Humanitarian Chemical Engineering

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A broader view of ethics and professional responsibility considers the engineer's impact on humanity.

Chemical engineers develop and apply technology to improve people's lives. Such technological advancements include affordable energy on demand via gasoline or batteries, electronic materials that make computers and smartphones possible, inexpensive polymer materials that enable almost every product we use, ready-to-eat and nutrition-packed foods, affordable medicines, and much more.

Our work is guided by the AIChE Code of Ethics (www.aiche.org/about/code-ethics), which helps ensure that we chemical engineers do our work in a morally and professionally responsible way. In the February 2015 issue of *CEP,* Deborah Grubbe discusses the importance of such codes of ethics, and how departures from ethical behavior contributed to some of the most infamous engineering disasters of the past 30 years *(1).* In particular, she points out that problems often arise from conflicts over time and money versus safety, and a neglect of adequate communication between decision-makers and those with technical expertise.

This article looks at ethics and the chemical engineer's responsibility in a broader sense.

The narrow view is that the chemical engineer's professional responsibility is to do his or her job well, according to the norms of integrity for the specific function he or she is given. These ethical norms include conscientiousness in providing a safe and reliable product for good value, confidentiality, avoiding conflicts of interest, and so on. The key idea is that being a responsible engineer is defined with reference to the job. It is this narrow professionalism that is addressed in codes of ethics.

A broader view is that the chemical engineer's professional responsibility is to do his or her job well in the context of human life. This includes upholding the norms of integrity for the specific function, as well as carrying out that function, whenever possible, to benefit human life. In addition to the ethical norms of narrow professionalism, the norms here include concern for social and global justice, environmental stewardship, and human development. The key point is that being a responsible engineer is defined by a connection to the human community — not only in the way the work is carried out, but also in the way one conceives of the work he or she is doing.

The human community includes many people who are, unfortunately, outside of the sphere of influence of typical chemical engineering. They do not experience the benefits afforded by the availability of gasoline, batteries, faster computers, or the many other types of products to which chemical engineering contributes.

This article describes two large chemical engineering projects led by universities in Myanmar and the Philippines that are motivated by the goal of helping marginalized members of society. As a bonus, these projects are based on environmentally friendly processes that convert waste to useful products.

Biogas enables rural electrification in Myanmar

Only 13% of the households in Myanmar have access to electricity, which is the lowest rate for any country in the world outside of Africa *(2).* This lack of access to electricity is perhaps the greatest impediment to people making their way out of poverty. Even small amounts of electricity that

▲ **Figure 1.** Life in Nyaung-U, a village in Myanmar. This rural home has no electricity, but it does have three cows. The woman is cleaning up the cow dung, which is used as a fuel source.

would allow people to continue activities into the evening would transform lives. Students would do better in school, as they could study and do homework in the evenings. Businesses could stay open later and increase their production and sales. Medical facilities could perform emergency procedures at night when necessary. However, the cost of extending the electrical grid to the array of small villages in the country is enormous.

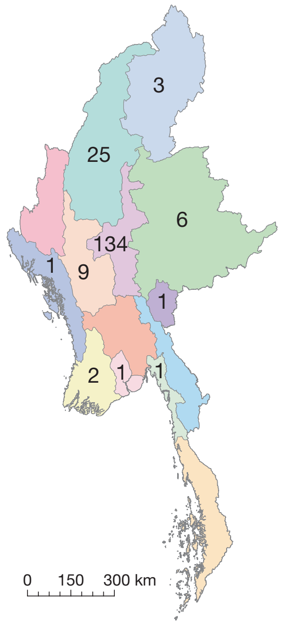
These considerations motivated the Dept. of Chemical Engineering at Yangon Technological Univ. (YTU) to conduct a project that has brought affordable electricity to over 100,000 impoverished villagers living far from the electrical grid, using an environmentally friendly process that converts waste to energy.

Myanmar is largely an agricultural nation, with many households in the central region of the country raising cows (Figure 1). Cow dung, which can serve as an energy source, is therefore widely available.

To harness the energy in cow dung, an anaerobic digestion process converts the dung to biogas, which fuels generators to produce electricity. The biogas can also be used instead of wood for cooking, thereby reducing deforestation. Even the processed cow dung is useful — the digestion process transforms the nitrogen content of the cow dung to ammonia, making the effluent slurry an effective organic fertilizer.

Led by chemical engineering professor Mya Mya Oo, faculty and students from YTU collaborated with chemical and civil engineers from the Myanmar Ministry of Science and Technology to design and install the biogas technology. Since 2002, the program has installed 183 biogas-powered generators throughout the country (Figure 2). Most of the facilities serve about 1,000 people.

A typical biogas facility processing the dung from about 100 cows in a 50-m^3 digester provides 30 kWh/day of electricity at a peak load of 6 kW. This electricity is sufficient to power about 300 fluorescent lamps (20 W) for 5 hr/day — providing lighting for all houses (which are small, with only one lamp per house), monasteries, and streets in a village of 250 families for 1–2 hr in the early morning and 3–5 hr in the evening.

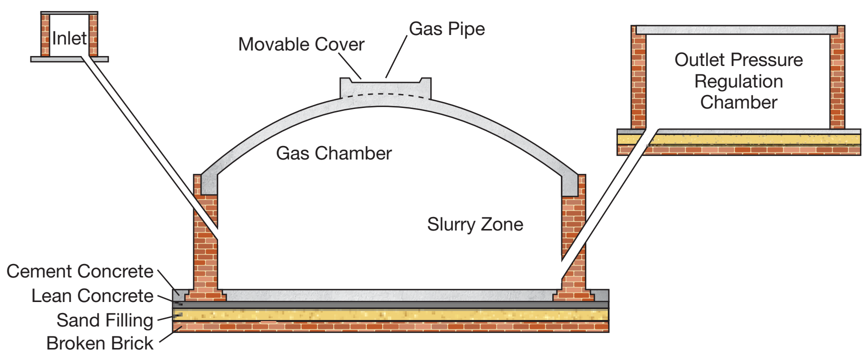


▶ **Figure 2.** The YTU-led program has installed 183 biogas facilities throughout Myanmar. This map shows the number of units in each state.

Because LED lamps have recently become more affordable, it will soon be feasible to replace the 20-W fluorescent lamps with 5-W LED lamps that provide the same lighting per lamp. This will allow four times as many lamps to be powered in each village.

Each biogas plant consists of a semi-continuous, fixed-dome concrete digester (Figure 3) with inlet and outlet tanks, a methane-powered engine, and a generator. Digesters can be sized from 8 m^3 to 100 m^3 for villages of different sizes. A typical 50-m^3 digester has a 25–30-hp engine and a 15-kVA generator, and provides a peak load of over 6 kW. Cow dung is fed at a rate of about 850 kg/day (which requires collection from about 100 cows) to produce 20 m^3/day of biogas. Approximately 1,600 L/day of digested sludge is withdrawn from the outlet tank, which can be used as fertilizer. The facilities are expected to last more than 20 years with proper maintenance.

The digester is fed twice a day. Each 1 kg of cow dung is thoroughly mixed with 1 L of water to create the input slurry. The pH of the slurry is usually in the range of



▲ **Figure 3.** The digester converts cow dung to biogas, which is used to generate electricity.

◀▲ **Figure 4.** Villagers construct the digester and inlet and outlet tanks.

5.5–6.5; $Ca(OH)_2$ is added to increase the pH to 7–8. The digester operates at ambient temperature, which during the summer is near the optimal operating temperature of 30–35°C. Winter temperatures are slightly cooler and the facility's performance is slightly lower, but the digester's underground location moderates the temperature swings. The normal retention time of the process is 7–10 days, although this can be reduced to 1–2 days by adding digested sludge. The digestion process is effectuated by bacteria in the dung *(3),* and the product is a gas mixture consisting mainly of methane (55–70%) and carbon dioxide (30–45%).

The YTU-led team developed a business model for the biogas facilities that is both sustainable and affordable for the impoverished villages. The salary of the project engineers who lead the project is paid by the national government, and the villagers provide room and board (in their own homes) for the engineers during the 3–6-mo construction period. The construction work is done by villagers (Figure 4), who are not paid for this work. The village must pay for the materials and components used to build the facility, but the payment can be made over the course of a year after the facility is completed. The capital cost for a 50-m^3 biogas facility, including the purchase of the construction materials, the engine, and the generator, as well as the accessories for lighting, was about 1,500,000 kyats (1,000 kyat ≈ 1 U.S. dollar) in 2003 (present costs are about 60% higher). If 250 houses in the village receive a fluorescent lamp, and each household pays 600 kyats/mo, the biogas plant is paid off in one year.

The operation of the biogas plant is carried out by the villagers collectively. The village council (an elected government body) appoints a village electricity committee of 10–15 people. This committee organizes and manages the biogas facility, and the villagers carry out most tasks without pay. The cow dung is supplied by villagers who own cows, and the slurry preparation and other operation activities are carried out by the villagers who do not own cows (Figure 5). One villager is paid 30,000 kyats/mo to run the engine; the funds for the salary come from the households who use the electricity, which in a village of 250 households is 120 kyat/mo per household — about 40 kyat per kWh of electricity used, which is lower than the cost of grid electricity in the U.S.

It may be surprising to some that this approach, which requires the villagers to perform duties without pay, succeeds. However, the sense of community is strong in Myan-

◀▲ **Figure 5.** Villagers carrying out their duties operating the biogas facility. Left: The two people on the right are preparing the slurry by mixing cow dung and water, and the two on the left are feeding the slurry to the inlet tank. Above: A villager removes the digested slurry from the outlet tank.

mar villages — for example, when a villager builds a new house, others volunteer to help. This communal approach was documented in a study that quantified, on a scale of 0–100, the extent to which people in various cultures are expected to look after *only* themselves and their families. This trait was found to be significantly less pronounced in Southeast Asian countries (*e.g.,* Thailand had a score of 23) than in western countries (*e.g,* the U.S. scored 91) *(4).*

As of 2014, 75% of the 183 biogas facilities are still operating and providing electricity for the villages, 20% of the facilities are no longer needed because the national electrical grid has been extended to the village, and only 5% are no longer operating due to mismanagement and lack of maintenance.

▲ **Figure 7.** Project leader Evelyn Taboada and co-author Daniel Lacks look over the waste seeds and peels laid out in the solar drying facility.

Mango waste treatment creates jobs in the Philippines

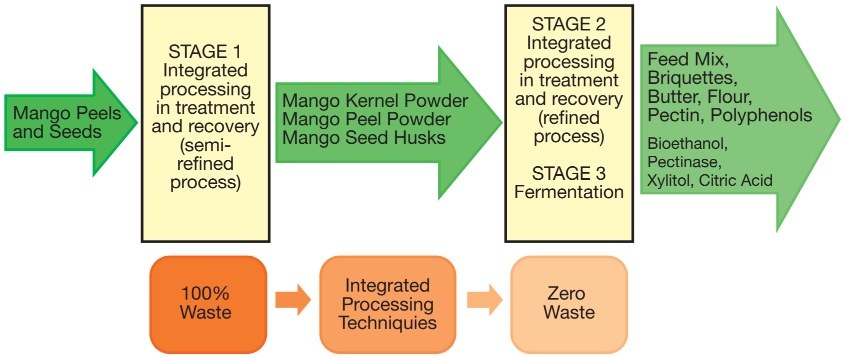
Many of the very poor in the Philippines survive by scavenging in dumpsites. A recent study described the difficult and dangerous lifestyle at a dumpsite in Cebu, where 300–400 households make their livelihoods *(5)*: Adults and children go into the dumpsite each day to collect recyclable waste. Some have improvised gear, such as sacks, gloves, and long bars with hooks, but many others work with their bare hands, wearing only shorts with no shirts or shoes. The people scavenging dumpsites regularly come in contact with medical waste, fecal matter, needles, scrap metals, air particulates, and chemical fumes from burning waste.

These people live in rudimentary housing built from materials (*e.g.,* plywood, metal sheets, tarpaulins) scavenged from the dumpsite. Ninety percent of these homes do not have toilets, and the residents either defecate in open areas or into bags that they dispose of in the dumpsite. The odor is overpowering, but perhaps more distressing is that the odor no longer bothers one-third of the people surveyed.

The Univ. of San Carlos (USC) in Cebu City has a central aim to help "the last, the least, and the lost" — *i.e.,* the marginalized members of society. In 2009, the university, through its faith-based nongovernmental organization Justice, Peace, and Integrity of Creation — Integrated Development Center (JPIC-IDC), built the Janssenville housing development. This 236-unit facility is now home to about 300 families that were formerly scavenging dumpsites for their livelihood. The project involved faculty, staff, and students from across the university — for example, volunteers from the civil engineering department designed the buildings and infrastructure; others from the psychology and sociology departments helped residents with personal issues such as developing job skills and overcoming substance abuse; and still others placed the building blocks and painted the houses.

A start-up company, Green Enviro Management Systems (GEMS), Inc., was recently formed out of the USC Dept. of Chemical Engineering to provide jobs to residents of Janssenville. It uses novel technology developed at USC *(6)* to convert waste from the mango processing industry into useful products. The effort is led by the Dean of the College of Engineering and Director of the BioProcess Engineering and Research Center (BioPERC) at USC, Evelyn Taboada. GEMS began operations in 2012 with initial seed funding of US$2 million. Its 2,500-$m^2$ fruit-waste-processing facility is located on a one-hectare plot near the Janssenville housing development, which makes it convenient for the residents to walk to work.

About 1 million m.t. of mangoes (*Mangifera indica L. Anacardiaceae*) are grown in the Philippines per year, and more than half of that is processed into products such as juices, dried fruits, fruit bars, candies, and jellies. The mango processing industries use only about half of the mango fruit (by mass); the remainder is waste such as the peels (~20% of the



▲ **Figure 6.** This zero-waste process turns waste mango peels and seeds into valuable products.

mango mass), seed husk (~10%), and seed kernel (~20%). This mango waste — approximately 250,000 m.t./yr — is simply disposed of in open dumpsites and left to rot, releasing foul odors and potentially hazardous leachates. The waste is also a health hazard, as people scavenging dumpsites often eat the freshly discarded mango parts.

The USC process (Figure 6) takes the waste from mango processing facilities as its only major input stream, and fully converts these wastes into useful products. First, the seeds and peels are dried in a solar drying facility (Figure 7), where they are laid out on racks under a transparent roof — drying in about half-a-day to one day. The dried seeds are sliced so that the kernels can be separated from the husks; the kernels are then collected, inspected, and separated by quality.

The high-quality kernels are ground to make flour (Figure 8). The mango flour, which is gluten-free and naturally rich in vitamins, minerals, and antioxidants (Table 1), demands a higher price, 100 peso/kg (44 peso ≈ 1 U.S. dollar), than wheat flour. It is sold to a local bakery (which holds the exclusive license for the mango flour) that makes packaged flour as well as cookies, energy bars, pastries, and bread. The low-quality kernels are ground and sold as animal feed to feed mills and farmers, at a lower price.

The seed husks are sold as low-cost burner fuel, at 3 peso/kg, to various industries, including a biscuit factory, a cement factory, and a small power plant. Plans are underway to further process the husks to form briquettes, which are of higher value (30 peso/kg). Briquettes are produced by grinding the husks, adding a binder, and pressing the mixture into blocks. The briquettes are more compact and better suited for shipping, and experiments at USC show that the briquettes have a high heating value (≥ 18,000 Btu/kg), low ash content (1–3%), and low sulfur content (≤ 1%), which are desirable qualities for a good alternative solid fuel.

The dried mango peels are collected and milled into a powder that undergoes further processing. Mango peels contain pectin and polyphenols. The mango peel powder is hydrolyzed with acid to extract pectin *(7)*, then the filtrate containing the pectin is further separated by simple decantation and/or filtration. A final alcohol precipitation step recovers the pectin. The process also recovers and purifies mango polyphenols, which are highly valued antioxidants used in food and nutraceuticals applications, from the alcohol extracts.

Faculty members and students at USC continue to work on research projects to find alternative processes and develop other high-value products from the mango waste. A process has been developed and optimized to extract the gelling agent pectin and the dietary supplement polyphenols from mango peels, and research is ongoing to optimize this extraction process and scale it up. Other research projects involve the development of inexpensive and environmentally friendly binders for producing briquettes from seed husks, a mixer-settler process to produce butter (solidified oils) from pressed kernels, and new recipes based on mango flour that take into account the high hygroscopicity of the mango flour compared to other flours. The long-term goal

◀ **Figure 8.** Mango seeds are processed into mango flour and a variety of other commercial products.

Table 1. Technical specifications and nutritional facts for mango flour and wheat flour.

Component	Content per 100 g	
	Mango Flour	Wheat Flour*
Total Fat	8.7 g	1.0 g
Saturated Fat	4.5 g	0.2 g
Trans Fat	0	0
Cholesterol	0	0
Protein	7.8 g	10.3 g
Carbohydrates	77.9 g	76.3 g
Calories	421	364
Total Sugars	8.7 g	0.3 g
Total Dietary Fiber	12.6 g	2.7 g
Vitamin A	< 25 I.U.	0
Vitamin C	12.5 mg	0
Vitamin E	1.4 mg	0.1 mg
Sodium	1,677 mg	2 mg
Calcium	181 mg	15 mg
Iron	2.7 mg	1.2 mg
Potassium	379 mg	107 mg
Magnesium	118 mg	22 mg
Phosphorus	72 mg	108 mg
Zinc	0.20 mg	0.7 mg
Polyphenols	≥ 100 mg	—
Antioxidant Activity	≥ 80,000 μmol TEAC†	—
Digestive Enzymes	300,000 units	—

* White, all-purpose unenriched
† TEAC = Trolox Equivalent Antioxidant Activity

of the research is to design and implement a biorefinery, complementary to the current facility, that can produce fermentation products, such as bioethanol and biogas, and some fine chemicals, such as xylitol, citric acid, and pectinase.

GEMS is on track to achieve financial sustainability in less time than originally expected. Currently, during peak season, the facility processes 20–30 m.t. of mango waste. Since the cost of the raw material (the waste) is negligible, and the resulting products have value, the integrated process technology is commercially profitable.

More importantly, the project has succeeded in creating jobs for the residents of the local community and Janssenville who had previously been scavenging dumpsites for their livelihood. GEMS currently employs 56 people, most of whom are unskilled workers with practically no employability skills, including 36 from Janssenville and 14 more from other local areas. The rest of the employees are technical staff and professionals, who manage the day-to-day operations of the facility. The company, in operation for only two years, continues to grow. Its short-term goal is to employ at least one member from each of the 300 households in Janssenville and in other local housing developments built by JPIC-IDC with the support of the university and its partners. The longer-term goal is to construct more fruit-waste-processing facilities throughout the Philippines and perhaps elsewhere in Southeast Asia, to help these areas develop proper and efficient fruit-waste management practices and to help more marginalized citizens obtain decent jobs.

Professional responsibility

Professional responsibility involves a continued grasp of the wider context of an engineering job. This wider context is the human community. Professional responsibility requires paying attention to the common good of that community, to the individual rights and dignity of its members, and, in many cases, to the nonhuman natural world as well.

This broad professional responsibility is embodied in the vision statement of the Univ. of San Carlos' College of Engineering: "An engineering institution where excellence, innovation, and concern for humanity guide education, research, and community service." In contrast, engineers often focus only the narrow view of professional responsibility, as described in codes of ethics. Engineers should be encouraged to consider their broad professional responsibility as well. CEP

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