Farming for fuel

U.S. biologists are re-engineering a once-prevalent prairie grass as an energy crop to replace gasoline

By Ian Hoffman, STAFF WRITER

Inside a locked greenhouse, prairie grasses rise as tall as a man, some literally propelled out of their gallon buckets on a snarl of roots.

"I've never seen a plant like this," said John Vogel, a Stanford-trained molecular biologist at the U.S. Department of Agriculture lab here. "The roots just keep growing and growing and growing."

It's switchgrass, if not exactly the wild, deep carpet of the American Great Plains that farmers plowed under to make way for the corn and wheat belts. What's growing in the USDA greenhouse in Albany is federal scientists' first stab at genetically re-engineering a grass as an energy crop.

It could take eight years or more for these grasses to be perfected and planted commercially. But if they reach that point, they will feed a new bioenergy industry worth billions of dollars, enjoying broad political support among automakers and environmentalists and competing with Big Oil to supply fuel and chemicals.

Years before President Bush made switchgrass the poster plant for weaning Americans off oil imports, scientists dreamed of wringing fuel out of cheap grass and identified switchgrass as ideal.

They saw this clumpy weed with a faint, rusty-orange glow as the nation's biggest feedstock for the industrial energy farm, capable of bolstering rural livelihoods and restoring the grasslands of the American prairie.

Given enough rain and a little fertilizer, a crop of switchgrass can last decades, every year reliably turning out tons and tons of plant mass that can be converted to hundreds of gallons of fuel in a process akin to making moonshine.

With more than a billion tons of plants and wastes from U.S. farms, forests and cities, scientists say the United States could distill at least a third of its transportation fuel at home, year in and year out, at prices below $1 per gallon.

Experts assembled by the U.S. Department of Energy concluded in a report this month that bio-fuels have the "potential to meet most, if not all, transportation fuel needs."

The bio-fuels industry already is soaring. Corn ethanol makers call it a "golden age," with a record 45 new bio-refineries built last year, boosted by 51-cent per gallon tax credits and demand for an oxygen-rich fuel additive to replace MTBE, banned by California and most other states.

But today's bio-fuels are derived from a small part of plants — the oils in seeds and beans for bio-diesel and the starch in corn kernels for ethanol — and they take almost as much fossil-fuel energy to produce as they replace. If all corn grown nationwide were converted to fuel, corn ethanol would supply only 15 percent of U.S. transportation fuel needs.

The answer, scientists say, is a vaster bio-fuels industry that uses whole plants. The catch is that no commercial-scale factory has been built in the United States capable of mining the rich energy locked inside the walls of plant cells.

Plants use sunlight and carbon dioxide to make long chains of sugars, called cellulose and hemicellulose that are the world's most abundant biological material. Raw feedstock can be found everywhere — in newsprint, in planks of wood, every plant, every fiber of a cotton skirt.

USDA MOLECULAR biologists Christian Tobias (right) and John Vogel are exploring the genetic makeup of switchgrass, chosen as the biggest of several U.S. biofuels crops. (D. Ross Cameron - Staff)

It can be chewed up, broken down and distilled into grain alcohol, dubbed the fuel of the future by Henry Ford, who selected ethanol to power his first Model T.

"The bulk of the (ethanol) capacity in the United States for the next few years is going to come from the starch world," said John Ferrell, head of the Department of Energy's Office of the Biomass Program. "But that's just the beginning of the story. The big story is the cellulosic world."

Kicking what the president calls an "addiction to oil" would mean collecting and processing plant materials and wastes on an unprecedented scale. Distilling it into enough bio-fuel to replacing a third of U.S. gasoline use would require 600 large bio-refineries scattered around the country, each fed by 162 square miles of forests and farm.

The first cellulosic ethanol plants are expected to be costly, about four times as expensive to build as a corn ethanol plant of the same output. Building 600 of them would take an investment estimated at $240 billion in the United States alone.

But if this bio-fuels revolution comes, it will be global and mostly rural. Some of the poorest nations, wrapped in a belt around the tropics, are poised to benefit the most, with fast growing seasons and plants rich in energy.

In the United States, more than 100 million acres of marginal farm and pasturelands could be turned over to switchgrass and other energy crops. That's an area roughly the size of California and more land than is now occupied by corn or soybeans, the nation's largest crops.

Most of the fodder for this new industry already is growing today and discarded or left to rot. The first bio-refineries will use crop leftovers, starting with wheat straw, as the Canadian firm Iogen plans to do in a plant slated for Idaho next year. The greatest mass is in corn stover or the stalks and leaves left after ears are harvested.

Those crop residues are expected to supply almost half of the feedstock for cellulosic ethanol for decades. Much of the remaining feedstocks are wastes from cities, pulp and paper mills, the timber industry and cattle feedlots.

A fourth of the feedstock would come from industrial energy farms, sown with switchgrass in the Midwest, poplar and eucalyptus trees in the Northwest and California's Central Valley, and a towering Chinese grass called Miscanthus gigantus in the Southeast.

The challenge is that the plants' cellulosic energy is encased and interlocked with a poorly understood substance called lignin that makes up about a quarter of the plant by weight and gives it rigidity, as well as resistance to water, rot, and disease.

Lignins "are very hard to look at. They look a lot like glass," said Christian Tobias, a USDA research molecular biologist at Albany whose work concentrates on understanding switchgrass and its genetics.

In a bio-refinery, lignin also produces substances that retard the breakdown of celluloses into simpler sugars. Scientists don't know efficient ways to break lignin down, nor do they understand the thousands of genetic instructions for making the cell wall.

Somehow, despite a green revolution that squeezed huge yield gains out of food crops and despite the decoding of the genetic recipe for several plants, science still lacks the details of how plants build themselves.

"We're starting this whole industry that rivals the oil industry on the basis of this material that we know vanishingly little about," said Vogel.

The toughness of plant cell walls makes ethanol made of whole plants about twice as expensive as ethanol made from corn starch — about $2.35 versus $1 to $1.20 per gallon. Cellulosic ethanol remains economic as long as oil prices stay above $40 a barrel. But scientists and engineers are looking for ways to double the efficiency.

"No miracles are required, unlike say fusion where you need breakthroughs," said Chris Somerville, head of the Carnegie Institution Department of Plant Biology at Stanford University and an adviser on bio-fuels to the Energy Department. "Everything is about improving things by a factor of two. And there are many places where we can get two-fold improvements."

Laboratories such as the Energy Department's Joint Genome Institute in Walnut Creek, Calif., are decoding the DNA of plant-devouring fungi from the forest and jungle to find enzymes better able to break biomass down.

For now, a fungus found eating away at soldiers' bandages in World War II called jungle rot supplies the enzymes for making ethanol. Other scientists are tinkering with bacteria and yeast used to ferment the sugars into fuel.

But some of the biggest gains are expected in the plants, either through breeding or the more controversial practice of genetic modification. Most energy crops are nearly wild or, like switchgrass, have been bred for pasture.

"It's nothing like what has been done on a lot of other cultivated crops. In comparison, there's been almost no breeding work done," said Kenneth Vogel, a USDA geneticist and agronomist at the University of Nebraska in Lincoln who has been working with switchgrass as an energy crop since 1990.

Mendel Biotechnology in Hayward, Calif., founded by Somerville and other pioneering plant biologists, is breeding and genetically engineering Miscanthus giganthus for energy use.

As early as 2008, Ceres Inc., a Thousand Oaks, Calif.,-based plant biotechnology firm, plans to market switchgrass bred for high biomass, about twice the tons per acre of corn. The company also is working on transgenic switchgrass.

At the USDA's Western Regional Research Center in Albany, Tobias and Vogel are collecting what they believe will be the world's largest genetic library for switchgrass. They've started subtly inserting changes in the genes to produce thicker cell walls or less lignin or lignin that's easier to break down.

Some changes aren't so subtle.

In one project with Edenspace Systems Corp., a Northern Virginia firm, the USDA scientists are helping to insert a kind of genetic Trojan horse into switchgrass so that the plant grows the enzymes that would take apart its own cellulose when triggered by the heat of a bio-refinery.

Scientists at the Energy Department's National Renewable Energy Laboratory in Golden, Colo., cobbled the Trojan horse together out of genes from a fungus and heat-loving bacteria taken from a Yellowstone National Park hot spring.

If transgenic energy crops are planted, scientist say they will make the plants sterile or use some other method of "gene containment" to prevent contamination of wild switchgrass.

Somerville spends much of his time figuring out how to turn plants into fuel for a growing global population while not adding more greenhouse gases to the atmosphere.

Unlike row crops like corn and soybeans, the grasses and trees considered ideal as energy crops are perennials. Their roots systems can be huge, with as much growth in switchgrass taking place underground as above. That suggests they can remove carbon dioxide, a greenhouse gas, from the atmosphere and store it underground but also that they do well at holding soil together.

Some, like switchgrass, draw nutrients back down into the roots at the end of the growing season and don't need much fertilizer. They won't have to be tilled, and if planted in land with enough rain won't require irrigation.

For the farmer, the lower level of effort and input means energy crops like switchgrass and Miscanthus can pay three to five times as much per acre as corn.

"It's fundamentally like growing hay," said Stanford's Somerville. "It's not new technology."

Those factors also mean energy crops could be grown on marginal soils, without crowding out food crops, and grown more sustainably than many food crops, Somerville said.

"We're going to see a lot of change in the next 10 years," he said. Farming for fuel "is going to be quite a different game."

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