Technology and Innovation in Canadian Industry

An Information Kit for Science Teachers

Canada

Technology and Innovation in Canadian Industry

An Information Kit for Science Teachers

J. Douglas Wrigglesworth
and
Graham Orpwood

Orpwood Associates
Toronto

1988

National Conference on
Technology and Innovation

Desktop Publishing by DTP Training Centre Inc., Toronto

CONTENTS

PREFACE

In January 1988, the Right Honourable Brian Mulroney, Prime Minister of Canada, invited some 200 "key decision-makers from industry, universities, labour and government" from all parts of Canada to meet with him in Toronto for a special purpose: "to discuss the challenge facing the Canadian economy and to develop a consensus on the changes needed to meet the challenge."

The objectives of the conference were:

- to consider the international challenges to the competitiveness of Canadian industry;
- to highlight the importance of technology and innovation as the basis for change; and
- to encourage a commitment on the part of industry, governments, universities and labour to accelerate the shift to a knowledge- and technology-intensive economy.

While education in elementary and secondary schools was not the major focus of the conference, its importance, in meeting the technological challenges facing Canada today, was constantly referred to. Not only does Canada need more people to enter the fields of science and technology, it needs a population that understands more about the impact that science and technology are having on society and it needs young people with the knowledge, skills and attitudes that are appropriate for work in a knowledge-based society. The quality of our elementary and secondary school education was therefore considered to be one of the most significant factors in the future competitiveness of Canadian industry.

From the point of view of the conference organizers, therefore, disseminating information about technology and innovation to schools was seen as important. It is equally important to schools as well. New curricula in science and social studies in most provinces stress the importance of students learning about the linkages between science, technology and society and of their learning this information "in a Canadian context."

These kits -- one each for science and social studies -- have been developed in the form of sets of case studies, in which accounts of recent technological innovations in a variety of Canadian industries illustrate the general themes of technology and innovation. It is intended that teachers will be able to integrate this information readily into their courses in science or social studies at the senior levels of high school.

It is also hoped that the information contained in the kits will stimulate both students and teachers to research further into the many ways in which Canadian companies are using science and technology to create new "higher value-added" products and to renew the methods of producing traditional products.

The kits have been produced by Orpwood Associates, a consulting firm specializing in the areas of science and education, through a contract with the Ministry of State, Science and Technology. The authors of the kits, Doug Wrigglesworth (Science) and Tim Fielding (Social Studies) are both

teachers with the North York Board of Education and their release to attend the Conference is gratefully acknowledged.

Orpwood Associates wishes to acknowledge the contributions of a very large number of people who have helped to make the publication of these kits possible, and especially the following: Janet Ferguson (Manager) and the members of the Secretariat (National Conference on Technology and Innovation, Ottawa); Christine Westover (Alcan International Ltd., Montreal) and James Davis (Alupower Inc. Bernardsville, NJ); Joseph Shlesak (Department of Communications, Ottawa); Catherine Enright (Seafarm Venture, Sambro Head, Nova Scotia); Danielle Gagnon, Diane Hardy and David Nostbakken (International Development Research Centre, Ottawa); Bruce Jenk and staff (Wastewater Technology Centre, Burlington, Ontario); Jim Hendry (MacDonald-Dettwiler, Richmond, B.C.); Don Nickerson (NewTech Instruments, St Johns, Newfoundland); Bill Atkinson (Forintek, Montreal); Lynda Moore (B.C. Forest Industries, Vancouver); James MacFarlane (International Submarine Engineering, Port Moody, B.C.); Susan Forbes (Allelix, Mississauga, Ontario); and Graham Johnson (Ostred Sea Farms, Halifax, Nova Scotia). The authors also acknowledge the assistance of their colleagues, particularly Dave Simpson and Nicole Hodge (North York Board of Education), in reviewing earlier drafts of this document.

June 1988

Graham Orpwood
Toronto

TECHNOLOGY AND INNOVATION

Teaching Science for the 21st Century

Teaching about technology and industrial innovation in the context of a high school *science* course is, for most teachers, something relatively novel. Traditionally, the objectives of senior science courses have centred on learning about the nature and processes of science itself -- as well as learning the science content itself, of course. But increasingly, teachers are being encouraged by Ministry or Department of Education curriculum guidelines to relate the scientific content of their courses to technology, to societal issues, and to the Canadian context in which it is applied.

This booklet contains information about three cases of the application of science in technological innovations developed in Canada. Each of these case studies is related to a science topic routinely taught at the high school level, one from each of physics, chemistry and biology, as follows.

1. ***SHARP: The Microwave Powered Plane***
   This account of the Stationary High Altitude Relay Platform (SHARP), a microwave-powered plane developed by the (federal) Department of Communications, will fit with topics in the physics curriculum such as "energy transformations."

2. ***ALUPOWER: The Aluminum-Air Battery***
   The Aluminum-Air battery system was developed by Alcan International at their Kingston laboratories. This case will readily be related to the oxidation-reduction unit of the senior chemistry program.

3. ***BELON OYSTERS: Genetics in a Resource Industry***
   Genetic engineering is finding a wide variety of applications in Canada, including this aquaculture venture in Nova Scotia. Information about the farming of oysters and other shellfish can enhance the teaching of genetics in the senior biology program.

Before we examine the individual cases, some general comments about science, technology, innovation, and their growing importance for the Canadian economy are appropriate. While it is interesting for students to learn more about the applications of microwaves, electrochemistry and genetic engineering, the more important lessons are general ones about technology and its impact on our society and economy.

The following is only a very brief introduction to these complex topics. Readers interested in pursuing the subject further might want to see the Proceedings of the National Conference on Technology and Innovation (available from the Ministry of State, Science and Technology in Ottawa) as well as reports from such agencies as the Economic Council of Canada, the Science Council of Canada, and the (Ontario) Premier's Council.

Science and Technology

The words "science" and "technology" both tend to be confusing because they both have a variety of meanings. They each refer to a process (and, by extension, to a corresponding professional enterprise). They also refer to the general products of these processes: in the case of science, to a body of knowledge; in the case of technology, to a collection of techniques or "know-how". Again, by extension, more specific references are to individual sciences (such as genetics) and to specific technological hardware (such as computers). Finally, the term "science and technology" is used to refer to an important social and political factor in the changing economic world.

For present purposes, however, it is important to distinguish the first two sets of uses and Figure 1 contains visual images with which to do this. In these illustrations, science and technology are each depicted as being both process and product.

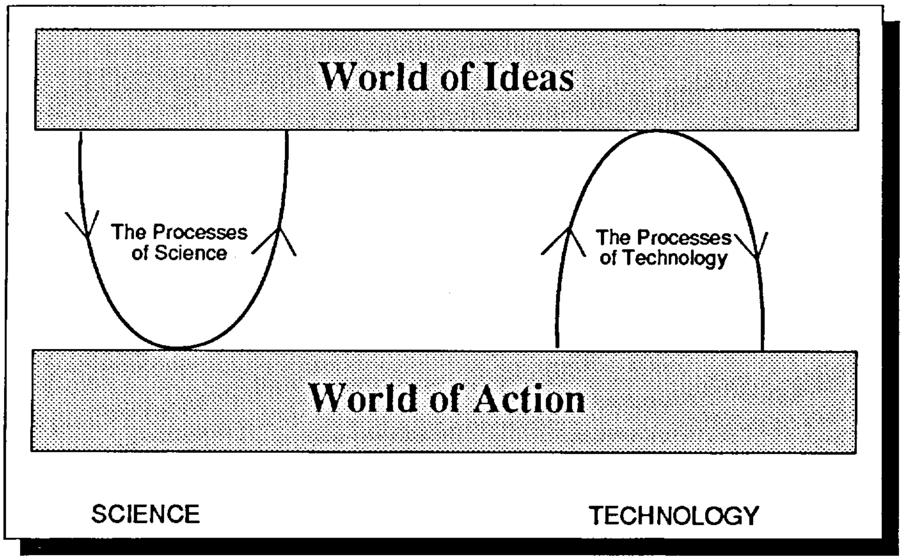


Figure 1: The Processes of Science and Technology

The word **Science** is derived from the Latin word for knowledge and is defined by the Oxford English Dictionary as:

> systematic and formulated knowledge . . . dealing with material phenomena and based mainly on observation, experiment and induction.

It also describes the process by which that knowledge is formulated. The word **Technology**, by contrast is derived from the Greek word for art, in the sense of technique, which is defined (also by the OED) as the:

> means of achieving one's purpose (especially skillfully).

Again the term has come to mean both technological product (a piece of hardware) and the process through which that product was developed.

Aristotle distinguished the two in terms of "the theoretic" (i.e. science) and "the practical" (i.e. technology). In simple terms, the essence of science is knowledge -- improved understanding of phenomena is its goal -- while the essence of technology is action -- making something happen or function better. And while we often think of "science and technology" together, these differences are important, especially for educators concerned with helping young people acquire the knowledge, skills and attitudes they will need throughout life.

For most of recorded history, science and technology developed relatively independently. Occasionally, technology developed something that enabled new scientific discoveries (such as the telescope). But it is only in the last century or so that science has itself provided the means for new technological developments. And only in the past few years has technology grown directly and rapidly from basic research in science.

The examples described in the three case studies here illustrate this point rather well. For example, the science of genetics is about one hundred years old. But it is only in the past few years that the detailed biochemical basis for the genetic make-up of life has been elucidated. Yet, the application of this knowledge to enable specifically desired changes in living species to be engineered has become a reality within a remarkably short period of time. And the specific case that is documented here is the story of scientific discoveries from the laboratories of Dalhousie University being applied immediately to the formation of a successful oyster farming business based on this technology.

Technology and Innovation

The process of technological change has been continuing throughout recorded history. And, like change in most areas of human life, it is often ignored, feared, or resisted by many. But while change may be a threat to some, to the entrepreneur it means opportunity. And as the rates of change of nearly all technologies increase, the challenge for Canadian industry is clear: to seize these opportunities and develop new products and processes or be left behind and eventually to go out of business.

The nature of this change process has been well described in one of the background papers published for the National Conference on Technology and Innovation, entitled *Technological Change and Innovation in Canada: A Call for Action* (by Brian Schofield and Robert Thomson of McKinsey & Company) and the following is a summary of their introduction to the topic.

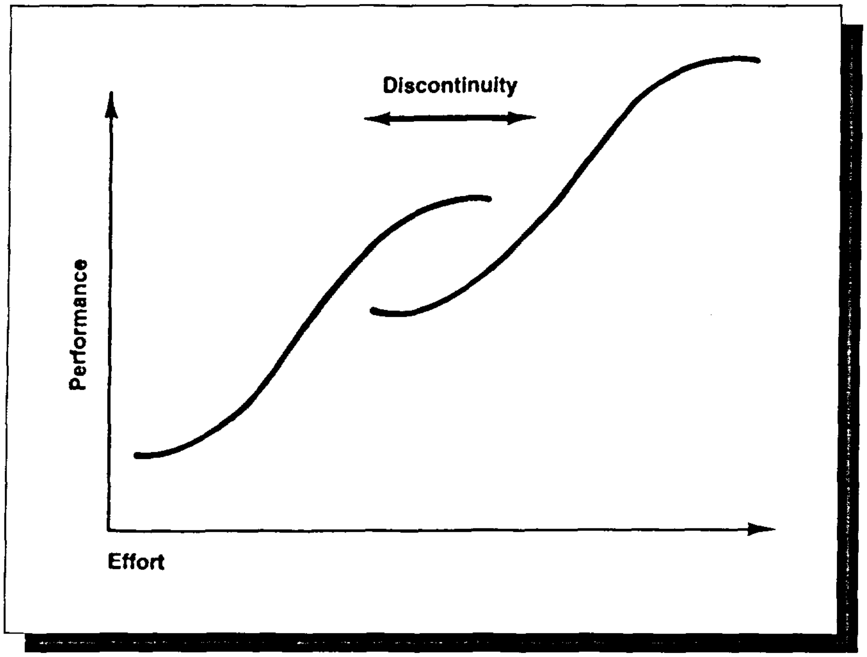


Figure 2: The S-Curve Framework ***(Source: McKinsey & Company)***

The technological change process is illustrated by means of what they call the S-curve (see Figure 2). The curve shows how any technology goes through a non-linear cycle of development and maturation until it approaches the limits of its performance. This is followed by a sharp discontinuity as a new technology emerges. Initially, and this is important, the performance of the new technology is less than that of the older one, tempting conservative industries to retain unchanged their traditional, proven, and (at this point in time) highly profitable processes or products. But as more effort is directed toward the new technology, its performance outstrips that of its predecessor.

In their discussion paper, Schofield and Thomson illustrate this sequence of events with numerous examples. In the evolution of tire cord for instance, they describe the rise and fall of cotton, followed by rayon, followed by nylon, and finally polyester, all of which followed the S-curve cycle.

The implications of this pattern for Canadian companies is the main theme of the paper. They argue that Canadian companies must innovate in order to compete in the global market place and they propose four main steps that companies should take to meet this challenge.

"1. ***Attack, don't defend.*** To compete successfully in the future, Canadian companies must proactively innovate and adapt technology rather than defend the status quo.

"2. ***Invest in knowledge and skills.*** To develop the capacity to attack, companies must build knowledge and skills through each stage of technological evolution.

"3. ***Broaden horizons.*** Canadian companies must build global and technological alliances to be competitive in the world arena.

"4. ***Instill a spirit of change.*** Companies must develop strong senior management leadership to surmount barriers to innovative behaviour and to ensure innovation and technological change become a corporate way of life."

As the National Conference showed, there are Canadian companies who have risen to this challenge and are successful in their use of new technology. The example of Alcan (whose Aluminum-Air battery is described in the second of the case studies) is reported in more detail in the conference proceedings by its Chairman, Mr David Culver, whose address dealt with "how technology and innovation can be managed in a real-life situation and under conditions of fairly rapid economic and technological change."

As Canadian business recognizes the need to innovate and use the latest technologies, it is also recognizing the strategic importance of education, especially in math and science, in meeting these challenges. The Conference concluded with such statements as the following:

> "We must ensure that Canada's education and training systems are positioned to produce the most important value-added product -- the qualified researchers, technicians and business managers who will lead us into the 21st century.
>
> "Pivotal to improving the quality and standards in education is a better public perception of the value of our teachers.
>
> "We need to support excellence in our teachers, those who first challenge our young minds and then prepare those young minds who are willing to learn."

This last statement was from the Prime Minister in his closing remarks. This information kit is intended to assist science teachers as they seek to challenge and prepare students to take their place in a technology-based world.

Educational Aims and Objectives

In order to provide practical help for secondary school science teachers, this kit is designed to contain easy-to-use material, suitable for classroom use. The kit will address two major themes:

1. The concepts of science, technology, innovation and entrepreneurship in Canada in the 80s;

2. The relevance of Canadian examples of innovation in science and technology to specific units found in science programs at the senior grade levels in all provinces of Canada.

Objectives

Through the use of this material, students will:

- acquire an increased sensitivity to the practical application of science and technology concepts;

- gain an appreciation of the accomplishments of Canadians in the fields of science and technology and be encouraged to pursue innovative activities on their own.

With respect to the individual subject-centred cases, students will:

(in the physics case)
- understand how the principles of transmission of energy through electromagnetic radiation can be applied to the powering of an aircraft;

- appreciate the applications that a microwave powered plane can have in the field of telecommunications;

(in the chemistry case)
- understand how the principles of oxidation-reduction are applied in the aluminum-air battery;

- appreciate several commercial uses of the aluminum-air cell, and the unique features of the cell that make it ideal in these applications;

(in the biology case)

- understand how the principles of genetics are being applied to commercial aquaculture, in particular to the farming of shellfish;

- appreciate how the integration of scientific principles and entrepreneurial methods contribute to the success of an innovative business venture such as an aquaculture enterprise.

References

(on science and technology)
Barnes B., & Edge, D. (eds.) *Science in Context* (Cambridge, Mass.: MIT Press, 1982).

Ziman, J. *An Introduction to Science Studies* (Cambridge, England: Cambridge University Press, 1984).

(on technology and innovation)
Drucker, P. *Innovation and Entrepreneurship: Practice and Principles* (New York: Harper & Row, 1985).

Foster, R. *Innovation: The Attacker's Advantage* (New York: Summit Books, 1986)

Schofield, B.T. & Thomson, R. *Technological Change and Innovation in Canada: A Call for Action*, Discussion Paper prepared for the National Conference on Technology and Innovation (Ottawa: Ministry of State, Science and Technology, 1988).

National Conference on Technology and Innovation, *Proceedings* (Ottawa: Ministry of State, Science and Technology, 1988).

Competing in the New Global Economy, Report of the Premier's Council, Vol. 1 (Toronto: Government of Ontario, 1988).

(for students)
Botting, D., Gerrard D., & Osborne K. *The Technology Connection: The Impact of Technology on Canada* (Vancouver: CommCept Publishing, 1980).

Gradwell, J., Welch, M., & Vincent, J-F., *Techno 2000: An Introduction to Technology* (Toronto, Copp Clark Pitman, 1986).

SHARP

The Microwave Powered Plane

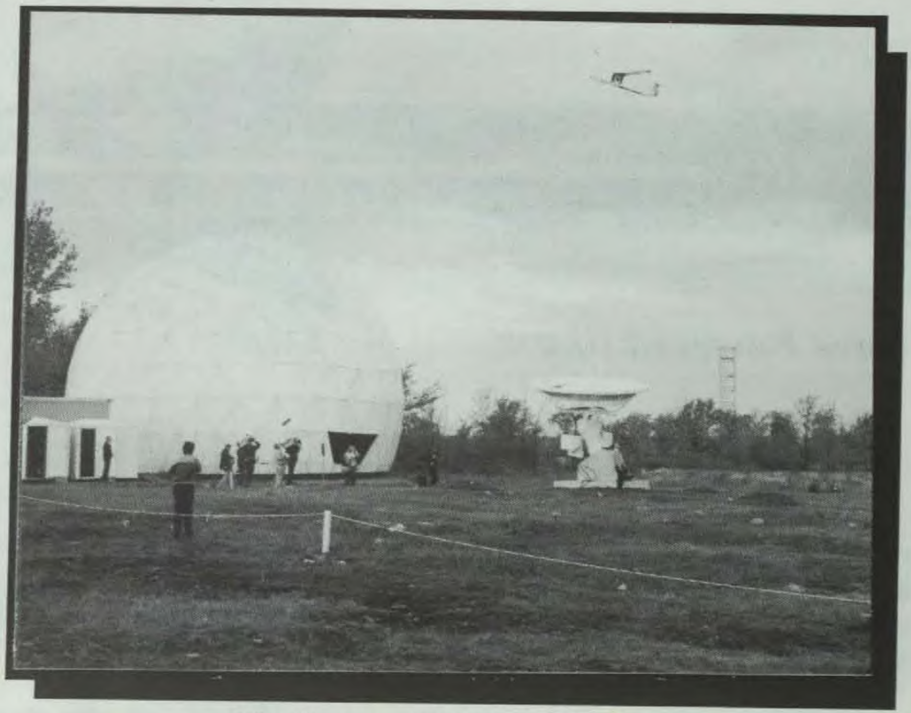
Difficulties in communicating over vast, largely unpopulated regions of a country such as Canada have only recently been alleviated by the use of communications satellites. Nowadays however, people living in large areas of Canada receive their television signals via the Anik series of communication satellites.

Satellites, however, suffer from disadvantages, not the least of which is cost. So, in order to provide a much less expensive and more flexible platform for communications purposes, the Department of Communications undertook the SHARP (Stationary High Altitude Relay Platform) project. Researchers at the Communications Research Centre (CRC) in partnership with their counterparts in industry and universities have been working on the SHARP concept and testing prototypes for about five years.

The SHARP system consists of a high altitude, microwave powered airplane which acts as a platform for the relay of telecommunications signals. These signals could provide everything from direct broadcast television, mobile telephone service, radar warning networks and border surveillance, to the monitoring of environmental pollution.

The goal of the Department of Communications SHARP program was to develop the world's first microwave powered, pilotless aircraft, capable of uninterrupted flight. Such an aircraft, with an appropriate payload, would provide a more reliable communications service than that provided by manned aircraft and at a lower cost than through the use of space satellites.

In a series of tests during the fall of 1987, the world's first microwave powered plane was flown in Ottawa (see the photographs overleaf). In these flights, a 1/8 scale model of the SHARP aircraft with a 4 metre wingspan was taken aloft under battery power. At an altitude of about 100 m, the battery was turned off and the plane was powered and controlled by microwaves beamed up from a dish antenna on the ground. A special receiving antenna on the aircraft transformed the microwave energy into direct current for the electric motor and propeller. At the end of the flight, the plane returned to earth under battery power.



The first test flight for SHARP

SHARP and its developers

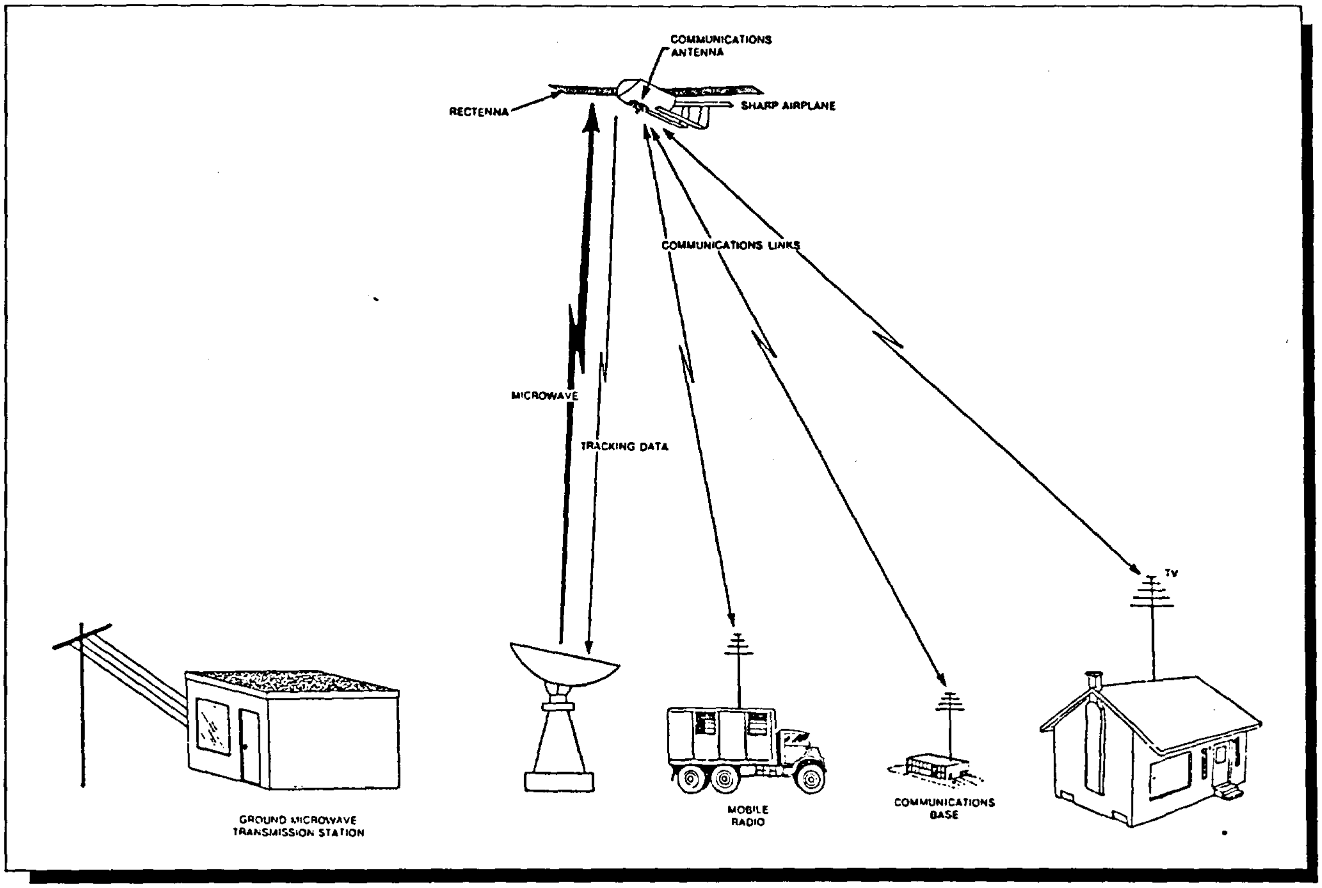


Figure 3: The SHARP System

This significant example of Canadian technology was recognized around the world, both in the science and technology literature and in the popular press. When developed to a commercial level, SHARP will be powered by a dozen or more microwave transmitters on the ground and will fly at an altitude of 21 km. A 600 kg plane will be powered by a 25kW motor and carry a 100 kg payload at a speed of more than 200km/h. Figure 3 illustrates a typical configuration of the SHARP system in action.

The Physics of SHARP

The eccentric genius, Nikola Tesla (1856-1943) made many discoveries and inventions of great value to the development of radio transmission and the field of electricity. Tesla also dreamed of the transmission of electricity without wires and devoted decades of fruitless efforts in experiments to that end. He even published in 1928 a prediction that, some day, aircraft would be powered by "wireless." Other pioneers of electrical research such as Hertz, Steinmetz, and Marconi also worked

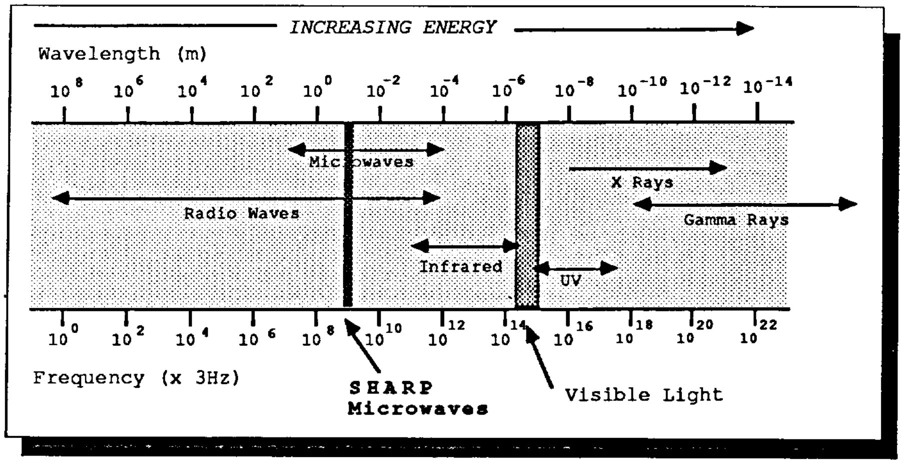


Figure 4: The Electromagnetic Spectrum

on the idea of broadcasting electrical power using radio waves. Many of the difficulties resulted from the problems encountered in focussing long radio waves into a tight beam.

Both radio and microwaves are forms of energy belonging to the electromagnetic spectrum (Fig 4.). The relationship of energy to frequency is given by Planck's famous relationship:

$$E = hv$$

(where E is energy in Joules, v is frequency in Hz and h is Planck's constant, 6.63 x 10^{-34} J.s).

The relationship of frequency to wavelength is given by:

$$v = c/l$$

(where v is frequency in Hz, c is the speed of light in m.s^{-1}, and l is wavelength in metres).
The AM radio band, with frequencies beginning at 560 kHz, has wavelengths in the hundreds of metres, while the waves in a microwave oven have a frequency of 2.45 gigaHertz and a wavelength measured in centimetres. The advantage of short wavelengths for power transmission is the ability to focus the energy tightly and this enables their use in television transmission.

Converting Microwaves to Electrical Power

Communications is one thing; electrical power transmission is something entirely different. In theory, microwaves are transmitted to a distant receiver, where they are converted to electricity. But to get a useful amount of power, very high power levels must be transmitted. Until the development of the Magnetron tube, for radar purposes during World War II, this was the limiting factor in power transmission. Magnetrons now power microwave ovens and form the basis of the power supply in the SHARP project.

The basic process of collecting and converting microwaves to Direct Current power is performed by a rectifying antenna (or rectenna) mounted on the airplane. The energy is collected by an array of simple dipoles. Conversion to DC power is achieved by incorporating solid-state electrical circuits using rectifying diodes at each dipole.

Much of the early work on rectennas was in support of the proposed NASA Solar Powered Satellite Program and was designed to collect satellite microwave power on the ground. Early efforts by William Brown at Raytheon Corporation in the 1960s resulted in a flight at 20 m altitude by a small tethered helicopter-like device. The most important advance made by Brown and his colleagues was the development of the rectenna. Serious problems with size and efficiency limited the development however.

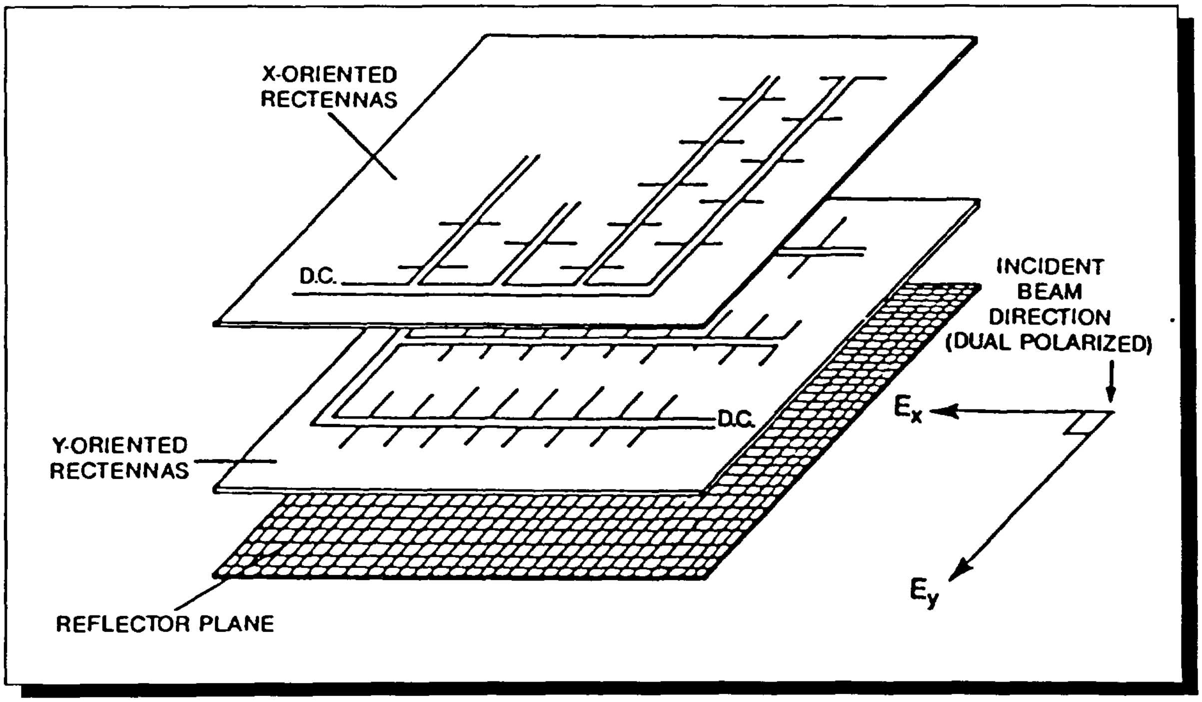


Figure 5: A Dual Polarization Rectenna

Major improvements were made at the (Canadian) Communications Research Centre by A. Alden and T. Ohno. These developments allowed the production of a version of the rectenna suitable for airplane power conversions. Figure 5 shows the new dual polarization configuration that allowed the focussing of microwaves on a moving object such as the SHARP airplane.

Using microwave power enables operators to keep SHARP flying continuously and provides it with more power than it needs to fly. SHARP might need 25 kW to fly, but the microwave system provides an extra 10 kW to power the communications system it carries.

The Aircraft

One of the biggest and most time-consuming questions to answer concerned which shape of aircraft would be the most effective. There were two key design considerations. On the one hand, the power needed to fly must be minimized, and this can be achieved with a glider-like design with very long and slender wings. On the other hand, capturing the microwave power requires large surfaces for the rectenna assemblies. The final design is a result of balancing these two conflicting demands.

The plane which was developed and built by the scientists at the Communications Research Centre in Ottawa, and which flew in the flight trials, has a wingspan of 4.5 m, a length of 2.9 m, and a mass of 4.1 kg. It is constructed of balsa wood, with other woods used where additional strength is needed. A high energy-to-mass ratio electric motor with Cobalt magnets drives a large diameter (60 cm) highly efficient propeller.

The final version, which will be offered commercially, will have a wing span of 40 m and a fuselage 17 m in length. In order to provide enough area for the rectenna, a very large disc will be set behind the wings. A more complete comparison of the characteristics of the 1/8 scale prototype and the full scale model is as follows:

Parameter	1/8 scale	full scale
Altitude	150 m	21 km
Wingspan	4.5 m	40 m
Length	2.9 m	17 m
Disc diameter	1.1 m	9.0 m
Weight	4.1 kg	600 kg
Payload weight	1 kg	100 kg
Power (motor)	150 W	25 kW
Speed	10 m/s	60 m/s
Rectennas	411	10,000

Applications of SHARP

Since the weather is less changeable at 20 km altitude than on the ground, exciting possibilities exist for the use of SHARP as a pollution surveillance aircraft. It could monitor emissions of sulfur dioxide (which produce acid-rain) and provide essential information regarding global transport that is currently unavailable. Carbon dioxide concentrations could be monitored in order to study the greenhouse effect.

SHARP also has possible applications in national defense. It could carry radar sensing systems which could monitor activities within Canada's 320 km offshore limits.

In communications, SHARP's potential uses are varied and elegant. A network of SHARPs carrying communications across Canada could provide truly regional broadcasting. SHARP could also enable cellular radio to be used in areas that are not heavily populated.

SHARP is also an inexpensive alternative to satellites. A commercial version would cost about $20 million -- about $1 million for the plane and $19 million for the dozen microwave transmitters needed. This compares favourably with the cost of the average communications satellite, which is $100 million or more, not including ground relay stations.

Suggestions for Classroom Use

It is expected that this material will be most useful in secondary school physics classes during the discussion of such topics as the following:

- Energy transformations and the laws of thermodynamics;
- Momentum and energy;
- Quantum theory;
- Electricity and electromagnetism;
- Electromagnetic radiation.

Where independent study projects are encouraged, students might use the SHARP project as a stimulus for further study in aeronautics, transmission of energy by radio waves, and many other related areas.

References

Brown, William C. "The History of Power Transmission by Radio Waves" *IEEE Transactions on Microwave Theory and Techniques*, vol. MTT-32, no. 9, September 1984.

Fisher, Arthur, "Beam Powered Flight?" *Popular Science*, January 1988.

Jull, G.W. *Summary Report on Sharp*, Communications Research Centre Report No 1393, (Ottawa: Communications Canada, 1985).

"Can a Plane Fly Forever?" *Newsweek*, September 28, 1987.

ALUPOWER

The Aluminum-Air Battery

In October 1987, shortly after the first public flight of the SHARP microwave powered plane (see the SHARP case study earlier in this kit), scientists at the Kingston (Ontario) labs of Alcan International launched the world's first plane using aluminum as its unusual energy source. Powered by aluminum batteries, the radio-controlled plane flew for 41 minutes (see the photograph of this historic flight). Incidentally, both the SHARP plane and the Alcan plane were designed by aerospace engineers at SKYTEK, a Canadian engineering company.

ALUPOWER technology in flight

The batteries, more durable than any other portable energy cell, had been the focus of a major research effort by Alcan. While other research groups in the U.S. had also been trying to develop the aluminum-air battery concept, it was 14 Alcan scientists who won the race and, through Alupower Inc. -- its subsidiary located in New Jersey -- Alcan hopes to develop the technology of the aluminum-air power cell for a wide variety of markets.

The Ideal Battery

Through the application of chemical principles, batteries allow us to store electrical energy in the form of chemical potential energy. Portability, found in most of today's batteries, is essential for many of their uses. Even the fairly old battery technologies, such as the lead-acid battery used in cars and the flashlight battery, have been improved greatly over the past few decades. And in some advanced applications, such as the space program, major advances have been made in battery technology.

The search for the ideal battery has continued however. Such a battery would have all the following features. It would:

- be lightweight;
- produce a large amount of energy relative to its size;
- be inexpensive and (ideally) disposable;
- use readily available raw materials;
- have an indefinite shelf life and long service life;
- be safe to use with environmentally safe byproducts;
- return to service rapidly following discharge.

A battery with these features would have immediate application in thousands of areas where the heavy, short-lived batteries of today simply would not be practical. Amazingly, the simple aluminum-air battery appears to come very close to this ideal.

The Chemistry of the Electrochemical Cell

One of the most commonly applied principles of chemistry is that potential energy contained in chemicals may be converted to electrical energy. Such electrical energy can power our personal stereos, our calculators and our watches; it can also be the source of power for more complex systems such as heart pacemakers and spacecraft. Not all the applications are beneficial; it is interesting to note that the same principle is responsible for many forms of corrosion as well.

Figure 6 illustrates a simple electrochemical cell that can produce enough electricity to light a small light bulb. In this cell, *atoms* of zinc metal in the anode lose electrons and are oxidized to form zinc *ions* in solution.

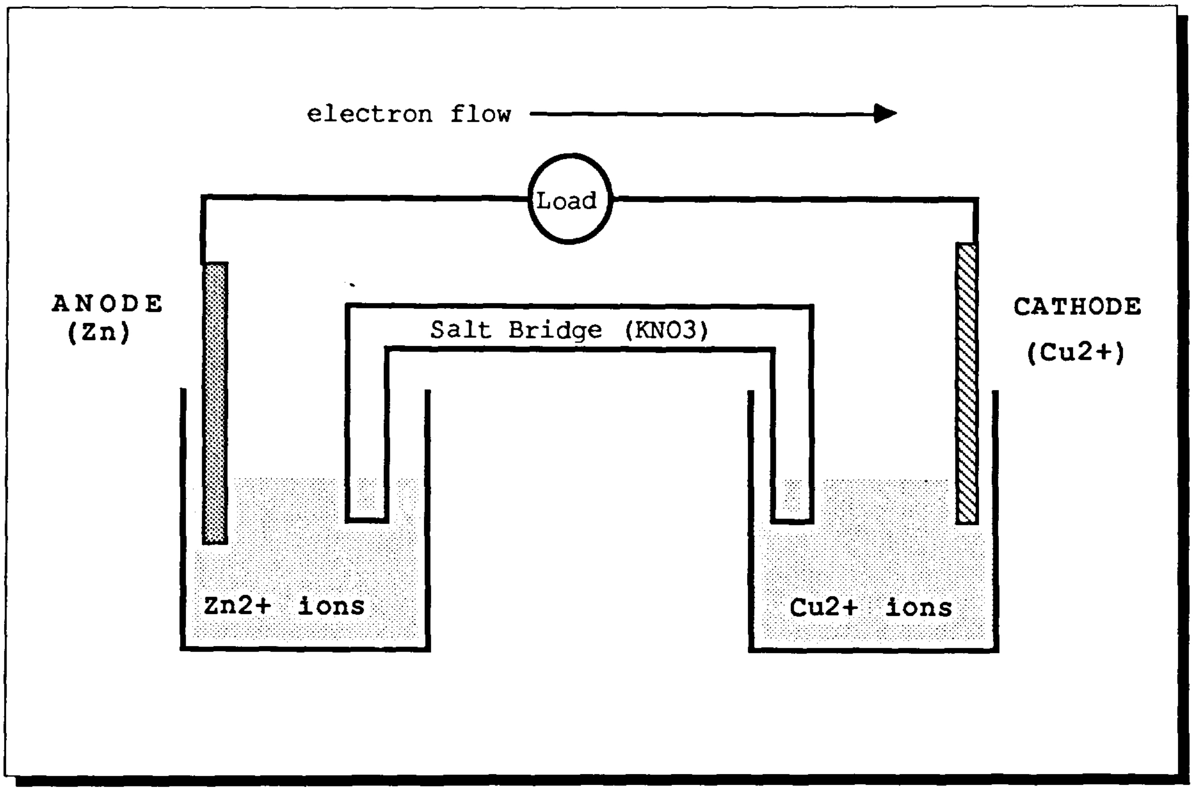


Figure 6: A Simple Electrochemical Cell

$$Zn_{(s)} - 2e^{-} \text{ ---> } Zn^{2+}{}_{(aq)}$$

The electrons produced in this way pass through the load -- the light bulb, for example -- and are taken up by the cathode -- in this case, copper metal in a solution of copper ions. The copper *ions* readily gain electrons and are reduced to *atoms* of copper metal:

$$Cu^{2+}{}_{(aq)} + 2e^{-} \text{ ---> } Cu_{(s)}$$

Cells like this depend on the fact that different substances have different tendencies to gain or lose electrons. Here, zinc metal *loses* electrons more easily than does copper, while copper ions *gain* electrons more readily than do zinc ions. These tendencies can be measured in volts and listed as *half-cell potentials*.

$$Zn_{(s)} - 2e^- \longrightarrow Zn^{2+}_{(aq)} \quad E° = +0.76\ V$$

$$Cu^{2+}_{(aq)} + 2e^- \longrightarrow Cu_{(s)} \quad E° = +0.34\ V$$

=====================================

$$Zn_{(s)} + Cu^{2+}_{(aq)} \longrightarrow Zn^{2+}_{(aq)} + Cu_{(s)}$$

These half-cell potentials can be added to calculate the potential of a complete cell. In the present case, the potential of the zinc-copper cell is 1.10 volts.

$$E°_{cell} = 0.76\ V + 0.34\ V = 1.10\ V$$

Metals vary widely in their ease of oxidation. This can be readily illustrated on a chart such as the following:

Easily oxidised --------------> Less easily oxidised

Li K Ca Na Mg Al Zn Fe Co Cu Ag Au Pt

Loses electrons easily ---> Loses electrons less easily

This is only a very small sample of the materials that can be used in electrochemical cells. All that is required is one substance that is easily oxidized -- i.e., one that loses electrons easily -- to be linked with another substance that will easily gain electrons -- i.e., one that is easily reduced. By selecting appropriate pairs of substances, many different cells can be created, with characteristics that suit many different applications and situations.

In any practical electrochemical cell, useful work can be done by this conversion of chemical potential energy into electrical energy. This useful work is described scientifically as "free energy" or, more precisely, as *Gibbs Free Energy* (G). The change in free energy of a chemical system is an indicator of the maximum quantity of work that can be done by the corresponding cell. Figure 7 compares the free energy changes corresponding to the oxidation of several different elements.

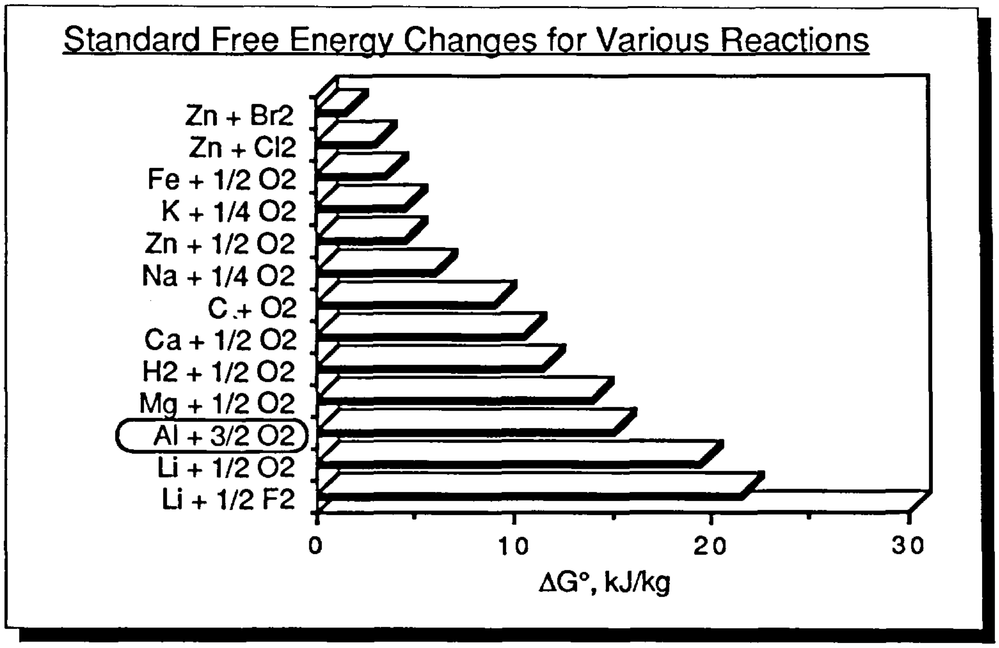


Figure 7: Standard Free Energy Changes of Oxidation

The Aluminum-Air Cell

In the century since the development of a practical process for producing aluminum, it has become an increasingly important material in our society. Its value as an inexpensive, light but durable metal is demonstrated by uses as varied as foil for the home barbecue and the primary material in aircraft production.

One property of aluminum, and one that makes it especially suitable for use in a fuel cell, has been generally overlooked until recently. It has a very high "energy density", the ratio of its (relatively large) standard free energy of oxidation (as shown in Figure 7) and its (relatively low) density.

This obvious advantage for the use of aluminum as an anode in fuel cells has been overshadowed by several difficulties. In the first place, a tough and compact oxide film is always present on the surface of metallic aluminum, which makes it somewhat inert. This oxide film can be removed with alkali but this leads, in turn, to a second problem, the production of hydrogen gas and a general reduction in cell efficiency. Yet a third problem was the clogging of the system with the precipitation of aluminum compounds that are a product of the cell reactions.

Now, as a result of the major research program undertaken by Alcan scientists in Kingston, a new cell design has been developed that overcomes these difficulties to produce a unique type of battery. Figure 8 illustrates the basic chemistry of the design.

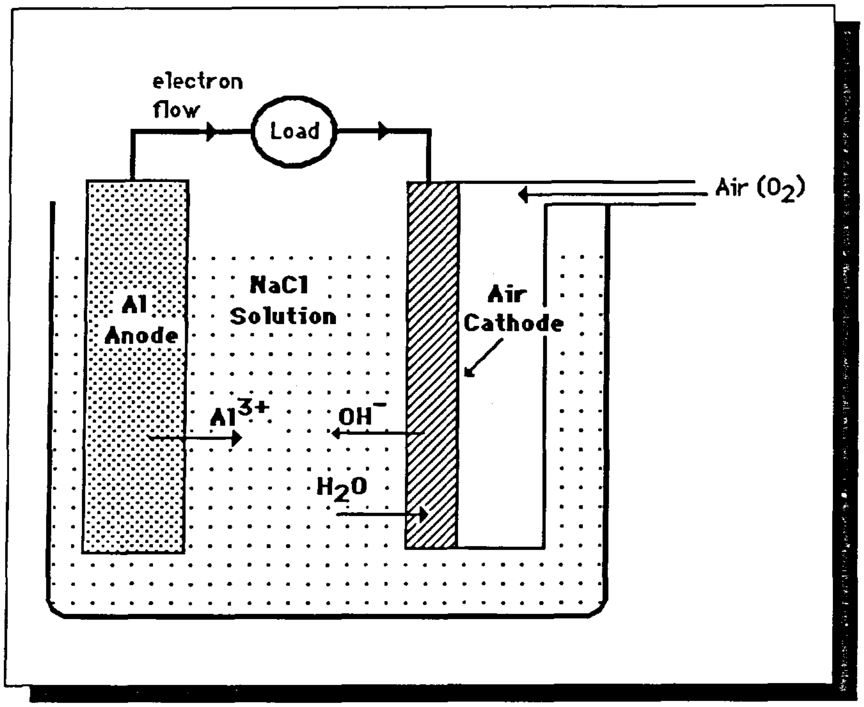


Figure 8: The Aluminum-Air Cell

Anode Reaction

$$Al_{(s)} - 3e^- \text{ ---> } Al^{3+}_{(aq)} \quad E° = +1.66 \text{ V}$$

Cathode Reaction

$$O_{2(g)} + 2H_2O + 4e^- \text{ ---> } 4OH^-_{(aq)} \quad E° = +0.40 \text{ V}$$

=====================================

Overall Reaction

$$4Al_{(s)} + 3O_{2(g)} + 6H_2O \text{ ---> } 4Al(OH)_3 \quad E°_{cell} = +2.06 \text{ V}$$

This new battery uses an aluminum alloy as the anode and air as the cathode. The electrolyte is salt water. Recharging simply involves replacing the aluminum anode as it is consumed, and keeping the salt water topped up.

Applications of the ALUPOWER cell

A re-examination of the list of features of the ideal battery will show that Alcan has come very close to this ideal. The aluminum-air battery is lightweight, powerful, easy to recharge and inexpensive. It is already being marketed in combination with a portable convenience lamp, an emergency strobe lamp, and a marine barge and buoy marker, and will likely be an increasingly important source of power in the future.

One important application that is being investigated is the aluminum powered automobile. The properties of the aluminum-air battery suggest real possibilities for the development of a practical electrically powered automobile which would have a range comparable to current gasoline powered cars.

Suggestions for Classroom Use

It is expected that this material will be most useful in secondary school chemistry classes during discussion of the following topics:

- Oxidation/Reduction;
- Electrochemical Cells;
- Thermodynamics (in particular, the second law and Gibbs free energy);
- Conversion of chemical potential energy to other forms.

Students in secondary school physics classes studying sources of electrical energy could also find some of this material useful. Other relevant electricity topics include voltage, amperage, simple circuits, types of batteries.

Students in more junior science classes could use this material in the study of alternative sources of energy. The environmental advantages of the aluminum-air battery could be pointed out.

In courses in which students are encouraged to take advantage of independent study units, the aluminum-air battery provides an interesting starting point for a series of investigative laboratory activities.

Measurement of the effects of various factors (such as temperature, electrolyte type, electrolyte concentration) on cell voltage and/or length of cell life;

Construction of competitive cells from different materials;

Innovative applications of electrochemical cells.

An excellent, inexpensive demonstration model of the aluminum-air battery has been developed for classroom use. It is available from:

SPECTRUM Educational Supplies
125 Mary Street
Aurora, Ontario
L4G 1G3 Phone: **(416) 841-0600**

The catalogue number is 11-210 and the cost approximately $30.00

References

Despic, A.R. "Aluminium and Electrical Energy Conversion," *Indian Journal of Technology* vol 24, August 1986, 465-472.

Scamans, G. "Development of the Aluminum-Air Battery," *Chemistry and Industry* February 1986.

Wald, Francine. *Alupower: The Story of The Aluminum Air Power Cell* (Bernardsville, NJ: Alupower Inc., 1987).

BELON OYSTERS

Genetics in a Resource Industry

Aquaculture and Biotechnology

The Belon Oyster: A Gourmet's Delight

A new technological revolution has been under way since the early 1970s. The application of biological techniques to industrial processes has created new products, enhanced the productivity of traditional industries, and helped to protect the environment.

The role of the entrepreneur in this revolution is typified by Dr. Catherine Enright, the owner of Seafarm Venture, a Nova Scotia oyster farming enterprise. Dr. Enright has used her academic training in marine biology, and her entrepreneurial skills, honed in an MBA program, to establish a thriving venture in aquaculture.

A native of Windsor, Ontario, Catherine Enright took her undergraduate education at the University of Windsor, and followed this with a PhD in marine biology from Dalhousie University in Halifax, which awarded her the degree "with distinction." Her thesis dealt with the care and feeding of "juvenile European oysters" -- the Belon oyster that has begun to form a significant part of the North American gourmet food market.

Seafarm Venture: A View of the Bay

Catherine Enright Preparing the Nets

During her time as a researcher between an undergraduate degree and the completion of the doctoral program, Catherine Enright found that her expertise with biological research was not really very useful when it came to applying her work to a commercial venture. Concerns over this led her both to embark on an MBA program and to establish her own private aquaculture enterprise, Seafarm Venture, in the bay next to her home in Sambro Head, on the South Shore of Nova Scotia.

The burgeoning aquaculture (fish farming) industry in Atlantic Canada is a classic example of the use of biotechnological advances to support an industry. Aquaculture has several advantages over the natural fishery: producers can concentrate on low volume, high priced species; they can ensure quality control and even alter the characteristics of species to meet customers' preferences; and they can guarantee a year-round supply (and therefore -- of considerable importance from their own point of view -- a year-round income). Through the application of genetic selection and through attention to factors affecting growth such as feeding and culling, production of shellfish and other marine products have been greatly enhanced.

The Nature of Biotechnology

Canada's National Biotechnology Advisory Committee has defined the term "biotechnology" as "the expansion and adaptation of biological knowledge toward practical ends." Mankind has therefore been using biotechnological methods for a very long time. Techniques such as cross-breeding and selection of breeding stock in animals and plants have been used in agriculture for thousands of years.

However, discovery in the early 1970s of recombinant DNA -- the fundamental genetic material that controls characteristics of following generations of a species -- has greatly enhanced our ability to manipulate biological systems. Acquisition of techniques for manipulating portions of DNA molecules, coupled with development of the technology of fusing cells from different species were fundamental to this biotechnological revolution. These two technologies allow the exchange of chromasomal DNA material between distantly related species of higher plants and animals. From this point, in the early 70s, biotechnology has moved very rapidly to the point where experts estimate that hundreds of products will be available for marketing by the year 2000.

Genetics and Shellfish Farming

The demands of the market for high quality shellfish, of a wide variety, to be available all year round have meant that controlling, manipulating and improving shellfish traits are essential to the shellfish industry. A variety of genetic approaches have been taken, including mendelian genetics, cytogenetics, quantitative genetics and hybridization studies. Not all of these approaches, however, have been equally effective in improving strains of mollusks.

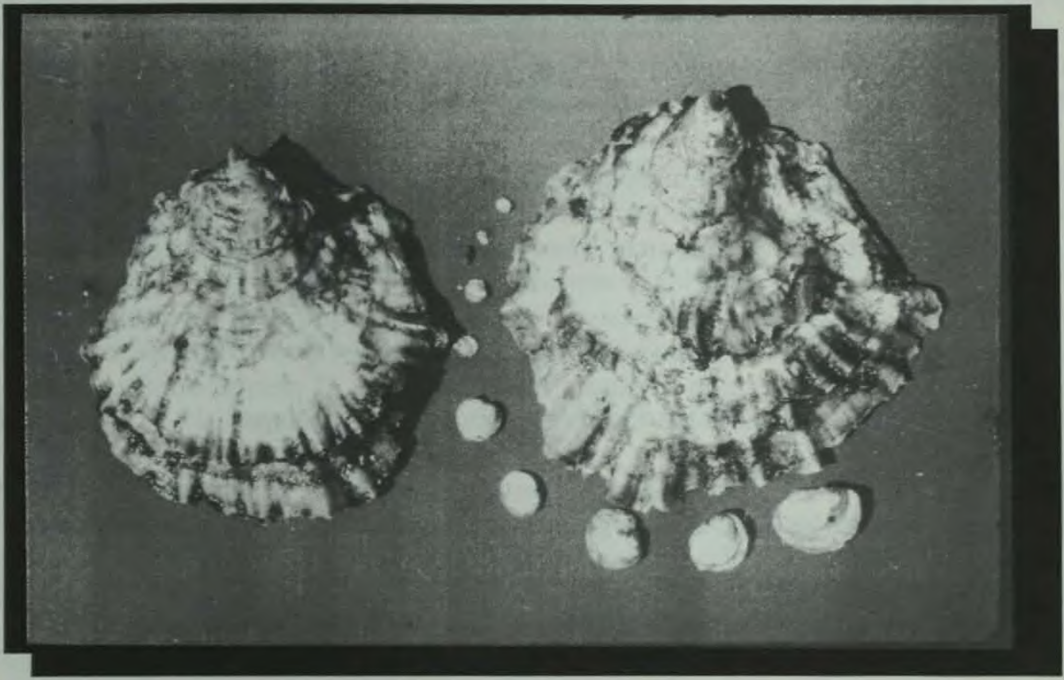
The European or Belon oyster *(Ostrea edulis)* was introduced to Nova Scotia in the late 1960s. Researchers (from the Department of Fisheries and Oceans) were attracted to these waters due to the presence of cool, high saline waters -- the traditional Canadian (Malpeque) oyster needs the warmer waters found around PEI and has never grown in Nova Scotia -- and an absence of Paralytic Shellfish Poisoning (PSP) or Red Tide -- a disease that has traditionally plagued the Malpeque.

The DFO researchers turned some of the new oysters over to Dalhousie University for what became a 10-year research program on the adaptation of the oyster to its new environment. Despite early difficulties, Dr. Gary Newkirk of Dalhousie University saw the potential for important genetics work and undertook the study into the culture of these mollusks, supported by the Nova Scotia Department of Fisheries and the Natural Sciences and Engineering Research Council (NSERC). In conjunction with an oyster growers' cooperative, a selective breeding and research program was begun in 1977, which resulted in great improvements in the culture of the oysters.

For example, Catherine Enright's doctoral research on oysters dealt with the chemical composition of the algae used to feed young oysters while they are in the hatchery. This research not only improved the diet of the oyster, but reduced the time they spend in the hatchery -- a not unimportant result from the business point of view, because this phase is the most expensive one.

Another contribution she has made to the industry is an innovative process to reduce the fouling of mesh in oyster boxes. Clean mesh is essential for the natural flow of seawater containing the plankton that the oysters feed upon. By introducing the common periwinkle to the containers,

The Oysters Growing in the Underwater Nets



Young and Mature Oysters

unwanted plant growth is controlled at very modest cost. This simple, but innovative solution to a common problem has earned Catherine Enright the recognition of oyster growers world-wide.

Freshly spawned oysters spend three to four months in a hatchery before being placed in nets in the ocean. Here they grow to maturity at the end of the three year cycle of oyster production. The attached photographs illustrate both the ocean nets in place and also a comparison between the mature Belon oyster and the young oysters early in their growth.

Other Applications of Biotechnology

Advances in our understanding of genetics over the past thirty years have opened other new fields for the commercial application of biological materials. While traditional applications have been mainly confined to the harvesting of biological resources (fish, forests, grains, as well as domestic plants and animals), more recent applications include the use of living organisms to process other raw materials, and the genetic modification of organisms to improve their value.

Some examples of current applications being studied include the following.

- Various methods of improving crop yields, such as the development of monoclonal antibodies specific for plant disease viruses, and genetic manipulation of plant materials.

- Research on the nitrogen-fixing ability of cereals and grasses through the use of ^{15}N isotope techniques -- it has been demonstrated that certain lines of wheat can fix as much as one-third of their plant nitrogen requirement when associated with the bacillus (C-11-25).

- The protection of crops from insect pests has generated a number of research directions. In many cases, more effective techniques have greatly improved control, while reducing the use of insecticides. The introduction of sterile insects, the use of pheromones as baits, and the introduction of specific parasites have all been factors in pest control.

- Current research on dairy cattle is directed toward improving genetic potential, increasing production and improving the processing of dairy products.

These are a very small number of examples of the directions that biotechnology is taking in Canada today. Detailed descriptions are readily available in publications listed below.

Suggestions for Classroom Use

While much of this material is generally applicable to many topics in secondary school biology courses, specific topics which might have particular relevance are:

- Genetics;
- The chemical basis of life;
- Invertebrates;
- Plant physiology;
- Ecology;
- The impact of science on society.

A scientific discussion of some of the ethical and values issues involved in biotechnology would also be valuable. Teachers are encouraged to refer to documents from the Ministry of State, Science and Technology for background material.

In courses where students are encouraged to pursue independent study projects, the variety of materials available on this topic allows for wide ranging discussions. Students should be encouraged to examine practical applications of biotechnology and the effects that biotechnology has on health care and the food supply.

References

Agriculture Canada *Progress in Research*, Centennial issue, 1886-1986 (Ottawa: Agriculture Canada, 1986).

A very thorough summary of research activities in Canada, and their application to crop improvement.

First Choice Canada vol 6, no 2 (Montreal: Promex Communications, 1987).

A special issue devoted to biotechnology in the private sector.

Beak Consultants Ltd. *Regulatory Policy Options for Canadian Biotechnology* (Ottawa: Ministry of State, Science and Technology, 1987).

A report prepared for the Ministry to provide information of interest to Canadians involved in biotechnology. This well-written document provides an excellent overview of high-tech biotechnology today - the methods, the processes and the applications to industry. The implications for regulation are well discussed and would be valuable input for a Science-Technology-Society curriculum emphasis.

Science Council of Canada *Seeds of Renewal: Biotechnology and Canada's Resource Industries*, Report #38 (Ottawa: Science Council of Canada, 1985).