatile Organic Compounds” Environmental Applications of Advanced Oxidation Tehnologies – Proceedings of the 2nd International Symposium. [conference paper, 4 or more authors]

xi L. A. Roscha et al., “Field Demonstration and Commercialization of Silent Discharge Plasma Hazardous Air Pollutant Control Technology”, Environmental Applications of Advanced Oxidation Tehnologies – Proc of the 2nd International Symposium. [conference paper, 4 or more authors]

xii SCB, Information Service, 1999.

xiii “VA-verk 1995 – Statistiska uppgifter över kommunala vatten- och avloppreningsverk”, Statistik VAV S95, Svenska Vatten och Avloppsverksföreningen, 1997.

xiv “Chemical Industry in Sweden, Facts and Figures”, Kemikontoret, 1998.

xv SCB and the Swedish Environmental Protection Agency, “Utsläpp till luft i Sverige – svaveldioxid, kväveoxider, koldioxid, metan, dikväveoxid, kolmonoxid, flyktiga organiska kolväten och ammoniak 1997”, Statistiska meddelanden, ISSN 1403-1655, SCB, 1998.

xvi Kjell Karlsson, Hedvig Froste, Niklas Svenningsen, Gisela Köthnig, André Zuber, Ola Jörnstedt, Katrin Rapp, Gia Vickbom, “Flyktiga organiska ämnen och kväveoxider”, SCB, Rapport 4532, 1996.

xvii Information material from Association of Swedish Engineering, 1997.

xviii Information from Bengt Lindqvist, Association of Swedish Engineering, 1998.

xix Information from Vattenfall business specialists.

xx Staffan Olofsson, ”Energi och miljösiffror i svensk massa- och pappersindustri,”Department of Chemical Engineering, LTH, 1998.

xxi Ingvar Björklund, Åke Undén, “Characterization of discharges from the chemical industry”, the STORK project, Rapport 4766, Swedish Environmental Protection Agency, 1996.

xxii “The Swedish Steel Industry”, Information from The Swedish Institute, www.si.se/eng/esverige/steelind.html, 1998.

xxiii Olof Krugloff, “Plasterna i vårt dagliga liv”, Plastbranschernas Informationsråd (PIR), 1995.