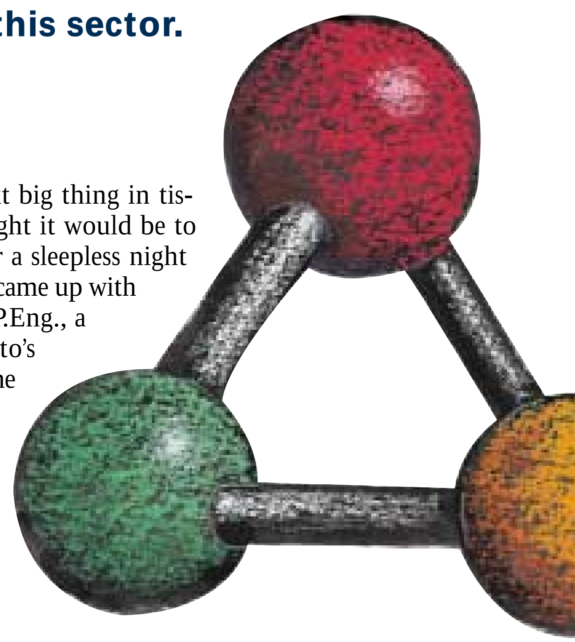
Bioengineering in action

By Dwight Hamilton

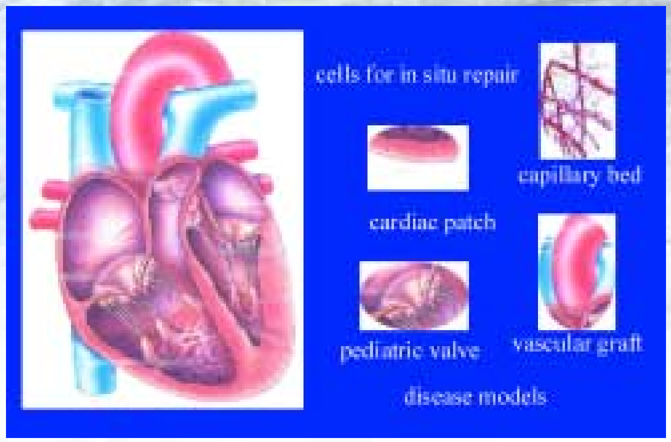
Where engineering and biology meet, there is a science that's vital to protecting public health and safety, as well as improving quality of life. Bioengineering affects the practice of medicine, agriculture and environmental management and is becoming regarded as an established engineering discipline. *Engineering Dimensions* highlights some recent research and development done by professional engineers involved in this sector.

Engineering a miracle



"People were asking me what the next big thing in tissue engineering would be and I thought it would be to grow three-dimensional objects. After a sleepless night pondering the future of the universe, I came up with the idea," says Michael Sefton, ScD, P.Eng., a professor at the University of Toronto's department of chemical engineering. The idea was to spearhead an international group of scientists to create living replacement organs–including a heart–for human use.

Known as the Living Implants from Engineering (LIFE) project, Sefton's big idea could potentially make donor organ transplants obso-



An exposed view of the human heart's chambers shows the challange ahead. Related developments at right may prove to be even more valuable says Sefton.

lete with a limitless supply of available vital organs. In the United States in 1999, Sefton says, about 6000 people died while waiting for a heart transplant because of the scarcity of donor organs. As well, heart transplant recipients must often take drugs for the remainder of their lives to prevent their bodies rejecting the organ. Sefton's "engineered" heart would be grown from "universal donor cells" to be compatible with anyone.

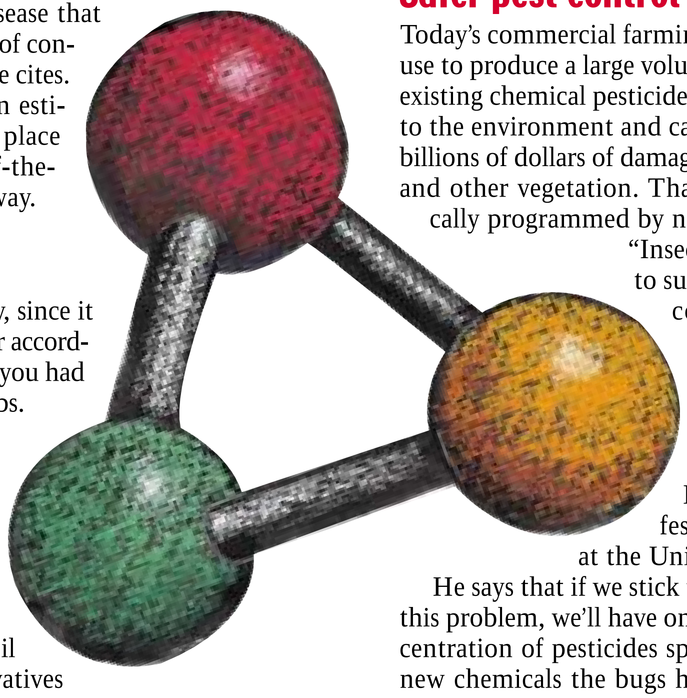
To grow a heart, one approach would be to put live tissue cells into a foamy polymer mould so that they can grow into the shape of the templates forming the various components and chambers of a human heart. The mould is perforated with thousands of tiny channels that transport oxygen, growth factors, nutrients and other signaling molecules to the cells. After the growth process, which could take only weeks, the mould breaks down, leaving live components that would be put together using valves made either of polymer or "grown" tissue.

Corn is the third largest crop in Canada but it rarely ends up on our plates. It's time to fix that, says bioengineer Ralph Brown

"Conceptually, tissue engineering is all about persuading the body to heal itself and providing it with the stimulus and ability to do so," he says. Creating a new generation of materials has already resulted in artificial skin for burn victims. Sefton's team is also researching how to combine synthetic polymers with natural human proteins to synthesize new biocompatible degradable materials. It's hoped this material will be able to repair damaged hearts, treat severe burns, and be used in facial reconstruction and in bladder augmentation for those with spinal cord injuries.

"The spin-offs from the initiative are likely more valuable than the organ itself," Sefton says. Having heart muscles available for injection to repair patches of heart tissue, growing valves for children who would grow with them, and even having small models of heart disease that can be used to understand the mechanisms of conduction blockages are just three examples he cites.

So when will the heart be ready? Sefton estimates that once large-scale funding is in place (likely from various governments), an off-the-shelf human heart may be but a decade away.



Perfect corn

You'd think Ontario would be corn country, since it produces about six million tonnes of it a year according to Statistics Canada, but the corn flakes you had for breakfast likely came from imported cobs.

According to Ralph Brown, PhD, P.Eng., the problem is our climate: A short growing season means the grain retains a substantial amount of moisture at harvest time. And unlike wheat or barley, damp corn cannot be stored at its harvest moisture, because spontaneous heating and fungus growth will quickly spoil it. So producers treat the corn with preservatives or dry it with artificial heat.

Not only is the process expensive, heat drying at 100C causes corn to crack from stress, decreasing its value and making it unsuitable for food processing. Unless shipped to the mill during our short two-month harvest, most Ontario corn does get dried before it ends up in starch and livestock feed.

But all that may change if Brown has his way. A professor of biological engineering at the University of Guelph, he's working on a process that allows corn to be stored "damp" and shipped to the mill when the processor is ready. The key is to keep the corn cold, using the night air to chill it to near freezing. To do this, Brown and his team developed storage bins with full-floor aeration and temperature-sensing cables for periodic monitoring. Temperature is monitored inside the bin and compared to the ambient temperature outside. If the difference will chill the corn to the desired temperature, the system's controllers turn on the aeration fans.

"The advantage of this type of system is its ability to track the temperature in the bin as the corn is cooled and to change the on/off setpoints accordingly," says Brown. "This way, the fan operates only during colder conditions, down to a minimum temperature."

Brown is also developing a "fuzzy logic" control system to improve even the current commercial drying process, by monitoring the corn as its dries to prevent damage. Brown's system monitors the temperature, airflow and humidity to determine how the drying is progressing. By using fuzzy logic, it can respond quickly to the variability of incoming corn by adjusting the flows of warm and cool air to minimize the chance that the corn will dry too slowly and crack from the heat.

Safer pest control

Today's commercial farming relies on widespread pesticide use to produce a large volume of food. The rub is that most existing chemical pesticides don't degrade when introduced to the environment and can be toxic. Yet insects still cause billions of dollars of damage each year to agriculture, forests and other vegetation. That's because they've been genetically programmed by nature for survival.

"Insects, like bacteria, have been able to survive for long periods of time by continuous genetic adaptation. Close to 400 species of insects have developed different degrees of resistance to chemical pesticides over the past 50 years," says Argyrios Margaritis, PhD, P.Eng., a professor of biochemical engineering at the University of Western Ontario.

He says that if we stick to traditional ways of combating this problem, we'll have only two choices: increase the concentration of pesticides sprayed on vegetation, or develop new chemicals the bugs haven't been exposed to yet. But both options are "vicious circles," he says. If the choice is to increase the concentrations of pesticides used, insects will develop even greater resistance with results that could be "environmentally disastrous." New chemicals, for their part, are costly to develop and experience shows that insects will eventually tend to become resistant to them too.

But Margaritis is betting bugs will find his "bioinsecticide" too lethal too survive. To produce his deadly brew, Margaritis grows *Bacillus thuringiensis*, a natural soil microorganism, in a bioreactor developed by his team at Western. With the addition of nutrients and oxygen, the microorganism matures and eventually produces delta endotoxin, a crystal protein that is extracted and then suspended in solution. When applied to vegetation, it quickly kills insect larvae that eat it. Other bacteria that live in the soil consume any of the solution that remains, as a life-giving nutrient. Not only is the bioinsecticide non-toxic, results so far indicate that the degree and rate of mutation of insect species exposed to it is much lower than if they were exposed to chemical insecticides, Margaritis says.

A further advantage is that the large variety of available crystal proteins are selective, killing only certain species of insect larvae feeding on particular species of plants. The trouble with some chemicals, says Margaritis, is that while they kill the bad guys they can also eliminate all the other living species that are part of a balanced ecosystem. He says the large number of proteins is also a factor in minimizing the chances and frequency of insect mutations.

In the works, he says, are larger scale trials to provide a more realistic picture of the bioinsecticide's cost. "Eventually," says Margaritis, "we hope to find an industrial partner to further scale-up our process. But our preliminary cost estimate looks very promising." ◆

Argyrios Margaritis holds a test tube with the soil bacterium *Bacillus thuringiensis*, which produces biodegradable, non-toxic bioinsecticids. In the background is a 1000L bioreactor used to mass produce them.