Half the sugars produced in the cellulose process are not fermentable by normal yeast. (As I discuss elsewhere, the use of GMO yeast might be an undesirable direction for cellulose ethanol to go.) One of the easiest uses of those unfermentable sugars is to produce methane. These sugars would spend only two to five days in the digester, and would certainly generate more energy than is needed to process the fermentable sugars to fuel.

If some of the sugarcane bagasse were also used in the digesters, the output of gas would be exponentially greater, since the cellulose would be converted to methane; the alcohol plants would have to install large cogeneration systems to feed methane-derived electricity into the grid. In fact, an alcohol plant with more extensive methane production could even be a local source of cooking gas and reduce deforestation further (see Chapter 13). So, as you can see, sugarcane alcohol is a massively energy-positive system that uses almost no fossil fuels at all.

When using corn as a feedstock, 41 percent of the residual corn is in liquid form, with the rest being DDG. This rich soup of nutrients has much more methane-producing compounds than the wash from sugarcane fermentation. In particular, the fat content of the DS, about 17% of the dry matter, is a major contributor to the amount of methane that can be produced.

CARBON DIOXIDE

Carbon dioxide (CO_2) is an odorless, colorless, and noncombustible gas. All animal life and some simpler life forms inhale oxygen and exhale CO_2. Plants, on the other hand, do just the opposite, breathing in CO_2 and releasing the oxygen part, while using the carbon.

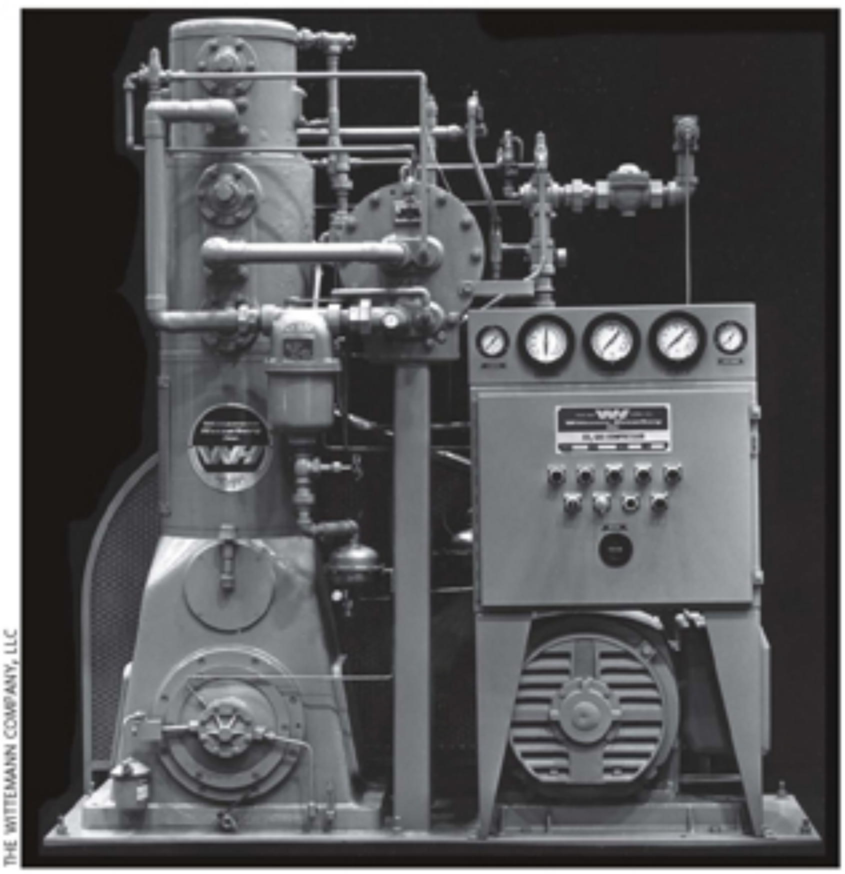
Carbon dioxide has gotten a bad reputation, since it's the main gas implicated in greenhouse effects of global warming and it is also not something that humans want to breathe. It's not poisonous, but in a closed environment, being heavier than air, CO_2 displaces what we do need to breathe.

In the course of fermentation, yeast converts half of the feedstock's starch and sugar into carbon dioxide, which is often just released into the air. Ecologists (and smart business people) are rightly annoyed by that kind of waste. As a surplus product of alcohol production, CO_2 has many uses: for carbonating beverages, for preserving food by displacing oxygen atmosphere in a container, for pressurizing spray cans (avoiding

CO_2 SAFETY CONCERNS

If you go into a greenhouse with a carbon dioxide level above 5000 parts per million (ppm), you will begin to experience symptoms of oxygen deprivation, such as hyperventilating, ringing in your ears, dizziness, a splitting headache, or maybe even falling down in convulsions—in other words, you'll probably realize something's wrong. Get out, pronto! Breathing normal air will revive you.

To avoid unexpected incidents, install a carbon dioxide meter that can be read from outside the greenhouse door. If the CO_2 level is too high, use a fan to draw air into the greenhouse, diluting the CO_2 so it's safe to work inside. This is rarely an issue in normal, single-wall greenhouses whose leaks often give rise to a complete replacement of air in an hour. But double-wall, plastic greenhouses may turn over only a quarter of the air in an hour, so gas buildup is a possibility.



THE WITTEMANN COMPANY, LLC

Fig. 11-21 Farm-scale carbon dioxide compressor. *This size compressor would do the job of compressing CO_2 gas generated at night so it can be stored until the next day, when plants can use it.*

DAVID BLUME

Fig. 11-22 English cucumbers. *These are producing in the middle of an Illinois winter. Note the high density of fruits, large leaves, and lack of cucumber beetle scarring in these cucumbers, grown in a greenhouse using carbon dioxide, and using beneficial insects for pest control.*

the use of ozone-depleting CFCs), enriching the atmosphere of greenhouses, enriching outdoor field crops, filling welding tanks and fire extinguishers, etc.

Although, by weight, CO_2 represents about half the original carbohydrates fermented by yeast, it contains only 10% of the chemical energy that was stored in the carbohydrate. So about 90% of the chemical energy of the sugar is retained in the alcohol. Another way of looking at it is that each unit of carbon dioxide used by plants has the potential to trap nine units of chemical energy as carbohydrates as a result of photosynthesis. At any rate, half your product stream by weight is a surplus—for which we permaculturists can certainly find uses.[53]

DAVID BLUME

Fig. 11-23 Greenhouse butter lettuce. *These nearly perfect heads of lettuce are near maturity at less than 30 days from seed due to carbon dioxide enrichment and optimum climate control. No insecticides were used to raise this crop.*

CO_2 is a growth stimulant for plants and a necessary component of their metabolism. Plants use the carbon dioxide to produce carbohydrates like sugars, starches, and cellulose. Once the carbon atoms are harvested by photosynthesis, much of the oxygen is vented out of the leaves or roots.

Our atmosphere today has roughly 340 parts per millions (ppm) of carbon dioxide. Although this is a lot higher than 100 years ago, CO_2 is still often the limiting factor in plant growth, when there is enough sun, water, and nutrients. Fed extraordinary amounts of CO_2, plants grow healthier and larger, flower earlier, produce higher fruit yields, reduce flower bud abortion in some plants (for instance, roses), increase stem length in flowers, and augment flower size.[54]

Using CO_2, many plants may be brought to maturity in 30 to 60% of their usual time and at a higher weight per plant. Some crops' photosynthetic rate, and therefore biomass, is increased by up to 300% with carbon dioxide.[55] How quickly plants mature with increased CO_2 depends on a matrix of conditions.

For instance, in the case of popular and profitable greenhouse crops like tomato, cucumber, and peppers, the bumper crops are due to a combination of more fruits per plant and faster flowering at CO_2 levels above 1300 ppm.[56] The ADM greenhouse gets almost 50 one-pound English cucumbers per plant in about four months, compared to perhaps 15 cukes without the extra gas.[57] Those big cucumber leaves really suck up the carbon dioxide and set flowers like there's no tomorrow.

With energy conservation in mind, modern greenhouses are being built a lot tighter than they used to be, with far less outside air circulation so as to prevent heat loss. This makes getting even a minimum amount of carbon dioxide into the greenhouse from outside air difficult. Modern greenhouse operations report that their plants consume naturally occurring CO_2 in the greenhouse by 10:00 a.m. This radically slows their growth, since once the carbon dioxide level drops to 200 ppm, photosynthesis is inhibited; growth is cut by 50%.[58] Eventually, additional carbon dioxide will be a required ingredient in all energy-efficient greenhouses, not just those looking for exceptionally high yields.

Seedlings and plants harvested for their vegetation fare better at CO_2 levels between 800 and 1000 ppm.[59] Although leafy greens grow best at a lower concentration of CO_2, they actually can consume greater quantities per hour than flowering or fruiting plants. This is due to the vegetative phase of plant growth being much more rapid than the flowering or fruiting phase. The input of CO_2 can reduce the growth time until harvesting time for leafy greens by half. The ADM greenhouse produces a mature lettuce head in 30 days from transplant,[60] compared to the 60 days I was used to at my California farm.

For most ways of producing vegetables or flowers, you want to maintain a level of CO_2 somewhere between 1000 to 1500 ppm.[61] In general, you'll find most crops will increase their photosynthesis about 50% when you maintain a 1000-ppm level.

Since plants use carbon dioxide only during the day, you would generally store the gas collected at night for use the following day. You can compress the gas and store it in a tank like compressed air or use the floating tank method as is done in methane storage. Of course, if you are extending day length with high-pressure sodium lights, you'd need to supplement the greenhouse with CO_2 during the additional lighted hours as well.

So, how much CO_2 should you use? Well, of course, it varies with light intensity from day to day and week to week, but to simplify a complicated calculation, we can average things out. The following example analyzes the CO_2 requirements in a greenhouse eight feet tall at the sides and twice that high in the middle. This calculation assumes nearly mature plants, which are using gas at a higher rate than little sprouts.

The first addition of CO_2 would usually occur an hour before sunrise. On an "average" light intensity day, to increase the CO_2 from 300 ppm to 1300 ppm would take about 1.7 pounds of CO_2 for every 120 square yards of bed space.[62] However, on a sunny day, in a pretty tight double-wall polyethylene greenhouse (where one-third of the atmosphere is replaced per hour), you'd expect to add an additional 1.3 pounds of CO_2 per hour per 120 square yards of bed space. For a standard 30-foot by 100-foot greenhouse (111 square yards), that would come to 144 pounds of CO_2 per hour of daylight.[63]

Since the study quoted above was conducted in Ontario, Canada, you can imagine that the brightness of sunlight varies widely from winter to summer. The "average" day cited above would require 4754 pounds of CO_2 per acre per hour in the month of January, and, due to the short day length in January in Canada, the CO_2 would only be added for 82 hours during the month. In July, an average day would require an enrichment rate of 16,408 pounds of CO_2 per acre per hour, and the longer days of summer mean that we would need to add this CO_2 for 283 hours over the course of the month.[64]

Over the entire year, you'd need about 143 tons of CO_2 per acre.[65] To produce this much carbon dioxide, you would need to ferment about 360 tons of corn. This would mean that you would be producing approximately 44,000 gallons of alcohol (143 tons divided by 6.5 pounds per gallon). Of course, you would end up with about 120 tons of DDGS, as well.

Among greenhouses' multiple uses is the nighttime heating of residences or other buildings. A greenhouse will almost definitely pay for itself in a couple of years if you use it for heating your home. Greenhouses can store the day's heat in some sort of thermal mass—in as simple a device as a concrete block wall painted black or 55-gallon water drums painted black and stacked in the "back" of the greenhouse, on the side away from the sun. During the day, sun will heat the mass, and at night the mass will radiate the heated greenhouse air, which can then be blown to where you need it.

Plants would rather not breathe CO_2 at night, preferring oxygen when the sun goes down. An hour or so before sunset, use exhaust fans at the

IMAGE COURTESY OF TOMCO EQUIPMENT COMPANY

***Fig. 11-24* Carbon dioxide storage.** *This tank holds several tons of carbon dioxide in liquid form.*