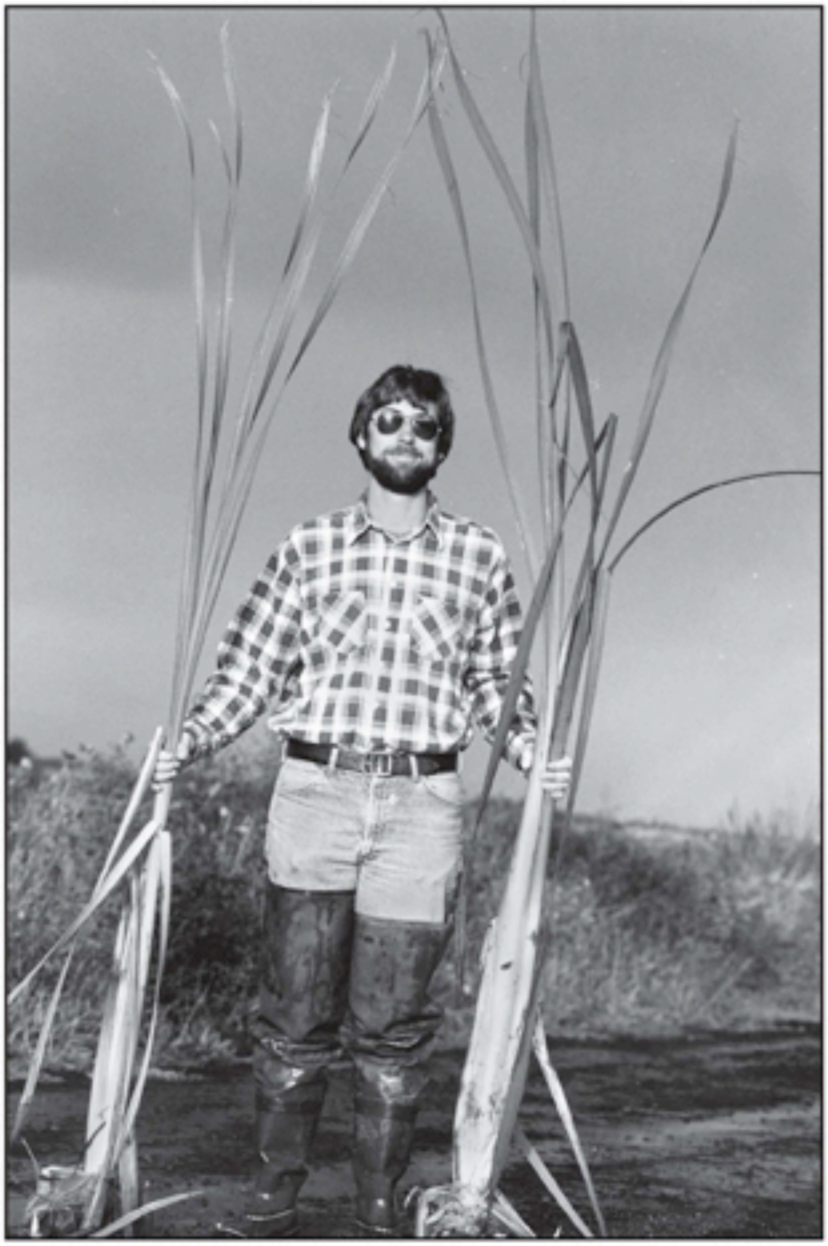
yields of 120 gallons of oil per acre per crop cycle are common, but yields of twice this are possible in lands with greater rainfall or irrigation.

When heated for an hour and put through a **screw press**, five gallons of pure castor oil is obtained from only 100 pounds of seed.[10] In developing countries, the castor bean seed is first roughly crushed by a roller press and then squeezed between hemp mats with a screw press, much like olive oil. But if the seeds are sprouted, the oil quickly turns into sugars and other fermentable carbohydrates at a ratio of 2.7 to 1;[11] thus, the alcohol yield from the sprouted castor beans should be 324 gallons per acre.



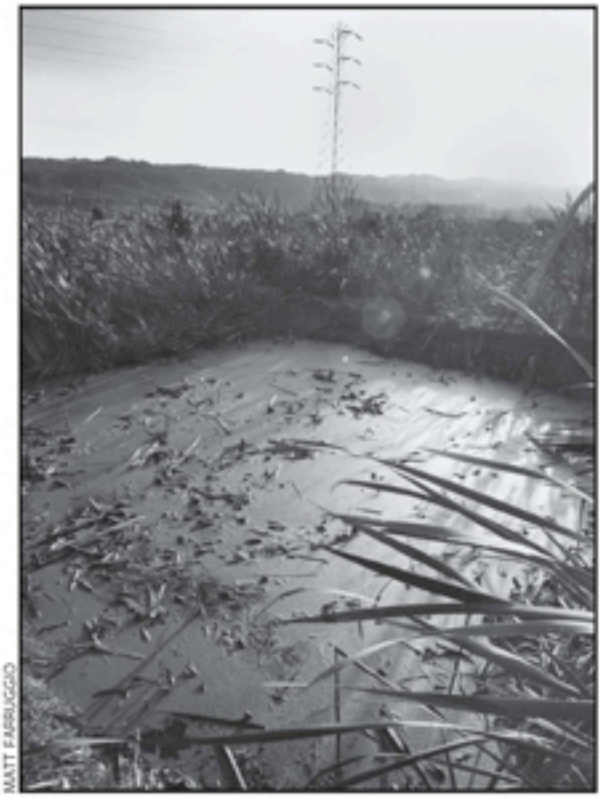
MATT FARRUGGIO

Fig. 8-10 Comparison of wild and wastewater-grown cattails. *The wastewater-grown plant on the right is at least three times heavier than the one on the left. Note the much larger starch-filled base of the plant.*

The spiny hulls of the castor bean are said to be comparable to barnyard manure and can be spread as fertilizer.

CATTAILS

Cattails *(Typha sp.)* live in marshy places where the water is rich in nutrients. They can tolerate a relatively high amount of salt, and they grow very fast and thick, outstripping bullrushes *(Scirpus sp.)* and most other marsh plants. Its **rhizome** (root-like structure) accounts for over 65% of a cattail's wet weight,[12] and it's the fast-growing rhizome that makes the plant such a pest in the waterways and ditches of the world. Rhizomes don't root very deeply, tend to grow laterally, and send up new foliage as the rooting network develops.



MATT FARRUGGIO

ABOVE: Fig. 8-11 Cattail experiment. *This section of a cattail marsh has been picked clean of rhizomes. The experiment will determine how quickly rhizomes will invade the area from the edges. The surface is covered with duckweed, a nitrogen-fixing floating plant. Researchers find that a couple of ducks are able to keep the various plots clear, which is a good practice in treating sewage since the point of the treatment is to oxidize the nitrogen. But in an energy marsh, co-culturing with duckweed would capture free nitrogen from the air to fertilize the cattails. On the other hand, duck eggs sell for double what you can get for organic chicken eggs. Decisions, decisions.*

LEFT: Fig. 8-12 Cattails, mature foliage. *The seed heads pictured are what give rise to the common name of the plant. Seeds are attached to a light fluff that allows them to be carried for miles on the wind until deposited on some new wet place.*

American Indians found the plant's rhizome a good source for a crude, starchy flour from which they made bread, and cattails are once again being recognized as a useful crop. Alcohol is being made from cattail roots in the former Soviet Union. Cattail foliage makes a good cellulose pulp source for the paper industry and a pretty good animal feed.

A crop of cattails is an excellent candidate for natural marshy areas in which few other energy crops thrive. And they can provide a profitable way to clean up rivers, streams, and oceans. It has been conservatively calculated that 35 acres of cattail marsh could treat five million gallons of secondary sewage a day.[13]

While cleaning up sewage better than any known crop, cattails can yield several high-quality byproducts from the process, one of them being alcohol. Cattail productivity in sewage liquid is incredible. Its nutrient uptake and biomass production is several times higher than corn's. A 1982 study produced results that were as high as 130,000 to 150,000 pounds of biomass *dry weight* per acre. Almost 100,000 pounds of that was rhizome mass. Cattails grown in the wild only produce between three to 30 tons per acre dry total weight.[14] Rhizome yield per acre of wild cattails would be about 15 tons average.[15]

Wild cattail protein content is regularly 6.9% dry weight. It's thought, although not verified, that protein content of wastewater-grown plants is higher. Assuming the 6.9% figure to be average, protein production per acre would be over two tons. Cattail protein stays fixed in its solids through fermentation, and crude protein readings from fermented wild cattails in dry stillage show 19.1%.

Cattail rhizomes are credited with having a higher starch content than potatoes. One 1975 study[16] and one in 1981 recorded 40 to 60% starch content (dry weight, rhizomes only). Such yields suggest a conservative per-acre alcohol estimate of 2500 gallons from cattail rhizomes fed by wastewater. This calculation is based on a mean yield of only 34.8 tons dry weight of rhizomes at 45% starch in a single crop cycle.[17] These results were achieved in relatively cold northern areas—in warmer climates, the researchers feel that a second crop or even a third crop could be harvested, depending on the length of the frost-free growing season.

A group of my alcohol fuel students, led by Dave Hull and Steve Wilbur, designed and built one of the first cattail marsh secondary sewage treatment facilities in the world, for the city of Arcata, California. Primary sewage treatment settles out or digests solids, but leaves a high level of nutrients in solution. Most rural plants stop processing at that point and release the nutrient-saturated sewage into a waterway or land disposal. Small plants typically cannot afford secondary or tertiary treatment, which typically use sunlight and microorganisms in pools to lower the **biological oxygen demand (BOD)**, as well as nitrate and ammonia levels.

Growing crops in nutrient-rich, secondarily treated sewage to absorb dissolved nutrients and chemicals works as an alternative to part of the secondary and all of the sophisticated tertiary treatment. Cattails excel at this. Not only do they remove solids, but cattails are powerful detoxifiers of chemicals dissolved in water; mercury, for instance, is taken up by the plant and evaporated out of the leaves. They do more than remove chemicals and nutrients, too. Pores on the lower portions of the plants actually capture bacteria and "eat" them.

Grown in wastewater, the plants may be said to be living almost hydroponically. In fact, they don't root any more deeply in wastewater pond soil than is necessary to keep them from falling over. This characteristic makes it possible to grow cattails anywhere trench ponds can be built to simulate aquatic conditions. Agricultural land need not be used at all. Plants grown this way in wastewater reach 12 feet in height, compared to their usual five

WETLAND ENGINEERING AND TECHNOLOGY

Fig. 8-13 Cattail rhizomes. *Note how the main plant on the left spreads by adventitious sprouting of new foliage a foot away.*

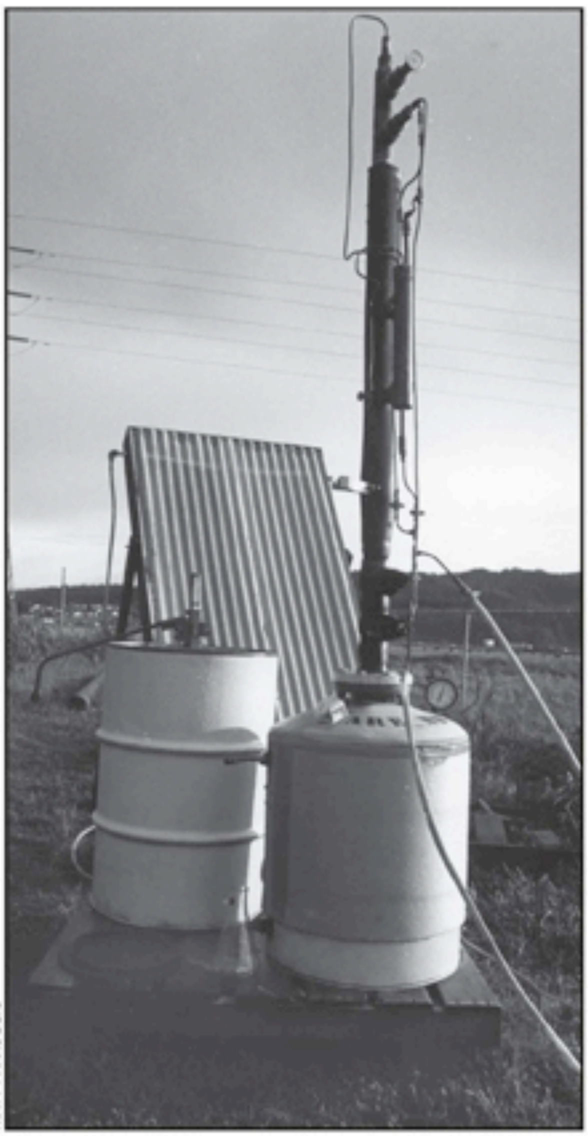


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Fig. 8-14 Experimental solar vacuum still. *Used by Wetlands Engineering and Technology for test batches. Heat energy comes from the panel in the rear.*

to seven feet. Using liquid stillage to fertilize cattails, instead of sewage, produces similar yields.

There is potential for closed loop fuel production, where the stillage left over from distillation goes back into the cattail marsh, enabling the growing plants to use those nutrients to trap more solar energy in the form of starch in a relatively small area. Matching up a cattail system located alongside an animal feeding operation or dairy, with alcohol production—where both the stillage and manure are cycled through the marsh—might make for a very dynamic, productive system.

The ten feet or so of cattails' top growth (leaves) should also be considered in energy planning.

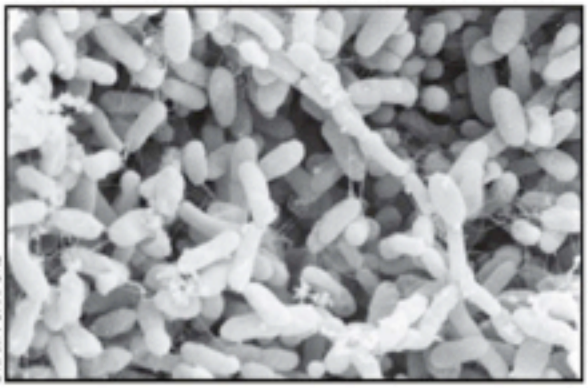
LET THE ROADSIDES PROVIDE THEIR OWN FUEL?

In another implementation of "the problem is the solution," how about using the roads to provide the fuel for the cars that use them?

Roadsides have to be mowed or sprayed by counties at considerable expense. Since roadsides are where water gathers, their runoff spreads herbicides and automobile excreta (oil, antifreeze, tire dust, etc.) for miles downstream.

If each county were to convert only 1000 miles of county-maintained roadsides so that a five-foot-wide strip of cattails was cultivated on each side of the road, boom mowers could shred and harvest up to three crops a year of starch and cellulose, as if it were **silage**. At the production level of wild cattails or a polyculture of other high-output cellulose crops, we'd be looking at four pounds of starch and cellulosic plant fiber per square foot from an average of two harvests. This could in theory produce 61 billion gallons of fuel (40% of U.S. gasoline use)—without using a single acre of farmland and while thoroughly detoxifying road runoff water. Planting energy crops in the nation's unused median strips in divided highways would generate additional billions of gallons.

Not everyone wins under this scenario. Monsanto and Dow would be deprived of a lucrative market for their herbicides.



DR. J.P. BARFORD

LEFT: *Fig. 8-15 Scanning electron micrograph of* Zymomonas mobilis. *This bacteria has been used extensively by genetic engineers working on the direct consumption of hemicellulose- and cellulose-producing alcohol without an intermediate sugar-producing step.*

Depending on the time of year, the sugar content in the leaves averages 10 to 15%. You could use the diffusion process to extract the sugar for fermentation or ferment it whole. But the alcohol yield would be pretty low for the mass of material handled. Combining the sugary foliage with cheese whey to increase the overall sugar content may be an attractive way to produce alcohol from the tops in several cuttings a year. Toward the end of the growing season, you would cease cutting the tops, to allow the sugar to sink down into the rhizomes for winter energy storage so the plants can sprout early in the spring.

On the other hand, now that cellulose technology is becoming economically feasible (see next section), the 25 dry tons of largely cellulosic leaves and the nearly equal amount of cellulosic byproduct left over after rhizome starch fermentation lead me to some provocative speculation. Using the state-of-the-art rate of 180 gallons of alcohol per ton for cellulose conversion, it is possible to project more than 10,000 gallons of alcohol per acre, based on very real cattail biomass production figures, when combining cellulose and starch. Bear in mind that these biomass yield figures do not take into account the potential of stimulation with fermentation carbon dioxide.[18]

At 10,000 gallons per acre, we'd need only about 6367 acres per U.S. county[19] to treat all of our sewage and to replace our entire 200-million-gallon fuel demands. That amounts to only 1.46% of our agricultural land.[20] The energy to run the plant would come from the **lignin** recovered from the cellulosic part of the crop.

Until cellulosic processes become practical on the scale of small municipalities or counties that process sewage, the cattail leaf matter could be dried using solar or waste heat, after diffusion of its sugars. Then it could be used like sugarcane bagasse to cogenerate all the process heat and electricity for the alcohol plant, plus sell surplus electricity back into the grid (see Chapter 11). All ash from the biomass boiler would go back into the marsh as fertilizer.

Remember, too, that if this tertiary treatment plant is, almost by definition, part of a sewage treatment plant, then methane from the primary sewage processing could also be available to provide all the process energy for the alcohol plant.

CELLULOSE BIOMASS TECHNOLOGY

After hearing about the potential from cattails in the previous section, you are really primed to hear about cellulose technology. Until recently, the various methods of producing alcohol from cellulose were only possible with large capital investments for heavy pieces of equipment. But intensive research has been under way over the last 20 years to find an economical method to produce ethanol from our planet's most voluminous carbohydrate. The varied approaches to the questions posed in pursuit of cellulosic alcohol have become a blizzard of research projects spanning more than a dozen universities and many government agencies.

Cellulose is a distant relative of starch and inulin. Like starch, it's essentially a series of linked sugar molecules; unlike starch, which is typically only 35 glucose units, the chains of cellulose are often more than 10,000 glucose molecules. Cellulose is made up of beta-glucose instead of the common alpha glucose that makes up starch. Plus, the chains of cellulose link up side-to-side, forming fibrous crystal-like units with their hydrogen atoms bonding to each other. These cellulose structures are very

"The extreme events to which climate change appears to have contributed reflect an average rise in global temperatures of 0.6ºC over the past century. The consensus among climatologists is that temperatures will rise in the 21st century by between 1.4º and 5.8ºC—by up to ten times, in other words, the increase we have suffered so far. Some climate scientists, recognizing that global warming has been retarded by industrial soot, whose levels are now declining, suggest that the maximum should instead be placed between 7º and 10ºC. We are not contemplating the end of holidays in Seville. We are contemplating the end of the circumstances which permit most human beings to remain on Earth."

—GEORGE MONBIOT, *THE GUARDIAN*, AUGUST 12, 2003