

# CHAPTER 6

## TECHNOLOGICAL AND COMMERCIAL



Figure 1. Commercial cranberry farm near Black River Falls, Wisconsin, USA. *Sphagnum* peatlands are necessary to protect the cranberries and maintain sufficient water for their growth. Photo by Janice Glime.

### ***Sphagnum* Peatlands**

Certainly the best-known uses for mosses in both modern and ancient times are the uses of *Sphagnum*. This is not surprising since it occupies 3% of the Earth's surface, mostly in the northern hemisphere (Clymo 1987). Its abundance, longevity, cation exchange (Clymo 1963; Fischer *et al.* 1968), and ability to hold water make it ideal for commercial exploitation. Its largest usage in North America is for horticulture and cranberry culture (Figure 1; Figure 2), but in Europe, fuel is an important use as well.

In the UK, *Sphagnum* has been recommended as a litter for milking cows. Peltola (1986) reported that compared to straw and sawdust, peat provides better absorption of urine and binding of ammonia than the other litters. The spent litter is good for growing plants because it contains more than the average amounts of nitrogen and magnesium in a form readily used by plants.

In Japan, the Technical Academy of *Sphagnum* and the Marsh Bowz Factory illustrate uses, including peat grown on clay shapes, a restful boardwalk through the green moss, a cover for an aquarium that presumably reduces water loss while still permitting the entry of fresh air, and a peat roof garden with stepping-stones  
<<http://www.marshbowz.com/>>.



Figure 2. Cranberries (*Vaccinium macrocarpon*) growing among *Sphagnum* and *Polytrichum*. Photo by Janice Glime.

### **Heavy Metal Detection and Cleanup**

Cleaning up heavy metals from waterways is one of the most important environmental problems facing Americans (and others) today (Trujillo *et al.* 1991). Such methods as chemical precipitation, ion exchange, reverse osmosis, and solvent extract have been widely used, but are less than desirable. Their metal removal is incomplete, they require large quantities of reagents or high amounts of energy, and they generate toxic sludge and waste products that require expensive and dangerous disposal. The U.S. Bureau of Mines is using *Sphagnum* that has been immobilized in porous polysulfone beads. These are able

to remove zinc, cadmium, and other metals selectively from zinc mine wastewater, reducing the concentrations to well below the national drinking water standards. Furthermore, the adsorptive capacity of the beads appeared to increase after the first few cycles.

The cation exchange ability of *Sphagnum*, with its walls packed with polyuronic acids, gives it unique properties unmatched by its tracheophyte counterparts, and often even by the connivances of humans. It serves well in an electrode for the detection of lead, offering a detectability level of  $2 \text{ ng ml}^{-1}$  (Ramos *et al.* 1993). The 10% moss electrode is easily regenerated by immersion in 0.05 M perchloric acid for only 60 seconds.

Now that the lead has been detected, one can remove it and other heavy metals with the biomass beads made of dried, ground *Sphagnum* in a porous polysulfone matrix (Spinti *et al.* 1995). However, they seem to have lower capacity than other commercially available ion exchange resins.

### Filtration

The ability of peat mosses to bind heavy metals and other substances on their cation exchange sites makes them ideal organisms for cleaning up a variety of heavy metals and organic compounds in liquids. I have used peat mosses to clean up creosote in a very small pond. The peat removed the toxicity and took the toxic substance with the peat when I removed the mosses. Before I used the mosses, the fish all died, even when fresh water sat in the pond for a month. After subsequently letting the mosses soak in the pond water for a month, the new fish survived.

Farmers may use both inorganic and organic (including *Sphagnum*) amendments to reduce the loss of ammonia from liquid hog manure and to keep the hog pens fresh by controlling odors (Al-Kanani *et al.* 1992a, b)

Other forms of wastewater benefit from peat filtration. A counter-current system is used to purify water, with peat serving to both absorb and adsorb contaminants (Asplund *et al.* 1976; Brown & Farnham 1976; Coupal & Lalancette 1976). Even organic waste such as pentachlorophenol can be removed by using peat as a filter (Viraraghavan & Tanjore 1994).

### Oil Cleanup

Mele, in his book *Polluting for Pleasure* (1993), claims that 420 million gallons of oil from pleasure boating enter our waterways in America each year. This staggering number is equivalent to 40 Exxon Valdez disasters! Peat mosses are among the very best absorbents of the oil and can even be used to rescue birds and other animals covered in oil. As early as 1972, D'Hennezel and Coupal recognized their utility for cleanup. They are readily available, and bales could be stored near a harbor, ready for small spills. Today, there are also commercial peat moss "fences" available from several sources, especially in Canada, to contain oil spills.

One supplier advertises that Hydro-Weed (Figure 3), made from a blonde *Sphagnum* peat from Newfoundland, is a lightweight, natural hydrocarbon absorbent (Hydro-Weed website). The processing sterilizes the plants and kills the insects.



Figure 3. This pile of Hydro-Weed, made with *Sphagnum*, is a good absorbent of oil while repelling water. Photo from Hydro-Weed website.

Hydro-Weed is extremely effective at absorbing oil and other hydrocarbons. One pound will absorb 8-12 times its weight in medium weight oil, fifteen times more than clay absorbers! But it won't absorb water! Anyone knowing the ecology of *Sphagnum* would immediately become skeptical, and I can only conjecture on this water-repelling shift. We know that oil and water don't mix. If the oil is absorbed preferentially, then the oil would undoubtedly contribute to the loss of water absorption by actually repelling it. Furthermore, if dry peat is used, it would float, and so would the oil, so the oil would be contacted first and make the plants as repellent as a duck's back.

A further advantage of Hydro-Weed is that it will not release the oil. The company suggests putting it along a fencerow where microbes will break down the oil or other absorbed chemical, leaving the peat moss to benefit the soil. And a bird landing on the floating or discarded Hydro-Weed will leave without "a single drop of oil on its feathers."

The saturated Hydro-Weed can be put to even more valuable uses. It can be incinerated as fuel, contributing 7,200 BTU's per pound during incineration (excluding hydrocarbons). It is clean, generating only 0.42% of ash residual per pound after incineration. This makes it a good fuel for cement kilns and coal-generating fossil fuel plants.

Hydro-Weed is currently used by all branches of the United States Navy, Army, National Guard, Marines, and Air Force.

Marcus (2002), in a science fair project, compared several materials [Sea Sweep, Spill Magic, saw dust, Enviro-Bond (a polymer that bonds to hydrocarbons), and peat moss] at two temperatures to determine which took the greatest weight of crude oil in salt water. When compared by weight of sorbent, at 6.6°C the Enviro-Bond worked best, but at 21°C the peat moss absorbed the most. Most of the sorbents worked best at 6.6°C.

While this was just a science fair project, use of peat mosses has a sound basis in practice. Hunt (1995-2007, 2000, 2002-2007) reported the use of *Sphagnum* from SpillSorb Canada Inc. to clean up an oil spill at the Dassen and Robben Islands off the coast of South Africa where 41% of the African penguins reside. First, the penguins themselves were dusted with peat dust, rendering them dry and safe to return to the water (Ark Enterprises Inc.). Next, peat-based absorbents were used to clear oil from rocks (Crawford *et al.* 2000). Although the spill occurred on 23

June 2000, the shore was clean by 5 July that year (Hunt 1995-2007, 2000, 2002-2007). The hyaline cells of the *Sphagnum* leaves readily absorb the oil, up to 10 or even 20X the oven-dry weight of the moss. The *Sphagnum* also aids in the conversion of the oil to safe products. Rich in humic acids, it becomes a natural catalyst to aid in breaking down the hydrocarbon molecules of the oil; with the help of some microbes, it can aid the conversion of the oil to fatty acids, CO<sub>2</sub>, and water. Peat Sorb is one such *Sphagnum* product (SANCCOB 2006).

Oclansorb Plus from Canada (Hi Point Industries 1991) is an oil-absorbent peat moss designed for application to surface oil and fuel spills in fresh and salt water marshes, wetlands and any open water environment which cannot be efficiently cleaned by manual techniques. It blends a time-release system of peat moss that begins soaking up the oil within seconds, non-pathogenic bacteria bred specifically to metabolize petroleum hydrocarbons, N, P, trace nutrients, and pH buffers to enhance efficiency of bacterial degradation, and non-toxic gelling agents that facilitate adhesion of Oclansorb Plus to exposed tree roots, aquatic plants, and shoreline rocks.

In New Hampshire, the Department of Environmental Services made a novel use of peat moss. They rehearsed their response to an oil spill in Portsmouth's Great Bay Estuary (Dillon 2003), using peat moss and oranges to simulate the spread of the oil! The peat moss spread across the water like thin oil and the oranges simulated the bobbing tar balls, both without harming the environment.

The terrestrial environment is not immune to oil problems. A diesel oil spill in an Alaskan subalpine meadow had poor recovery after nine years, but the moss *Racomitrium sudeticum* was one of the three species that survived (Belsky 1982). The moss was one of the few plants making the area green.

Leaking crude oil production wells can create contaminated soils that must be cleaned up. For example, in McKean County, Pennsylvania, the use of fertilizers and leaf detritus or peat moss boosts the nitrogen content of the soils. This, combined with aeration by rototilling has been very successful in reducing total petroleum hydrocarbons (TPH) in soils. "Healing" is evident in a few weeks and the area can be replanted with grass seed the same season. The Maryland Department of the Environment suggests peat moss, among other things, for heating-oil cleanup. In New Zealand, Enviropeat™ is sold for cleanup of service stations, driveways, forecourts, maintenance areas, parking areas, refuelling areas, vehicle repair shops, ports & marinas, shoreline, and open sea oil spills (Enviropeat).

## Fuel

The use of mosses for fuel is not just ancient history. Nearly half the world's peat production is used for fuel, particularly in Scotland and Ireland, providing the equivalent of 100-200 million tons of oil (UNERG report 1984). In Canada the peat deposits store more energy than do the forests and natural gas reserves combined (Taylor & Smith 1980). Nevertheless, the use of peat as fuel is down in Scotland, from 70,000 tonnes in 1955 to 20,000 tonnes in 1999 (Macleod 2006).

We might cringe that Ireland burns over 100 million tons of peat each year to generate power (Turner 1993), requiring large peatlands (Figure 4). What a scourge on the

landscape! And it certainly does not renew at that rate, if ever. It is also used for waxes, resins, and oily materials for dyes and varnish and in treatment of leather.



Figure 4. Large peatlands like this one at Farwell, Michigan, USA, are rapidly disappearing due to development. Photo by Janice Glime.

At least it doesn't further pollute the environment. For example, in Minnesota it is used to remove chromium from power station wastes (Turner 1993), and it has been important in rescuing penguins in South Africa by cleaning up oil spills (Hunt 2004).

Peat is a promising replacement for our dwindling oil supplies, packing more than 8,000 BTU per dry pound, and is renewable when harvested carefully. It is such a clean-burning fuel that some have attributed the lovely complexions of Irish and Swedish women to use of peat as fuel (Drlica 1982). Its attractive feature as a fuel is that it is low in sulfur content, cleaner burning, and superior in heating value compared to wood, similar to lignite.

No longer restrained in use to the developing countries, liverworts and mosses are important sources of fuel in northern Europe, especially in Finland, Germany, Ireland, Poland, Russia, and Sweden. In Ireland, 25% of the fuel source is mosses (Richardson 1981). It serves not only to produce heat, but also electricity, with the former Soviet Union burning ~70 million tons and Ireland 3.5 million tons of mosses in 1975 for that purpose (Boffey 1975). If Hinrichsen (1981) was correct, the world should have been using peat in the equivalent of 60-70 million tons of oil by the year 2000.

Although peat is renewable, little of it has been harvested with a renewal plan in mind. Hence, many scientific studies are currently focusing on regeneration of various *Sphagnum* species in the hope of restoring some of our lost peatlands. Unfortunately, little of it regenerates at the rate it is being used.

Hence, we need improved methods for harvesting, drying, and conversion to a burnable fuel (Lindstrom 1980). Although harvesting is easy, compared to that for coal, forests, and hunting for oil, we need to find ways that do not destroy the wetlands and convert them to non-peat-producing vegetation.

The Finns, in their attempt to become 40-50% self sufficient (Miller 1981) and provide a cleaner fuel (Johansson & Sipilae 1991), have suggested that placement of processing stations on the peatlands will reduce transport cost (Taylor & Smith 1980). They have introduced a dewatering process that produces dry pellets of partly

carbonized peat (Taylor & Smith 1980). Finland is also exporting pulverized peat to northern Sweden, where it is used in industry and municipal heating, power generation, and oil burners of pulp and paper companies (Summerton 1981). However, for heating houses alone, replacement of light fuel oil with peat will require up to 6.2 million tons of peat pellets per year (Kinnunen *et al.* 1982). If this is reduced to only a 5% replacement, that consumption could be reduced to 310,000 tons per yr.

It took a coal miners' strike in 1903 to interest Americans to use peat as a fuel, but the cheaper availability of other fuels has prevented its widespread use (Thieret 1956). Nevertheless, planning for the future, the U. S. Geological Survey and other organizations have mapped North American peat deposits and estimated their extent (Miller 1981). This time it was an energy crisis with the possibility of diminished oil trade that fueled interest in peat fuel in the 1970's. In 1975, First Colony Farm in North Carolina began peat harvest to make methane and to generate electricity; their land has an estimated 400 million tons of peat, enough to fuel a 400 megawatt power plant for 40 years (Carter 1978). The Minnesota Gas Company planned for its use of methane by applying for a long-term lease on 200,000 acres of peatland (Boffey 1975). Use of peats for production of methane eliminates the chopping that is required for other plants, and peat products can be used to produce ethylene, hydrogen, methanol, synthetic or natural gas, and low and intermediate BTU gas.

### Peat in Construction

Whereas other mosses have played minor roles in construction, mostly for chinking, *Sphagnum* (Figure 5) has the potential to enter the arena big time. As early as 1903, the Swedes ground peat with asphalt to make a durable street pavement (Drlica 1982). Peat Crete, a mixture of peat with light concrete that is hydraulically pressed with Portland cement and water, provides a low-cost material that boasts easy sawing, nailing, casting, and molding, does not need to dry, is inflammable, and of low density (0.7 to 1.2 sp. gr.; 45-70 lb/ft<sup>3</sup>) (Ruel *et al.* 1977). Its only negative quality is its low mechanical strength, but this seems more than balanced by its light weight for use in places where transportation is a problem.



Figure 5. *Sphagnum magellanicum* is a large moss that can be used in making various construction products. Photo by Janice Glime.

In June, 1972, Andrew Gilchrist, Chair of the Highlands and Islands Development Board at Bridge House, Bank Street, Inverness, Scotland, presented to the Right Honourable Gordon T. C. Campbell, Her Majesty's Secretary of State for Scotland, a report in which he referred to the possibility of production of peat Crete as a means of improving the economy, stating: "We continue to watch over prospects for possible uses of peat, including the Building Research Centre's work on 'peatcrete.'" Unfortunately, or perhaps fortunately, a Google search does not indicate any commercial sources of this commodity.

In 1920, peat-based pasteboard and wrapping paper appeared in Michigan, USA, near Capac (Miller 1981). Like many other mosses, *Sphagnum* was used in chinking in log cabins (Lewis 1981), and the northern Europeans, living where peat is abundant to this day, stuffed it between the timbers of their houses to deaden sound (Thieret 1954). To this purpose, the Russians added slabs that they heated and pressed for insulation of refrigerators, and of course their houses (Sukhanov 1972; Ruel *et al.* 1977).

Peat then made its debut in place of particle board, as peatwood (Ruel *et al.* 1977). Dried *Sphagnum* is blended with a phenolic resin and pressed into a heating mold; it offers quick hardening, attractive texture, good strength, easily nailed, screwed, and glued, and light weight (40-60 lb ft<sup>-3</sup>). Other construction materials include the ultra-light peatfoam (peat moss and foamed resin) and peatcork (made from the coarse fraction of peat) (Ruel *et al.* 1977).

### Harvesting Peat and Peatland Destruction

In 1991, a survey of Finnish peatlands revealed that only 26% of the peatlands remained in natural condition (Euroala *et al.* 1991). The majority are drier, less productive, and more forested than just 30 years ago. Most of the loss of peatlands is due to forestry (Finland) and agriculture (France) (Francez & Vasander (1995), although peat harvesting for fuel is a growing concern in northern Europe. In North America, most of the harvest is for horticulture (Ferland & Rochefort 1997). This horticultural loss began early in the 20th century, with the practice of leaving the peatlands to regenerate in their own way when the mining operation was over (Lavoie & Rochefort 1996). Upon examining a typical "regenerating" peatland in Quebec, Lavoie and Rochefort found that although the block-cut trenches had more than 50% cover and were occupied by typical peatland species, *Sphagnum* was much more common in the natural conditions than in the cutover peatland. They concluded that this location was not returning to a functional peatland ecosystem.

Loss of peatlands affects the forestry species that were growing there. For example, in the New Jersey pinelands, *Chamaecyparis* swamps may suffer from loss of *Sphagnum* cover because the tops of hummocks become more prone to drought, making them less suitable for seedling regeneration (Ehrenfeld 1995).

Even large browsers like caribou depend on refuge in peatlands (Dyer *et al.* 2001), but these losses have ramifications far beyond the simple loss of peatlands. Their loss is a contributor to global warming. Reduction in peatlands means that less carbon will be tied up in that carbon sink, instead going to rapidly cycling grasses. Furthermore, it leads to greater decomposition of accumulated peat, releasing yet more greenhouse gases.

Ohlson and Økland (1998) found that it can take 40 years of peat accumulation before any significant amounts are lost through decay, resulting in a net carbon sink. In hummocks of *Sphagnum fuscum* and *S. rubellum*, carbon accumulation exceeded  $2 \text{ g dm}^{-2} \text{ yr}^{-1}$  during a 50-year growth period.

"Harvest" is usually a misnomer for what is more accurately called peatland mining. With an accumulation rate of 10-40 cm per thousand years in Finnish peatlands, repeatable harvests must be discussed in geologic time scales (Crum 1988). Consequently, peatlands the world over are diminishing. Knight (1991) bemoaned the dwindling number of peat bogs in Britain due to exploitation for horticulture.

Others have more encouraging numbers, considering peat formation of ~1-2 mm per year (note, that is not rate of growth). Using this estimate, they consider that harvested (not mined) peat can be replaced in ~20 years. In Ireland, 1 million  $\text{m}^3$  of peat is used for horticulture and another 7-9 million pounds are exported yearly (Richardson 1981), not to mention the use for fuel that seriously threatens that country's 3 million acres of peatland (Drlica 1982). Yet 90% of the world's marketed peat comes from Wisconsin, USA, primarily from Jackson and Monroe Counties (Epstein 1988). The series of pictures below shows one company's attempt to maintain a sustainable crop that can be harvested again in about ten years (Figure 6 -Figure 13).



Figure 6. At this peat harvesting operation in Wisconsin, USA, peat can be reharvested in about a 10-year cycle. The rake being used is wooden and pulls both *Sphagnum* and accompanying sedges. Photo by Janice Glime.



Figure 7. A tractor with a wooden tread pulls the wagon on which peat is loaded, minimizing damage to the peatland. Photo by Janice Glime.



Figure 8. A full wagon of peat is ready to be spread for drying. Photo by Janice Glime.



Figure 9. Freshly harvested peat is spread to dry. Photo by Janice Glime.



Figure 10. Spent tires will be used to anchor the mosses. As mosses dry, they become lightweight and can blow away. Photo by Janice Glime.



Figure 11. This packaging equipment is used for bagging the dry mosses ready for sale without need for a building or power. Photo by Janice Glime.

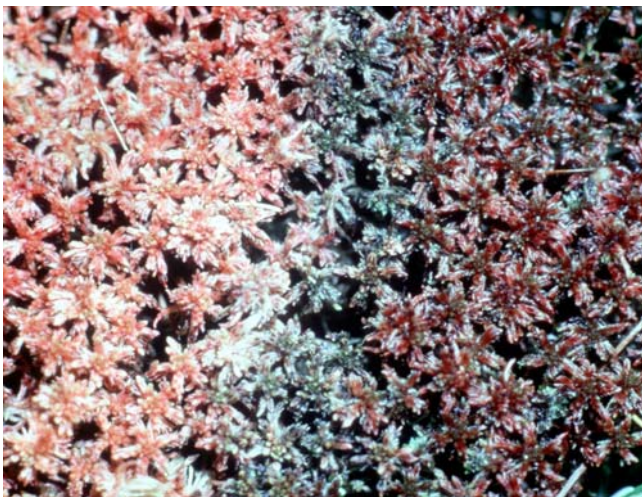


Figure 12. This *Sphagnum* is infected with fungus and could cause sporotrichosis. Photo by Janice Glime.



Figure 13. This mined peatland in Maryland, USA, exposes the peat profile. Photo by Janice Glime.

### Climate Reconstruction

Peatlands are history books, recording for us what has occurred long before humans considered maintaining a written record (Grosse-Brauckmann 1979; Janssens 1988; Klinger *et al.* 1990). While this often has only heuristic value, it can be invaluable in attempting to interpret our tempestuous climatic variation in the present decades.

Whereas fossil and other paleoecological records are scanty and difficult to interpret in other habitats, buried peat can provide us with clear chronosequences of vegetation, giving us indications of alternating dry and wet periods and even of warming and cooling. The pattern of cores can easily be calibrated between locations (Ellis & Tallis 2000). The peat stratigraphy of a blanket mire in Scotland, coupled with radiocarbon dating, indicates eight wet shifts that began about 3250, 2550, 2150, 1400, 1150, 875, 600 & 325 years ago. Seven of these correlate closely with similar indications from peat in Britain and Ireland.

Likewise, in the coastal region of Maine, USA, bryophytes, along with pollen, diatoms, and other plant fossils, have been useful in reconstructing past conditions (Tolonen & Tolonen 1984). In this case, the bryoflora support the other taxa to indicate that the flora is predominately that restricted to calcareous habitats.

Jonsgard and Birks (1995) were able to reconstruct the climate (moisture, temperature, light availability, and pH) from partially decomposed fossil mosses at Krakenes, western Norway by comparing the taxa with bryophyte communities at various present day altitudes. They found that mosses are able to colonize new habitats as rapidly as their tracheophyte counterparts. The advantage to using mosses for this purpose is that they provide evidence for microhabitats that cannot be obtained from tracheophyte fossils.

Jonsgard and Birks (1995; Birks 1982) also used fossil mosses to characterize late-glacial climate, pH, light availability, and continentality of Norway, using the mosses as ecological indicators.

Glaciers are often the site of modern dispersal of moss fragments. This wide, smooth surface also permitted ease of travel of fragments that became fossils in the frozen water, preserving the communities surrounding them. Thus, ice cores serve as historic records of the surrounding communities, much as peatlands do in other areas (Lindskog & Eriksen 1995).

While studying the Quelccaya ice cap in Peru, Ohio State University glaciologist Lonnie Thompson found mosses that had appeared out of ice laid down 5200 years earlier (Rozell 2005). This date of preserving a green moss coincides with the age of the Ice Man found recently in a melting ice field in the Austrian Alps. Thompson used the moss example to demonstrate the rapid response of a sensitive environment. When he returned to the site, he found more of the exposed mosses. Upon sending them to Woods Hole Oceanographic Institute for dating, he learned that one of them was 50,000 years old! In disbelief, Thompson sent the moss to Lawrence Livermore National Laboratory in California. Results were the same. Thompson reasoned that the only way these 5200-year-old mosses and the 50,000-year-old ones could appear together is that the ice field has not been smaller than it is today in the last 50,000 years and that it had to be colder than it is today for the past 50,000 years! Indications are that the ice cap is melting 40 times faster than it was in 1963.

### Antibiotic Uses

Frahm (2004) extolled the virtues of bryophytes as anti-snail and anti-fungal sources. He reported that bryophyte extracts only spoil the appetite of the snail without killing them (Figure 14).



Figure 14. Slugs (*Arion lusitanicus*) can devour garden vegetables, especially soft tissues such as those of lettuce. Here the untreated control on the **left** has been almost completely eaten whereas the liverwort-treated leaf on the **right** remains unharmed. Photos by Jan-Peter Frahm.

When fungal spores fall on bryophyte leaves, the plant releases phenolic compounds when the surface becomes wet, inhibiting spore germination. To support the antifungal use, Frahm encouraged the head of the Department of Phytopathology at the University of Bonn to test their properties in greenhouse experiments. Crop plants such as green peppers, tomatoes, and wheat were infected with such fungal plant pathogens as *Phytophthora infestans*, *Botrytis cinerea*, and *Erysiphe graminis* (Figure 15). These infected plants were treated with alcoholic extracts from 20 European species of bryophytes. The extracts had various effects, with liverworts being most effective (Figure 16), followed by *Sphagnum*, then mosses (Tadesse 2002). Two of the liverworts caused systemic effects. Plants that were sprayed prior to their inoculation were not affected at all by the fungi; the leaves that developed after the application of the extract were resistant, suggesting that the antibiotic substance was translocated within the plant.



Figure 15. Extracts of 20 species of bryophytes inhibit the growth of fungal pathogens on vegetable crops such as these tomatoes. The plant on the **left** is the control and is infected with the fungus *Phytophthora infestans*. The other two have been treated with two concentrations of alcohol extract from bryophytes. Photo by Jan-Peter Frahm.

The ability of moss extracts to inhibit fungal growth is easily demonstrated by saturated disks on inoculated Petri plates (Figure 17).



Figure 16. The healthy tomato plant on the **left** has been treated with liverwort extract, whereas the untreated plant on the **right** is infected with *Phytophthora infestans*. Photo by Jan-Peter Frahm.

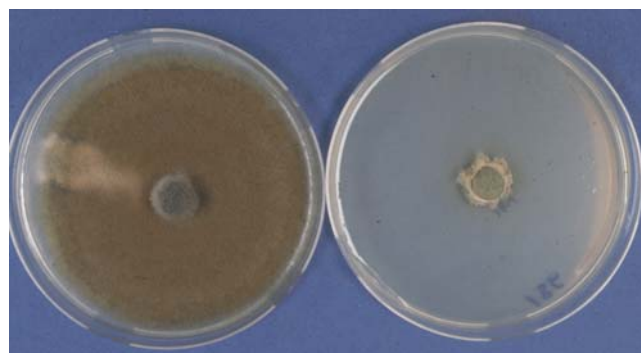


Figure 17. Rampant fungal growth occurs on the plate lacking bryophyte extract (**left**) while growth is inhibited on a plate with a bryophyte extract disk (**right**). Photo by Jan-Peter Frahm.

Once the news of this antifungal activity was distributed to the news media, there was a huge response, indicating a great need for such an alternative product. The moss extracts are a safer alternative to the copper sulfate and other heavy metal salts currently being used. The heavy metals accumulate in the soil, whereas the bryophyte extracts quickly degrade in the soil. Furthermore, it is easy to produce and farmers in third world countries could even produce it themselves.

A private German development company, Red de Accio'n en Alternativas al uso de Agroqui'micos (RAAA) persuaded the Universidad Nacional de San Martin in Peru to test extracts of local bryophytes on coffee and tomatoes as protection against tropical plant diseases in the field. Unfortunately, they tried only mosses and not the more potent liverworts, but they still achieved positive results. Sadly, the high cost of the alcohol prevented wide-scale use in Peru.

In Bolivia, the Unidad de Investigacio'n y Desarrollo FAN made extracts of *Frullania brasiliensis* and *Sphagnum* sp. and applied them to tomatoes and potatoes. While controls were infected, the treated plants exhibited no visible bacterial or fungal infections (Figure 15; Figure 16).

Frahm, failing to persuade any German company to produce the product, took the product to a company that produces herb liquors. It was sold by a chain of drugstores(!) as an alternative to fungicides. Finally, a new commercial company received permission from

Biologische Bundesanstalt to produce the product commercially. Several thousand liters of bryophyte extract were sold during the first 8 months. This product is diluted 1:100 for use. A major limitation is obtaining enough plant material in the field. Although the moss used is abundant in silvicultural fir forests, the quantities needed for agriculture is enormous.

Frahm's group is conducting further testing to produce the moss horticulturally and hopefully to find clones with higher biological activity. Such commercial production would also eliminate the need for cleaning, reducing costs and time.

## Erosion Control

The role of bryophytes in erosion control is well known (Figure 18), and several people have considered their commercial use, through transplantation or propagation from fragments.



Figure 18. Erosion control on steep streambanks is an important use for bryophytes, both naturally, and on manmade slopes along canals or roads. Here, *Polytrichum* does the job. Photo by Janice Glime.

On dunes, seaside bluffs, and other areas where tourists often disturb the clinging vegetation, few plants, commercial or natural, survive the unstable conditions. Nevertheless, certain mosses may cling there when most other plants have been destroyed. Michel Chiaffredo and coworkers have a patent for Procédé BRYOTEC (BRYOTEC Process) that uses bryophytes instead of tracheophytes to stabilize such fragile sites (Chiaffredo, Bryotec). The company MCK Environnement, using the BRYOTEC Process, has managed to restore, in only five years, the indigenous vegetation of a cliff top in a maritime setting in the Vendée region of France, where the tourist trampling had completely eradicated the original vegetation (Figure 19). This restoration involved the introduction of bryophytes with a small number of seeds from the native vegetation.

The association *Ceratodonto-Polytrichetea piliferi* (Dierßen 2001) is one that has proved particularly successful in helping to restore lost vegetation on a disturbed site.



Figure 19. Restoration of a trampled cliff using a mix of bryophytes and other naturally occurring plants. Photo by Michel Chiaffredo.

In France, one may observe granitic embankments along a highway with the grass *Festuca ovina duriuscula* enduring the summer sun, but only in crevasses where mosses share the space. Perhaps the moss is necessary to provide sufficient moisture for seed germination.

One approach to rehabilitation has been to accelerate the establishment and growth of mosses by introducing mosses to the damaged area. However, the technique has used fragmented or chopped mosses and has met only limited success, despite the humid climate (rain on 80% of days). Furthermore, it has required collection of great quantities of samples from nature, which is contrary to the objectives of such a project. The BRYOTEC Process, on the other hand, produces large quantities of pioneer mosses from small samples of several cm<sup>2</sup>. It therefore enjoys the status of a non-destructive biotechnology.

In addition to controlling erosion, mosses may help to stabilize and build soil on mine spoil. Peat mosses have been used for recultivation of ash dumps from brown and hard coal, a difficult substrate to colonize (Biernacka 1976).

## Revegetation

Occasionally mosses are used to revegetate mining spoils. In a discussion on Bryonet in August 2007, several people suggested *Polytrichum* species, measuring some degree of success in the United States and Canada, as pointed out by Jean Faubert. Justin Wynns reports that in Boone, NC, USA, large carpets of *Polytrichum* have been planted in full sun, covered with large pieces of cloth to stabilize and retain moisture. Steve Timme suggested that naturally appearing mosses on mine tailings of one South Kansas site included *Ceratodon purpureus*, *Bryum argenteum*, and *Bryum pseudotriquetrum*, making those good choices to start. Shana Gross has found that she can get *Ceratodon purpureus* and *Bryum argenteum* to grow easily from fragments in the greenhouse, but they do not easily form thick mats. It is even more difficult to get such mats in the field.

Road cuts, construction, and other forms of "progress" often leave huge scars on the landscape that do not quickly heal and soon become unstable detractants from the landscape around them. Thus, it is desirable to solve both

the technical stabilization problem and to create an attractive replacement for the former vegetation. To this end, the Bryotec Corporation has introduced mosses as a solution to both problems. They have found that such bare terrain can be stabilized in a few months with a bed of bryophytes combined with other vegetation to form a presod. The mat is both stable and attractive and helps to prepare the landscape for larger plant species (Michel Chiaffredo, Bryotec Corp., Pers. Comm.)

## Graves, Burial, and Preservation

Tombstones more than 100 years old typically are encrusted with lichens and mosses. In a recent bryonot discussion, Sean Edwards sought a way to expedite this process (2005). In an old churchyard, strips of marble on a tomb had been replaced and no longer matched the weathered and lichen/moss-covered older marble. He was seeking ways to encourage the mosses and lichens to grow to age the stone.

Burial ceremonies seem to have been a part of human culture for a long time. Hence, it might be expected that the resourceful human found mosses to be a suitable way to preserve the bodies of loved ones. In the Canary Islands, the Guanche mummy (1380 ± 80 years B.P.) was preserved with the epiphyte *Neckera intermedia* in its abdominal cavity (Horne & Ireland 1991). However, an earlier report of a frozen Eskimo woman with moss in her lungs seems instead to have been the result of inhalation of the moss as she was being accidentally buried alive (Zimmerman & Smith 1975; Horne & Ireland 1991).

In one case, a strange coincidence got a man to confess to the murder of his wife (Dente 1997). Police in Macclesfield, England, had investigated reports that Peter Reyn-Bardt had boasted of murdering his wife 23 years earlier and buried her dismembered body in his backyard. But the police could find no such evidence. However, the backyard bordered a peat excavation site where only a short time later an excavation uncovered a well preserved skull of a 30-50-year-old female. After the man confessed to the murder of his wife, the Oxford University Research Laboratory for Archaeology determined that the skull was 1660-1820 years old!

More recently, it appears that mosses have been used to clothe the last resting place. In Siberia 2,500 years ago, large mosses like *Pleurozium schreberi*, *Ptilium crista-castrensis*, and *Rhytidium rugosum* (Figure 20) were used with sheets of bark to line the roofs of tombs (Rudenko 1970). In Alaska and Japan, they have provided a burial bed (Bland 1971; Ando & Matsuo 1984) with larger mosses such as the pendant *Aerobryopsis subdivergens* (Iwatsuki & Inoue 1971).

The expansive peatlands of northern Europe seem to have provided a grave for hundreds of men, taking us back to the days of Roman rule – The Iron Age (Glob 1969; Figure 21). At first, these men were assumed to be peat cutters who had in recent years been trapped in the muck (Robinson, Murder Preserved). But with 1500 bodies (Robinson, Murder Preserved), speculation about the reasons for the early demise of these "bogmen" soon abounded (Painter 1991). Sanders (Tales from the Bog) relates that the Nazis used them as propaganda, claiming that two men found together in a Dutch peatland had been executed for their crime of homosexuality, whereas

Heinrich Himmler was more cautious in a 1937 speech, stating that the deaths had been "not a punishment, but simply the termination of such an abnormal life."



Figure 20. *Rhytidium rugosum* is a pleurocarpous moss that has been used to line the last resting place of humans in Siberia. Photo by Michael Lüth.



Figure 21. The "bogman" was perfectly preserved for centuries by the tannic acid in the peatland. Original photo source unknown.

In 1835, a well preserved woman in a Danish moor was identified as Queen Gunhild, a monarch in a Norse legend (Sanders, Tales from the Bog). When the Danish King, Frederick VI, learned of this find, he prepared her for a royal burial beside Danish royalty in a churchyard. However, carbon dating belies the royalty theory, placing the lady in a much earlier time.

In Tollund Fen in Bjaeldskor Dale in Denmark, two brothers (peat cutters) were surprised in 1952 by a body that surely was a recent victim of an onerous crime (The Discovery of Tollund Man). On closer inspection, the man had a twisted leather noose about his neck, but his face bespoke peace, as if death was his salvation. Police work turned to archaeologists who determined the "crime" to be 2000 years old. That look and the grains in his stomach have led many to conclude that he was a holy man sacrificed and preserved in the peat.

### The Tollund Man

*Seamus Heaney*

#### I

Some day I will go to Aarhus  
To see his peat-brown head,  
The mild pods of his eye-lids,  
His pointed skin cap.

In the flat country near by  
Where they dug him out,  
His last gruel of winter seeds  
Caked in his stomach,

Naked except for  
The cap, noose and girdle,  
I will stand a long time.  
Bridegroom to the goddess,

She tightened her torc on him  
And opened her fen,  
Those dark juices working  
Him to a saint's kept body,

Trove of the turfcutters'  
Honeycombed workings.  
Now his stained face  
Reposes at Aarhus.

#### II

I could risk blasphemy,  
Consecrate the cauldron bog  
Our holy ground and pray  
Him to make germinate

The scattered, ambushed  
Flesh of labourers,  
Stockinged corpses  
Laid out in the farmyards,

Tell-tale skin and teeth  
Flecking the sleepers  
Of four young brothers, trailed  
For miles along the lines.

#### III

Something of his sad freedom  
As he rode the tumbril  
Should come to me, driving,  
Saying the names

Tollund, Grauballe, Nebelgard,  
Watching the pointing hands  
Of country people,  
Not knowing their tongue.

Out here in Jutland  
In the old man-killing parishes  
I will feel lost,  
Unhappy and at home.

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In the same year, 1952, Grauballe man was found in a similar manner by peat cutters (Grauballe Man). His body was dated to about 210-410 AD. His stomach was full of porridge of 63 different grains, but no fruits or leafy green material, no meats, suggesting a winter meal or a poor harvest? A gruel with that recipe tastes horrible (Lienhard, The Bog Men). Unlike the Tollund man, his face expressed terror and pain (Grauballe Man). His throat had been cut and his skull was fractured. Later, in 1984, Lindow man was found under similar circumstances in England (Lindow Man). Like the Grauballe man, his skin betrayed a man of high rank, not one who labored. He was at least 2000 years old, yet preserved well by the peat. He had died a violent death, with two blows to the head, his throat cut, and a thong for hanging. Was he a human sacrifice, or victim of a brutal murder?

As history unfolds and great minds conjecture, it seems that Druid priests, important in the Celtic tribes, may have died in this manner, chosen as a sacrifice to the Earth Goddess (Robinson, Murder Preserved). The Lindow man had a last meal consisting only of a small cake containing bits of charred flour that would have required 400°C – much hotter than one would ever consider for baking. Archaeologists Ann Ross and Don Robbins speculate that this cake was used in a lottery to determine who should be sacrificed – perhaps explaining the look of pain and terror! Parts of such a ceremony still existed in England in the 20th century, but without the ultimate sacrifice.

Peatlands have a number of qualities that make them ideal preservation sites (Robinson, Murder Preserved). Although the low oxygen and high acidity discourage most bacteria, it is the peat itself that imparts the preservation. The **sphagnum** resulting from phenolic breakdown binds the sparse minerals in the water. Lacking their essential minerals, bacteria are unable to grow. Much like the tanning of cowhide to leather, the body is turned to leather by the tannins from the *Sphagnum*, preserving wool and leather garments along with the skin. The calcified bone, however, loses its calcium in the acid water, becoming rubbery and crumpled under the weight of the peat. And linen, faring less well than wool, disappears due to decay, accounting for the Tollund man wearing nothing but his leather belt and hat when he appeared in the 20th century!

*Sphagnum* even has a modern use in commemoration of the dead. In Wisconsin, USA, thousands of cemetery wreaths are made. These usually have various decorations and flowers attached to them, with the *Sphagnum* peat retaining water to keep them fresh.

### Anthropology and Archaeology

An archaeologist investigating Palaeolithic settlements reported finding animal and human bones in cave sediments (Patxi Heras & Marta Infante, Bryonet, 5 April 2006). These are often eroded with shallow depressions and holes. The zoologist she consulted disclaimed the marks, suggesting they were created by plant growth. Since there is typically abundant moss growth in the cave entrances, the archaeologist considered that they could make the marks. While no one could confirm that mosses make such marks on bones, we do know that mosses in the Splachnaceae, among others, can grow on bones.

Peat mosses (*Sphagnum* species) are well known for their ability to preserve the dead (Folger 1992). When a

giant mastodon was found in Ohio, USA, it likewise had been preserved in *Sphagnum* for 11,000 years. It was so well preserved that its last meal remained.

Hawes *et al.* (2002) attempted to use bryophyte growth markers to hindcast ice melt patterns in Arctic lakes, but they were unable to establish any correlation, concluding that the relationship was more complex.

## Forensics

Bryophytes can accomplish their own form of DNA fingerprinting (Korpelainen & Virtanen 2003). Mosses can be used in much the same way as tracheophytes in crime investigation. Virtanen and coworkers (2004) are developing protocol for linking patches of bryophytes from the crime scene with fragments found on a suspect. Their approach is to find specific microsatellites to identify globally common bryophytes. Many species fragment easily and stick to clothing, making DNA analysis possible long after the event of fragmentation. Such evidence can tie the suspect to the scene of a crime.

## Rearing Fish

The Nashua National Salmon Hatchery has considered using the aquatic moss *Fontinalis* (Figure 22) in the salmon raceways (Abigail Walker, Intern, Nashua National Fish Hatchery, 19 April 2005). It grows there on the cement and they hope to use it as both a nutrient sink and a natural cover for young fry in the rearing tank.



Figure 22. *Fontinalis antipyretica* is a moss used in fish hatcheries today, but formerly used for chimney chinking with the belief it would insulate against fire. Photo by Michael Lüth.

As described in the Aquarium subchapter, Bohlen (1999) reported the use of aquaria equipped with a thick moss tuft for spawning of the spined loach *Cobitis taenia*. The moss was placed on top of a gauze-covered plastic box. The fish laid their eggs in the most dense vegetation available. The dead eggs fell through the gauze and collected in the box.

The bryophytes may well be protected from herbivory by the fish at the same time. Asakawa *et al.* (1985) has shown that at least one liverwort (*Riccardia lobata* var. *yakishimensis*), although not itself aquatic, has piscicidal secondary compounds (diterpenoidal).

## Toxicity Testing

Numerous studies have used bryophytes as indicators of pollution, with symptoms indicating, in many cases, the type of pollution. These are so numerous as to warrant several chapters, if not an entire volume. It is almost

predictable that one of the organisms that has been studied for this potential is the bryological lab rat, *Physcomitrella patens*. Morgan *et al.* (1990) used cultures of this moss to examine effects of various salt solutions (Al sulfate, barium chloride, boric acid, Cd chloride, cobalt chloride, & lead nitrate, mineralized-acidic leachate, & coal combustion fly ash leachate) on various life cycle stages (Figure 23). Aberrations such as altered morphology, loss of regeneration ability, reduced dry weight, and altered chlorophyll contents indicated damage by the salts. Surprisingly, the spore and gametophore cultures differed little in their responses. Cadmium chloride and aluminum sulfate caused the greatest reduction in chlorophyll concentration and dry weight, whereas boric acid and barium chloride were least toxic. Fly ash likewise seemed to cause no harm to the plants.

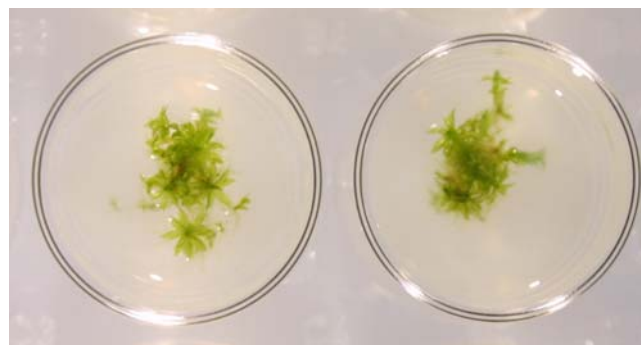


Figure 23. Mosses such as *Physcomitrella patens* can be used to test effects of salt concentrations, acidic leachates, heavy metals, and fly ash on morphological alterations and changes in chlorophyll concentrations. Photo by Ralf Reski.

## Scientific Use

Today, bryophytes are receiving considerable attention from the scientific world. *Marchantia* (Figure 24) has been a subject of physiological studies. *Funaria hygrometrica* and *Physcomitrella patens* are everyday names to the plant physiologists. And *Syntrichia* (*Tortula*) is being studied by the Department of Agriculture (Comis 1992; Hoffman 1992)! What is it that has caused this sudden interest in bryophytes?



Figure 24. *Marchantia polymorpha*, a common liverwort, is used for teaching and scientific research. Photo by Michael Lüth.

The ability to grow bryophytes from spores and fragments has made some kinds of physiological studies easy. Much of what we know about tropisms has been

learned from studies on moss protonemata, which respond to gravity and demonstrate what occurs inside the cell. With only one cell in thickness, and an easily observable and measurable linear structure, the moss protonema provides an ideal study organism for this purpose. But agriculture? It seems that mosses have characteristics that are desirable for crop plants. They tolerate desiccation better than almost any crop plant and can withstand freezing while still in a state of hydration, yet recover almost instantly (Rütten & Santarius 1992). Furthermore, they seem seldom to be eaten, especially by insects. With our new tools for moving genes around almost anywhere we want, the genes of mosses suddenly became an attractive commodity.

## Model Systems

It seems fitting, yet ironic, that these plants of ancient use may once again reach the forefront of technology. But this time, their uses are much less obvious and much more sophisticated.

In the early part of this century, bryophytes led the arena of genetic research (Wettstein 1932). Mutagenic effects of X-rays (on *Sphaerocarpos donnellii*, Knapp 1935, Schieder 1973, Figure 25; on *Marchantia polymorpha*, Miller *et al.* 1962a, b, Figure 24; on *Physcomitrium pyriforme*, Barthelmess 1941a; and on *Physcomitrella patens*, Engel 1968),  $\alpha$  particles (*Physcomitrium pyriforme*, Barthelmess 1938), and  $\gamma$ -rays (*Brachythecium rutabulum*, Moutschen 1954), and chemical mutagenesis (*Physcomitrium pyriforme*, *Physcomitrella patens*, among others, Barthelmess 1941a, b, 1953) were more easily studied on these haploid organisms, and their multi-year life exposed to the atmosphere made them ideal for integrating effects over time. Both morphological and physiological effects were manifest (Cove 1983).



Figure 25. *Sphaerocarpos*, a liverwort, was used to test the effects of X-rays. Photo by Michael Lüth.

Although bryophytes seldom reach the headlines, they have served as model systems in many branches of biology for a long time. The first sex chromosomes in plants were described from a liverwort, then the continuity of chromosomes during mitosis, then the discovery of non-Mendelian inheritance (Reski 1998). Mutagenesis, using UV, was first demonstrated in mosses (Reski 2005).

Many aspects of plant physiology have been elucidated using mosses as model systems. It seems that photorespiration was first recognized in *Fontinalis* (Buch 1945), although Buch is not given credit in modern literature. And it is much easier to study tropisms, amyloplasts, and statoliths in the one-cell-wide protonema (Walker & Sack 1990; Young & Sack 1992; Sack 1993; Chaban *et al.* 1998; Kern *et al.* 2001). This system likewise is ideal for trying to understand the early developmental pathways and their hormonal controls (Bopp 1974). The moss provides a simple plant system in which to understand mechanisms of Ca regulation and signal transduction in plants (Schumaker & Gizinski 1995).

Thus, in recent years bryophytes have become established as model plants for the study of many physiological aspects of plants, especially in linking genes to function, including developmental processes [cell polarity and plastid development (Jenkins & Cove 1983)], homologous recombination, and cellular (calcium signaling) processes. Expression of characters in the haploid state makes it much easier to understand gene expression (*e.g.* Wood *et al.* 2004 on GAPN enzyme effects), and isolation of mutants has facilitated the breakdown of developmental and biochemical pathways. Now, the ability to transplant genes or target knockout genes in mosses, especially in *Physcomitrella patens*, permits us to understand gene/pathway/phenotypic response relationships through the use of reverse genetics (Reski 2005).

Sineshchekov *et al.* (2000) transplanted the moss *Ceratodon purpureus* (Figure 26) CP2 gene to the yeast *Saccharomyces cerevisiae* to reconstitute phycocyanobilin. This permitted examination of emission spectra in isolation from the influence of other pigments. Studies such as this are being used to understand a variety of gene functions in plants, with bryophytes expressing transplanted genes more easily than other plants. Hence, they have been invaluable in advancing our understanding of plant functions.



Figure 26. The moss *Ceratodon purpureus* was used for transplanting genes to yeast in order to identify pigment emission spectra. Photo by Janice Glime.

## Genetic Engineering

While genetic engineers are making the headlines with marketable fruits, vegetables, and even modified animals, the genetic engineers of bryophytes remain quietly in the background figuring out "what makes things tick." Although few people have any interest in how a moss functions, the ability of using mosses to figure out how a

tracheophyte, especially a crop plant, goes about its daily life is of enormous importance to the agriculture industry.

Cove and coworkers (1997) have suggested that mosses "hold many attractions" as model organisms, arguing that position as the simplest of land plants permitted them to shed light on the development of terrestrial plants from formerly aquatic ancestors. But this simple evolutionary approach soon blossomed into a new and strategic use of bryophytes in understanding not only evolution, but in understanding the functioning of plants in general (Reski & Frank 2005).

To quote Reski (1998), "due to the simplicity of the plants, development can be pinpointed to the differentiation of a single cell and be analyzed in living tissues, making mosses ideal candidates for analysis of development in an integrated approach of cell and molecular biology." In fact, it is the humble moss *Physcomitrella patens* that is proving to be an appropriate model for studying the molecular development of not just mosses, but plants in general. The nuclear genes of this moss can be targeted for homologous recombination, making reverse genetics a viable tool for plant physiologists.

In the past, we have studied gene function by identifying the gene product, then trying to identify the gene involved. With reverse genetics, we instead identify the gene on the basis of its position. We can then remove it or insert it in another organism to determine the effect that gene has on phenotypic expression. As haploid organisms, mosses are ideal for this approach because the gene is not masked by a second allele that may alter or prevent its expression. It is as easy in this moss to target nuclear genes for recombination as it is in yeast, providing a powerful tool for understanding plant gene function (Reski & Frank 2005). Using *Physcomitrella patens* to confirm the transgene in chloroplast transformation, Cho and coworkers (1999) were able to demonstrate the applicability of this moss as a model system for basic biological research.

The model moss *Physcomitrella patens* not only is useful for expressing genes transferred from other plants, but it also has genes of its own to contribute. Its high tolerance against drought, osmotic stress, and salt (Frank *et al.* 2005) suggest that it has genes that could be useful in other plants. Because it is easier to identify specific genes and link them to their functions in haploid plants, it could serve as a source for genes that could be moved into crop plants to endow them with these desirable traits.

One advantage of using mosses to understand physiology is their ability to exhibit conditional lethal genes (King 1986). Such mutants permit physiologists to understand processes because the gene is lethal until the problem is corrected.

## Manufacturing Human Protein

Most recently, the mosses, and especially *Physcomitrella patens*, are being used to culture needed human proteins because they are much easier systems than tracheophytes for gene manipulation (Reski 1998; Baur *et al.* 2005; Figure 27). And mosses are much cheaper and easier to culture than human cell systems.

Reski and Frank (2005) have identified three public demands in modern plant biotechnology:

1. More people in the population require more food, but they also reduce the area of arable land, constraining the food production.
2. The mean age of the population is increasing, requiring a higher quality of food to prevent typical "diseases of civilization" such as cardiovascular diseases and cancer.
3. Medical science is experiencing a paradigm shift from broad-based treatments to very patient-specific treatments, requiring safe and cost-effective production of complex pharmaceuticals.

Reski and Frank (2005) suggest that *Physcomitrella patens* can contribute in all three of these needs. "Virtually every gene can be knocked out by targeted ... approaches in attempts to establish saturated mutant collections." And the phenotypes can be screened within weeks! Gene targeting in this moss is about five orders of magnitude more efficient than in any seed plant and about two orders of magnitude more than in embryonic mice stem cells.



Figure 27. *Physcomitrella patens* is cultured for gene manipulation and proteomics. Photo by Ralf Reski.

It appears that there are already over 200,000 expressed sequence tags in *Physcomitrella patens* (Reski & Frank 2005). There are about 6000 protein-encoding genes which are not identifiable in the public databases, most likely representing novel genes, out of the 30,000 protein-encoding genes present in the moss. It is interesting that about 100 genes in this moss can be matched only to non-plant organisms, including humans!

One advantage to working with a moss such as *Physcomitrella patens* is the ability to culture it in a bioreactor (Figure 28), thus eliminating the problems of contamination from soil or other growth media (Reski & Frank 2005). This makes the study of proteomics (examination of the protein complement of a genome) much easier.

Mosses may help us to address needs in the human diet that are not available from other plants. For example, eicosapentaenoic acid (EPA) and arachidonic acid (AA) are only produced by non-seed plants, including bryophytes. Yet these acids play a role in human eicosanoid metabolism. Furthermore, polyunsaturated acids are most abundant in non-seed plants, including mosses, and likewise are beneficial for human growth and continued

good health. As our fish (also large sources of polyunsaturated acids) dwindle and become contaminated with metal pollutants, these plants may become an essential source of these important fatty acids. Genes from *Physcomitrella patens*, identified to have this function of producing polyunsaturated fatty acids, have already been planted and expressed in tobacco (*Nicotiana tabacum*) and linseed (*Linum usitatissimum*) (Abbadi *et al.* 2004).

One problem with many plant cell culture systems is genetic instability (Reski & Frank 2005). The *Physcomitrella patens* bioreactor, on the other hand, maintains well-differentiated and genetically stable cell types. The culture conditions are much simpler than those required for mammalian cells.

Targetted gene removal or transfer can render the moss products safe for humans, avoiding production of allergenic products that are unsafe for humans (Reski & Frank 2005). For example, xylose and fucose form allergenic residues of plant glycoproteins in most plants, but in the mosses, a targetted double knockout provides moss plants with no fucose or xylose residues attached to their proteins. This modified moss was still able to produce the same level of recombinant human growth factor, serving as a living reservoir for this purpose.



Figure 28. Moss bioreactors provide sterile cultures of *Physcomitrella patens*, avoiding the contamination problem prevalent with soil-grown plants. Photo by Ralf Reski.

## Summary

*Sphagnum* is the most widely used moss, including uses for bandages, diapers, boot liners, sanitary napkins, horticultural soil mixes, cranberry farms, orchid and mushroom culture, green roofs, flower arrangements, fuel, peatwood, peatcrete, litter for animals, lead detection electrodes, filtration, and oil spill cleanup. Products such as Hydro-Weed, SpillSorb, Oclansorb Plus, and Peat Sorb are peat products designed for hydrocarbon cleanup projects.

Peat is a renewable fuel and horticultural source, but it must be harvested with sustainability in mind. Hand raking and light-weight wagons travelling on restricted paths can leave sufficient live plant material that harvesting may be repeated in 10-20 years. Lack of care about renewability has caused mass destruction of peatlands, along with destruction caused by development of industry, business, and housing land.

In addition to burning the peat, peatlands can be used to generate methane for fuel. Peat has been used in construction to make asphalt, peatcrete (light concrete), peatfoam, peatcork, and peatwood. Their natural role to control erosion has recently been copied in road construction.

Peatlands harbor a rich history and because of their antiquity can be used for aging and determining past vegetation and climate.

Bryophytes produce a wide range of antibiotics that have been used against fungi, slugs, and other invertebrate herbivores. The antibiotic and absorbent capabilities make bryophytes good agents of preservation, as seen in ancient tombs, stuffed mummies, and the preservation of bogmen.

Modern science is now using bryophytes to put suspects at the scene of a crime, using the techniques of DNA fingerprinting to match fragments to a particular location.

Bryophytes are good organisms for testing the toxicity of various substances, using the bryological "lab rat" *Physcomitrella patens*. Other scientific uses include unravelling the mysteries of gene function and plant physiology by studies with knock-out genes and gene transplants. Mosses are ideal for this because of their dominant 1*n* generation. This same advantage permits us to put genes for producing human substances such as blood protein into a moss and produce it in culture, avoiding any animal rights violations.

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