“Power plant” takes on a new meaning

Waste heat from a 100-MW electric plant could, in theory, warm 100 acres of greenhouses.

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About 15% of tomatoes consumed in the U.S. come from greenhouses, and that number is rising. One reason: Yields for greenhouse-grown fresh produce are about 10 times that of open fields. Not to mention, imported tomatoes are expensive, especially in off-season. Transatlantic shipping costs in most cases exceed the cost of the tomatoes. Then there are the growing concerns of food safety and bioterrorism associated with imported crops.

Of course greenhouses require heat and (ideally) a carbon-dioxide (CO₂)-rich atmosphere to accelerate growing, jobs mostly handled today by dedicated and costly natural-gas-fired boilers and, in some cases, cryogenic CO₂ systems.

But there is another source of CO₂ and heat that is now literally going up in smoke: electric power plants. Flue gas from fossil-fuel-fired power plants is rich in CO₂. The burning of 1 m³ of natural gas makes about 2-kg CO₂ or 10% by volume, for example. A controlled amount of flue gas can be vented to a greenhouse, while waste heat from electricity generation provides heating. Greenhouses would collocate with power plants to reduce thermal and piping losses as well as tap electric power for artificial lighting, yet another requirement for growing tomatoes and other crops during winter days and feeble sunlight.

That is the concept being forwarded by the Greenhouse Corp. of America (GCA), Newton, Mass. GCA plans to team with power-plant designer/builder Calpine Corp., San Jose, and improve upon technology developed in the Netherlands.

The idea of using waste heat to warm greenhouses isn’t new. Since 1987 the 13-acre Cologne 6 greenhouse in Germany has been

Artist rendering of greenhouses heated and enriched with CO₂ using waste from a power plant.
heated entirely with cooling-tower water from the nearby Niederau em coal-fired 2,700-MW power plant. A system of water-to-air heat exchangers with computer-controlled forced ventilation maintains an indoor temperature up to 72°F when outside temperature dips to 70°F. Water-inlet temperature ranges from 86°F in winter to 104°F in summer.

This relatively tepid water requires huge heat exchangers to make the system work. For comparison, a 10-acre greenhouse run by Garden State Growers in Home City, Pa., on average gets about 30% of its heat from 110°F cooling-tower water of a nearby 2,000-MW power plant. The plant provides the hot water at low cost in exchange for a tax credit. Dedicated gas-fired boilers supply the rest of the energy. Still, the savings can be substantial. Last December, for instance, the bill for supplemental gas totaled $56,000 because the pipeline carrying the hot water was out of commission. Gas cost was only $8,000 the year before when the system worked.

However, more practical systems need water inlet temperatures of about 176 to 194°F. Unfortunately cooling-tower water from modern combined-cycle power plants such as one in Westbrook, Maine, is only 80 to 90°F. And many combined-cycle plants are air cooled so there is no cooling water whatsoever. Yet another approach uses small (40 to 60 MW), dedicated cogeneration plants that simultaneously output electricity and hot water. “But greenhouses don’t need both resources all of the time so there is wasted capacity,” explains GCA founder Moshe Alamaro. Larger cogeneration plants such as the ROCA5 plant in the Netherlands provide 220 MW of electricity and 200 MW of heat plus CO₂ to greenhouses up to 15 miles away.
But moving the resources over long distances tends to be costly.

**STEAM ON DEMAND**

The GCA design avoids these shortcomings. Here’s how it works: Steam from the low-pressure inlet of a power-plant steam turbine pipes to a quencher. The quencher combines the steam with water to release latent heat. The heated water circulates through forced-air heat exchangers, then a small portion loops back to the power plant’s heat-recovery and steam-generation sections after passing through a reverse-osmosis unit. Make-up water also passes through the ROU. Unlike dedicated cogeneration systems, growers pay for steam only when it is needed. Greenhouses share land with the power plants, which lowers infrastructure and operating costs.

Heat gain to a greenhouse equals — minus losses, of course — the enthalpy difference between steam at the turbine tap and quencher, a relatively large number because the steam changes phase. In theory, assuming saturated vapor and liquid, the ratio of greenhouse heating-to-turbine-power-loss is about 20:1. In practice, steam vapor at the turbine tap is superheated so its enthalpy is higher. Moreover, steam has less enthalpy at the condenser than idealized systems so actual heating-to-loss ratios are about 6 or 7:1. Heating a typical 20-acre greenhouse in winter — assuming an outside air temperature of 5°F and a 200-W/m² heat loss from the greenhouse — requires about 16 MW of thermal energy or 55.3 million Btu/hr. Dividing thermal energy by 7 gives the reduction in power output from the power plant, or about 2.3 MW.

**GOOD GAS, BAD GAS**

The GCA system works best with modern, gas-fired power plants because unwanted contaminants in flue gas from plants burning other types of fuels can be difficult and costly to filter out. Gas-fired plants would as well require scrubbers on smoke stacks to remove phytoxic gases. Phytoxics can severely damage plants, even in small amounts. Ethylene, and to a lesser degree sulphur dioxide and NOx (nitric oxide plus nitrogen dioxide), are phytoxic.

Fuels containing high concentrations of sulphur such as coal, wood, and heavy oil generate significant amounts of sulphur dioxide when burned, making them unsuitable for CO₂ enrichment in greenhouses. Fossil fuels that are virtually free of sulphur include pure propane, butane, LPG, natural gas, premium kerosene, and low-sulphur oil. However, sulphur-free fuels may also generate NOx, though burners that better control fuel-to-air mixtures and combustion temperatures significantly lower these emissions. Here, regulation has driven much of the improvement in burner technology.

Incomplete combustion in low oxygen conditions is another source of harmful-to-plants flue gases, in-
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including carbon monoxide, nitric oxide, and ethylene. Ethylene is especially problematic because it acts as a hormone that stimulates plants to ripen, mature, age, and rot. It is generally agreed that ethylene levels of about 10 to 20 parts per billion (ppb) or higher can damage plants. For reference, ambient ethylene concentrations are about 1 to 5 ppb but can be much higher in industrial areas and population centers with large numbers of motor vehicles.

Obviously CO₂ is the only useful component of flue gas for use in greenhouses. CO₂ concentrations of about 1,000 ppm dramatically boost plant growth rates. Ambient CO₂ levels are typically 350 to 400 ppm, for reference. Plants absorb CO₂ in photosynthesis so the gas must be continuously replenished to maintain proper levels inside greenhouses, either through enrichment or ventilation. Harmful gases, on the other hand, are not absorbed by plants and tend to accumulate. The accumulation of these gases depends on several factors including their percent concentration relative to CO₂, CO₂ injection rate, and losses from greenhouse ventilation and leakage.

For example, say CO₂ enrichment influx = 0.7 m³/m²/hr and the concentration of harmful gases = 1 ppm of CO₂ influx. Assuming no greenhouse leakage, concentration of harmful gases would reach 7 ppb after 10 hr. Factoring in a ventilation loss of 0.5 m³/m²/hr balances harmful-gas influx and efflux at 1.4 ppb. Under these conditions, harmful gas concentration reaches 0.8 ppb after 2 hr and 1.1 ppb an hour later then rises slowly to a steady-state 1.4 ppb. Ethylene concentration after 6 hr is of particular interest because this duration corresponds to CO₂ enrichment on a winter day.

**SEED CAPITAL**

If all goes as planned, GCA will first develop a 20-acre greenhouse with power plant heating and CO₂ enrichment. Estimated cost: $7 to $10 million. The design and size would be standardized to ease expansion. Eventually greenhouses would be franchised to local growers with equipment shared among regional locations.

The time may be right. “Recent studies suggest that the U.S. will need an additional 6,000 acres of greenhouses to satisfy domestic tomato demand in the coming decade,” says Alamaro.