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Teaching Sustainability across Scale and Culture: Biogas in Context

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Abstract

Teaching sustainability invariably involves teaching about energy – its use, its sources, its environmental impacts, and its social implications. This paper explores how one renewable energy alternative – biogas – is adapted and applied across scale and culture. Biogas is made by capturing the methane released during anaerobic digestion of organic matter such as manure, sewage, and food waste. In Nepal, biogas is a household scale technology used to create a cooking fuel that replaces firewood and improves both environmental and human health. In the United States, biogas is used as part of large-scale waste management systems for livestock, wastewater treatment, and landfills to create electricity for on-site use and for sale into electric grids. In Sweden, biogas is used as part of a regional effort to reduce greenhouse gas emissions and fossil fuel usage by using locally generated biogas for district heating, electricity, and vehicular fuel. By comparing these three cases, we gain insight into how one technology is adapted across diverse needs and from household to regional scales in the pursuit of more sustainable energy practices. Such an exercise can be an asset in the classroom to teach students about the importance and relevance of place-based solutions that address diverse cultural and economic realities.

Keywords

Biogas, Nepal, Renewable Energy, Sustainable Development, Sweden, United States

Introduction

There is a growing global awareness that sustainability -- how to live gently on this earth such that all beings can live a full life with dignity without robbing contemporary or future others of their ability to do the same -- is a critical practice that needs to be adopted globally and enacted fairly. To discuss sustainability in the classroom is to ask students to critically reflect on their own lives and places as embedded in a wider global network of social and environmental systems. A recurring theme in sustainability discussions is energy; teaching sustainability inevitably means teaching about energy. The finite fossil fuel energies that power modern life and are used "behind the scenes" to produce the food and products we consume emit high levels of carbon dioxide making a society dependent upon them unsustainable. Teaching sustainability is more than teaching energy choices and their social impacts, it is also a method to improve living conditions, alleviate poverty, and move towards more environmentally and socially just communities. Teaching sustainability involves teaching alternative ways to structure society that may vary by place, culture, and scale -- there is no one global solution.

Rather than asking how a community becomes sustainable, we can instead choose a method that is deemed "more sustainable" than current alternatives and explore how that one method is adapted across scale and cultural contexts in the pursuit of sustainability. Biogas capture and use is one technology capable of moving societies in the "more sustainable" direction. Biogas is made by capturing methane from anaerobic digestion. It has proven to be versatile in that it has been successfully adopted at a variety of scales, in both rural and urban

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areas, and in a variety of cultural contexts in both the Global North and Global South. In my own extensive qualitative fieldwork in Nepal, I have researched the use of biogas as well as its promotion and the public perceptions surrounding biogas and sustainable development. When I incorporate discussion of sustainable development and renewable energy in the college classroom using biogas in Nepal as my example, students often inquire about the use and status of biogas in the United States. Based on such student inquiries, I shifted from teaching "this is how one place is working towards sustainability" and instead focus on "this is how one sustainable alternative technology is used and adapted in different places from Global North (developed countries) to Global South (developing countries)." In this article, I examine how biogas has been implemented as a renewable energy alternative in three separate contexts: Nepal, the United States, and Sweden. Following some summary remarks and commentary, the article concludes with a discussion of what we can learn from such comparisons and how such concepts can be incorporated into college classroom learning.

Biogas Basics

Biogas is the result of gases released during the decomposition of organic matter by methanogenic bacteria. Biogas is comprised of multiple gases, the most dominant of which is methane (CH_4) followed by a smaller concentration of carbon dioxide (CO_2). It may also contain traces of hydrogen (H_2), nitrogen (N_2), water vapor (H_2O), and hydrogen sulfide (H_2S). Biogas turns what would be waste -- such as sewage, manure, or food scraps -- into a clean renewable energy. The gas burns cleanly, is smokeless, and is non-toxic.

The premise behind biogas is a simple one – organic matter decomposes. The decomposition resulting from anaerobic digestion releases methane. Methane is a potent greenhouse gas and is estimated to be 21 to 23 times more damaging than the same volume of carbon dioxide (Sharma et al 2010; Themelis and Ulloa 2007). When methane (CH_4) is burned, the carbon and hydrogen atoms combine with oxygen to create carbon dioxide (CO_2) and water vapor (H_2O) as the by-product. Technology systems, ranging from the very simple and affordable to the very complex and expensive, can capture methane from decomposing material and convert it into a usable energy. This process can replace a range of other emission-producing energy sources from firewood to coal to fossil fuels. While burning methane still releases greenhouse gases, CO_2 is less potent than the methane and it also avoids the release of CO_2 currently sequestered in other sources. Thus, the emission reduction results from the combination of two factors: (1) The methane that would have been emitted regardless through natural processes of decomposition is now harnessed for energy, and (2) The emissions from the energy source replaced by biogas are eliminated, or at least reduced.

The technology to harness the energy potential released by anaerobic digestion varies in scale, complexity, and feeder materials. Regardless of design, a biogas plant has three primary components: an *inlet* to get organic matter into the *digestion chamber* where anaerobic digestion and gas capture occurs and an *outlet* to remove the digested organic matter (Karki et al 2009; see Figure 1 for typical Nepali design). The gas use devices and equipment vary based on the intended end-use of the generated biogas. A biogas plant can be constructed at home with some ingenuity at minimal cost and can use methane from human sewage, animal excrement, food waste, or a combination thereof to provide cooking fuel or lighting (see Figure 2). A biogas plant can also be constructed at considerable expense costing millions of dollars (see the United States Environmental Protection Agency's website for anaerobic digesters at http://www.epa.gov/agstar/anaerobic/ad101/anaerobic-digesters.html for diagrams and photographs of typical biogas facilities in the United States). Plants can serve as waste management facilities for concentrated animal feeding operations with thousands of animals. The biogas from such a plant can be used to generate electricity for on-farm use or for sale into the power grid, for heating, or for conversion into vehicle fuel. Alternatively, it can simply be flared to burn off the methane. Plants of many sizes and designs exist. For example, in Nepal an undergrad fixed-dome construction is common with a manual mixer, a ball valve above the underground dome to control gas flow, and an area to collect effluent (see Figure 1 for example). After anaerobic digestion is complete, a solid waste by-product remains that can be used for fertilizer; this is also depicted in the promotional poster in Figure 1. Thus, anaerobic digestion provides an additional use-value before manure fertilizer reaches the field by capturing and using the methane produced through its decomposition as a renewable energy source (see AgSTAR's basic anaerobic digester system flow diagram at http://www.epa.gov/agstar/documents/digester_flow_diagram.pdf).

Figure 1 *Figure 2*

Figure 1: Promotional poster "Correct Use of Slurry from Biogas Plant Increases Production" which shows a typical biogas digester in rural Nepal and the benefits of the fertilizer slurry effluent. Source: BSP-Nepal.

Figure 2: Homemade biogas digester on a rooftop in Kathmandu. Cow manure was used as the initial feeder material to begin the anaerobic digestion after which only food scraps have been added. The biogas is used to operate a kitchen burner. Photograph by author.

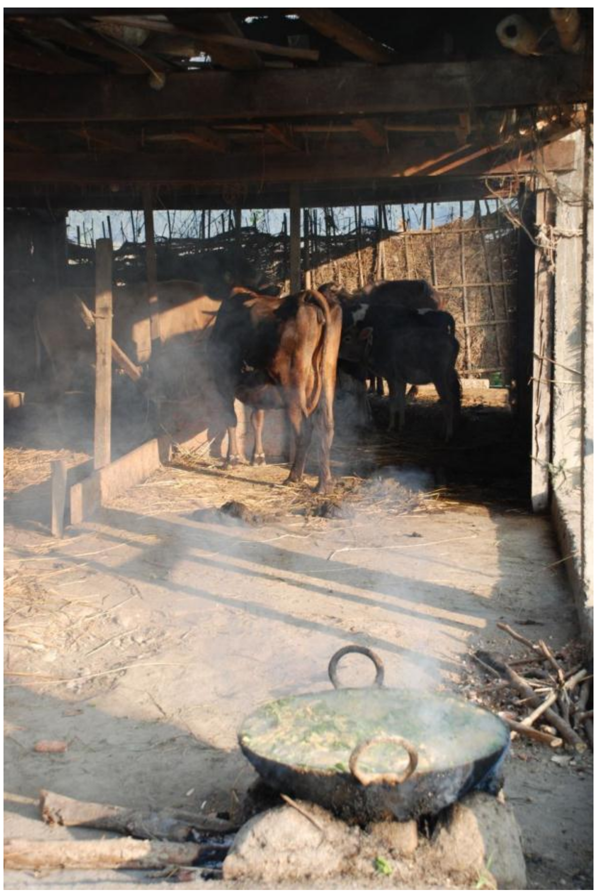
Biogas in Nepal

In Nepal, biogas is largely a household scale technology designed to replace firewood as a cooking fuel. Users collect cow manure from a few cattle, mix it with water in a hand-churned mixer, and then pull a plug to release the mixture into an underground tank where anaerobic digestion occurs. When it is time to cook, the biogas user turns a ball valve on top of the underground digester that allows the gas to flow to a burner in the kitchen, which is then lit with a match (see Figure 3). The pressure from the gas in the underground tank pushes the solid, digested waste out into a side holding tank where it can then be composted and later used as a fertilizer (see Figure 1). Over 225,000 households in Nepal use biogas, the majority using biogas in place of firewood, thus contributing to woodland conservation while reducing indoor air pollution from smoke and reducing the drudgery work of collecting and hauling firewood by hand over steep Himalayan terrain.

Figure 3: The two images above represent the change from cooking on a traditional fireplace indoors to cooking with biogas. Biogas does not entirely replace firewood needs; it reduces the need for firewood. The image of milk boiling on firewood is in a home that also has biogas. Photographs by author.

Biogas as a government program in Nepal dates to the mid-1970s. The program was, in part, a reaction to the oil price shocks of that decade. This program was an attractive option in the 1970s to reduce reliance on expensive oil-based imports for energy and fertilizer (Silwal 1999). The biogas digester design during that time involved a floating steel drum that raised and lowered based on the gas content. As the gas pressure rose in the underground anaerobic digestion tank, a steel drum suspended on top and visible above ground "floated" up and down with the change in gas volume in the digester. This meant that the construction of a biogas plant was restricted to areas where the large steel drum caps could be easily transported. This made the technology largely inaccessible to remote Himalayan communities accessible only by narrow mountain trails. Thus, most plants were built in the Tarai flatlands at the base of the Himalayas and were restricted to large landowners who had the capital to invest in a new technology (NBPG 2007; van Nes and Lam 1997). By the late 1980s, an underground fixed dome design was developed using brick, stone, sand, cement, and a few metal pipes and plastic tubing. The design is more affordable (around $300) and can be built in rural and remote areas as many materials can be locally sourced. This design is still favored today. In the 1990s biogas construction surged in part due to the introduction of monetary and technical support from the Netherlands Development Organisation (SNV). In 1992, SNV formed the Biogas Sector Partnership (BSP - formerly Biogas Support Program) in Nepal whose function is to develop, promote, and monitor household biogas construction.

With subsidies available from the government, funded in part by support from the Dutch and German governments, and increasing availability of micro-credit loans, biogas is a technology available to small farmers and is no longer a luxury reserved for large landowners. A household plant in Nepal may range from 2 to 8 m^3 (although larger models are possible), with the average being 6 m^3. Such a plant accommodates manure from one to a dozen cattle in addition to the waste from an attached family toilet. An estimated two-thirds of biogas plants in Nepal have an attached family toilet (BSP 2009). Due to Hindu beliefs of ritual purity, many are reluctant to add human feces to their biogas mixture as food cooked with methane generated from human waste can be viewed as polluted and unfit for both human consumption and use in religious offerings. However, this attitude is changing. In my own research, families who had enough land to accommodate two separate underground holding tanks -- one for biogas and one for a toilet -- cited religious beliefs and concerns of pollution if a toilet were attached to the biogas plant. However, there is also a generational difference in decisions to join a toilet to a biogas plant. Some extended families with elderly relatives explained that they did not attach a toilet out of respect for the beliefs of the elderly in the household; but once those elderly pass away, they will consider attaching a toilet as they want to increase biogas production. Families who lacked adequate land and finances to install two separate underground tanks were more likely to opt for a joint toilet-biogas system and explain such ideas of impure biogas from sewage as outdated.



Installing biogas does not replace all firewood needs, though it reduces firewood dependence. After installing biogas, a family may need firewood for multiple reasons. Boiling milk takes a long time and people do not want to waste their limited biogas. People also commonly cited taste preference as a reason why milk is boiled over firewood and not biogas (see Figure 3). During winter months, gas production may drop, and firewood is needed to close the cooking energy gap. Farmers cook a soupy mixture known as *khole* or *khundo* composed of water, greens, left over food, and supplements for their cattle daily. It is often cooked over firewood in a large vat in or near the barn (see Figure 4). Some snacks, such as roasted corn on the cob and popcorn, are cooked with firewood – both for flavor and to conserve biogas for cooking meals. However, by replacing the firewood for primary cooking needs, biogas contributes significantly to forest conservation, reduces drudgery workloads, and helps improve health by reducing indoor air pollution (see BSP 2009; Karki et al 2009 for more details on these benefits).

Figure 4: Khole, also called khundo, – a soupy mixture of nutrients for cattle – is cooked daily requiring firewood. Photograph by author.

Nepal is also home to community and institutional biogas plants. In the 1980s, communal plants were built for generating farm machinery fuel or for rural electrification, but most of these plants only operated a few years before falling into disuse, due in part to communal management issues. Communal plants are being built and used again with more success. Institutional plants have also proven successful. Institutional plants are typically operated by boarding schools or monasteries where human sewage from hundreds of pupils or monks is used to generate biogas that is then used as a cooking fuel in the institution's kitchen (NBPG 2007).

While biogas has clear benefits for households and local environments, it is also tied to international efforts to reduce carbon dioxide emissions. Biogas is a clean development mechanism (CDM) and is eligible for carbon credits. These market mechanisms are made possible through the Kyoto Protocol, which entered into force in 2005. The Kyoto Protocol is a greenhouse gas (GHG) reduction treaty that sets targets for emissions reductions and creates market mechanisms for countries to achieve those targets. In addition to using national measures to reduce emissions, countries can participate in the global market-based mechanisms of emissions trading, clean development mechanism, and joint implementation. These three mechanisms jointly create what is now commonly referred to as "the carbon market." The basic concept is that an industrialized country with set emission reduction targets can sponsor a CDM project in a developing country to reduce emissions in the receiving country. The receiving country can then apply for certified emission reduction (CER) credits that represent the emission reductions realized through the CDM. If CER credits are obtained, they can then trade the "emission reductions" in the international emission trading market. Industrialized countries with emission reduction targets can then buy those credits to "offset" their own emissions.

Biogas is an approved (CDM) in Nepal pursuant to the Kyoto Protocol. This means that the government can apply for CER credits to trade the carbon reductions realized through biogas in the global marketplace. Obtaining CER credits is a bureaucratic process that can take years and must be approved through the CDM Executive Board. For biogas in Nepal, this on-going process requires aggregating the energy decisions of hundreds of thousands of households into project clusters that can then be approved for credits. It is not feasible for the individual farmer, whose energy choice may reduce emissions by one or two tons, to trade those emission reductions on the open market. Instead, the farmer receives a subsidy from the government to build a biogas plant and signs a contract giving his carbon trading rights to the government with the understanding that any revenue realized through his biogas plant's carbon reductions will be used to fund subsidies to future biogas builders. Assuming the applications for CER credits are approved, Nepal's biogas program has the potential to be self-funded.

There are roughly 89 biogas companies in Nepal registered with BSP to promote, build, and service biogas plants. There are an additional 16 metal working shops across the country that build biogas plant components including the mixers and stoves. Thousands of skilled masons are trained to build biogas plants on-site. Over 163 micro finance institutions are involved in providing loans to biogas users to finance construction. From sales to metal-working to masonry, the BSP estimates that the biogas sector in Nepal has created over 9,000 jobs (BSP 2009). Based on surveys by the BSP, 95% to 98% of all biogas plants that have been constructed since 1992 are currently in operation (BSP 2009). Once a fixed dome digester is built, it can operate with minimal maintenance for 20 or more years. Biogas has improved living conditions, created employment, conserved forests, and provided a potential source of government revenue through carbon credits, all by creating a durable, household-scale, renewable energy technology.

Biogas in the United States

While biogas in the United States is not as ubiquitous as it is in areas of the developing world, the underlying concept is the same – creating a productive energy source from waste. Although there are fewer biogas systems than in Nepal, the systems in the United States are built to handle much larger volumes of waste and can be found at livestock facilities, landfills, and wastewater treatment plants. As of December 2011, there were an estimated 176 anaerobic digester systems in operation at commercial livestock facilities in the U.S. (EPA 2011c). Such biogas systems represent important parts of manure management systems for farms that house thousands of animals. The biogas produced is typically used to create electricity for on-farm use or for sale to an electric utility company. The gas is also used for heating and refined for use in fuel applications (EPA 2011a). Mason Dixon Farms in Gettysburg, Pennsylvania is one such example that has been using biogas since 1979 for on-farm electricity and to sell excess electricity to the local electric utility (EPA 2011b). Despite such successes with farmer owned and operated biogas systems, some discovered that selling their manure to a shared biogas producer is more economical than investing in an expensive on-farm system (Vance 2010). However, the infrastructure for a centralized collection and processing system is not commonly available.

Of the 176 livestock biogas projects, 159 use the biogas to create electrical or thermal energy, producing about 490,000 megawatts (MWh) of electricity annually and an additional 51,000 MWh annually from other energy projects including boilers and pipeline injection. Not all biogas systems use the captured methane for energy; some simply use the biogas systems as way to control odor and then flare off the methane to reduce greenhouse gas emissions rather than turning the gas into a usable energy. By burning the methane -- either for energy use or as a direct flare -- methane emissions from these livestock facilities are reduced by about 56,000 metric tons annually, the equivalent of 1,176,000 metric tons of CO_2 (EPA 2011c).

In addition to commercial livestock biogas operations, over 300 landfills in the U.S. capture the methane generated by decomposing trash and use the gas for heating or electricity generation. Sometimes the gas is also flared off rather than captured for productive energy use (Themelis and Ulloa 2007). Of the over 16,000 wastewater treatment plants in the United States, about 3,500 use anaerobic digestion. Wastewater treatment plants using anaerobic digestion commonly use the gas generated to provide heat needed for digestion to occur, either directly or by producing steam in a boiler. Only about 2% of these wastewater treatment plants use the gas for electricity. This electricity is typically created through internal combustion engines that power a generator with the electricity used on site and the excess sold into the grid (FEMP 2004).

Household biogas designs in Nepal are relatively simple -- and cheap -- compared to their American counterparts designed to handle waste from thousands of animals or people. With the scaled up version of the technology comes a much higher price tag. However, similar to Nepal, government assistance is available. The 2002 and 2008 Farm Bills included provisions for funding biogas systems, in part through USDA Rural Development funds used to help offset the steep capital investments needed to install a large capacity biogas digester for livestock operations (EPA 2011c). Grants are also available under the American Recovery and Reinvestment Act of 2009 (referred to as Recovery Act) to offset construction costs. The largest animal based anaerobic digester project in the United States is currently under construction in Idaho with 30% of the construction cost eligible for government funding under the Recovery

Act. Although the projected completion date is summer 2012, a 20-year purchase agreement for the anticipated electricity generation is already in place. It will process waste from 15,000 cows with an electricity generation capacity of 4.5 MWh at a construction cost of $25 million (Austin 2011). Photographs documenting the construction process can be viewed on AgPower Group's website http://www.agpowergroup.com/projectphotos.php.

Biogas from a farm can do more than generate electricity for on-farm use or for sale into an electric grid – it can be part of a closed loop operating system. In 2010, researchers from Hewlett-Packard (HP) released a paper that garnered much media attention in which they demonstrated how a hypothetical dairy farm with 10,000 cows could generate enough power to run a one MW data center (Sharma et al 2010; Vance 2010). Data centers house information technology equipment such as computer servers and other networking, communications, and data storage equipment. As data centers become larger and more complex, they require ever increasing amounts of electricity to operate them. Data centers need electricity to power information technology devices and to drive a cooling system as the electrical equipment generates heat. As a result, new centers are increasingly located close to a source of energy. HP's objective in undertaking their study was to make their data centers energy neutral in terms of production and consumption of electricity, and the hypothetical data center/dairy farm biogas system could achieve that goal (Firth 2010). The sketch in Figure 5 demonstrates how such a system may be arranged with manure feeding a biogas digester that creates energy to run the data center with the heat from the data center being used to maintain digester temperature.

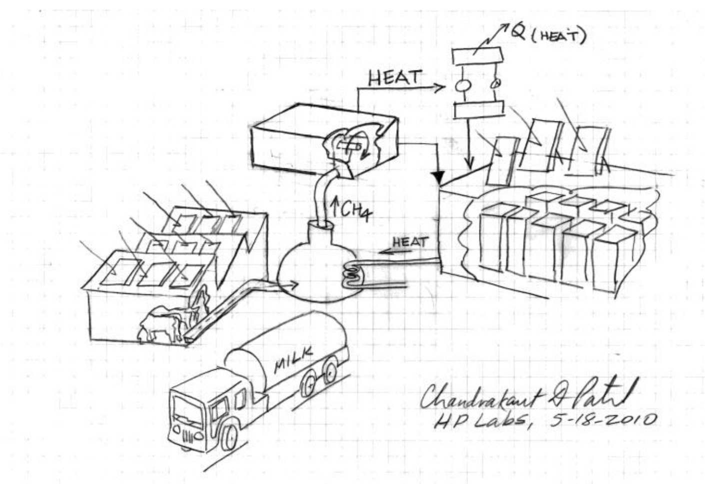


Figure 5: Drawing of how a data center could be powered by biogas in a closed loop operating system. Copyright 2010 by Chandrakant Patel. Reproduced with permission.

The electricity demands of a data center may overwhelm a traditional electric grid. In current models, the heat generated by the center is transferred to an external cooling tower and then expelled into the air. Anaerobic digestion requires heat to maintain the digestion process. Large digestion systems need to maintain temperatures of 50-60˚ C (122-140˚ F) while small systems can operate with 35-40˚ C (95-104˚ F). Given that a biogas plant needs heat to operate and a data center produces heat as a waste, the two technologies can have a symbiotic relationship as illustrated in Figure 5 (Sharma et al 2010). The proposed HP system would use cow manure as the feeder material in an anaerobic digester that would be heated by the data center's waste heat to create biogas that would then be used to generate electricity for both on-farm operations and to power the data center. The waste heat from the power generation would also loop back to the digester to maintain optimal digester temperature (see Figure 6). While HP has not yet built this hypothetical data center powered by biogas, the research into this possibility demonstrates how biogas technology can be adapted to specific cultural, economic, and social contexts to satisfy localized energy needs.

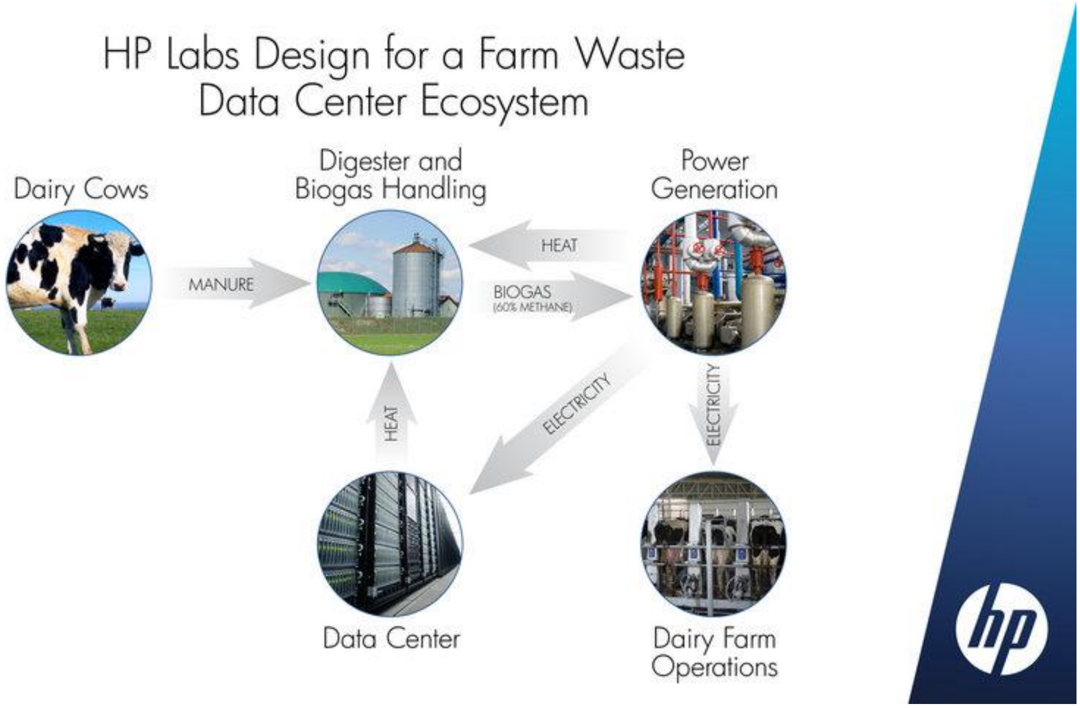


Figure 6: This flow chart demonstrates the symbiotic energy production-consumption relationship between a dairy farm and a hypothetical data center. Copyright 2010 by HP Labs. Reproduced with permission. Also appeared in Vance (2010) and available at: *http://www.nytimes.com/2010/05/19/technology/19cows.html?_r=1&emc=eta1*

Biogas in Sweden

In Sweden, biogas is produced at over 200 locations throughout the country, ranging from a few small on-farm systems to large-scale centralized systems that provide heating, power, and fuel to entire municipal areas (Lantz et al 2007). This section focuses on the Swedish city of Kristianstad, which is using biogas as part of its plan to make the municipality and surrounding areas fossil fuel free. In contrast to Nepal, where biogas is about rural household energy self-sufficiency, and the United States, where biogas is about large-scale waste management, the case of Kristianstad, Sweden, is an example of biogas as a locally sourced fuel used for regional benefit.

The city of Kristianstad is home to about 30,000 people. Including the surrounding communities, the larger municipality has a total population of approximately 80,000. In 1999, the Kristianstad municipality's executive committee resolved that Kristianstad would become a "Fossil Fuel Free Municipality." Prior to this declaration, steps had been taken to reduce fossil fuel dependence, such as establishing a power and district heating plant fueled by biomass in 1994 and the initial establishment of a biogas production plant in 1997 (Municipality of Kristianstad 2010). Also predating this declaration is Sweden's complex energy taxing system, implemented in 1991, that includes a tax on carbon dioxide emissions from fossil fuels. With fuels from renewable sources exempted from carbon taxation, the tax resulted in expanded use of alternative energy sources such as biomass and biogas (Carbon Tax Center, 2011). The 1999 decision to become a "Fossil Fuel Free Municipality" derived from on-going localized renewable

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energy projects and provided a sustained momentum to continue working towards independence from fossil fuels through energy efficiency, behavioral changes (i.e. more biking and public transport, less individual vehicular driving) and reliance on locally sourced renewable energy sources such as biomass and biogas for heating, electricity, and fuel (Municipality of Kristianstad 2010).

Kristianstad generates biogas from three different facilities: a sewage treatment plant, a landfill, and a biogas production facility fueled by collected food waste and manure. Since 1999, biogas from the sewage treatment plant has been used for district heating, where heat is generated in a centralized location and then piped to individual buildings, and refined into vehicle fuel. Biogas from the landfill is used in combined district heating and electricity generation. The third biogas production facility operates as a treatment facility for manure, household organic waste, and food industry waste. Inputs may include, for example, pig intestines from a slaughterhouse, stale food tossed out by restaurants, and potato peels and table scraps from residences that are sorted at the home and collected like other recyclables. The municipality's website boasts that "every day, everyone in Sweden eats or drinks something from the Municipality of Kristianstad." Food production results in food production waste. With the largest concentration of food production in Sweden, appropriating that waste for biogas production contributes to local energy self-sufficiency. Half of the biogas produced at this combined organic waste treatment facility is used for district heating and the remaining half is refined into vehicle fuel. (Municipality of Kristianstad 2010). The solid waste remaining after anaerobic digestion is then used as fertilizer, creating a closed loop system for food, energy, and fertilizer (Municipality of Kristianstad 2009; for a short description and photograph of the plant, see http://swentec.se/en/Start/find_cleantech/Plantscontainer/Karpalund-biogas-plant-in-Kristianstad/). From 2009 estimates, 65% of the biogas created from these three facilities was used for district heating or combined heating and power with the remaining 35% refined for vehicle fuel (Municipality of Kristianstad 2009).

Eleven years after the executive council's commitment to becoming fossil fuel free, the city and surrounding areas use virtually no fossil fuels (oil, natural gas, or coal) for heating, using instead a combination of biomass and biogas. Now that heating no longer relies on fossil fuels, the city is turning its attention to reducing fossil fuel use in transportation, which accounts for 60% of the area's fossil fuel usage (Rosenthal 2010). At least 30 public buses in Kristianstad run on locally generated and refined biogas, and approximately 250 other vehicles -- both municipal and private -- do as well. Now that municipal cars run on biogas, the municipality is working to encourage private drivers to purchase biogas-fueled vehicles by providing grants to help offset the additional cost of buying such a vehicle. Biogas fuel costs about 20% less than gasoline, but the biogas-fueling network in the Municipality of Kristianstad is not ubiquitous, making consumers reluctant to spend the $4,000 premium for a biogas or dual-fuel car. Running a municipal fleet and private vehicles on biogas requires an infrastructure to distribute vehicular biogas fuel. The limited number of refueling stations in the Kristianstad Municipality is a drawback that is being addressed. (Rosenthal 2010). With the lower cost of biogas fuel and government grants to offset the cost of new vehicles, the demand for biogas vehicle fuel continues to expand (Municipality of Kristianstad 2010).

Creating a regional system to generate and distribute biogas-based energy requires substantial start-up costs. Just as biogas systems in Nepal and the United States receive government grants or subsidies for construction, in Kristianstad, these costs have been largely covered by the city and grants from the Swedish government. However, the shift away from fossil fuels and towards a diverse renewable energy portfolio has also resulted in annual fuel cost savings. The cost of heating municipal buildings has fallen from $7 million to $3.2 million annually. With the municipal fleet running on locally generated biogas, the city no longer needs to buy fossil fuels in a volatile market, resulting in a net reduction of vehicle fuel costs. In addition to saving money, the process of making and using biogas also generates revenue, which helps to offset the costs. The obvious source of revenue is the sale of heat, power, and fuel created by the biogas facilities. Less obvious are the fees paid by farms and factories to have their waste hauled away to the biogas production facility (Rosenthal 2010).

The case of Kristianstad, Sweden, demonstrates how biogas technology has been adapted to specific localized needs (district heating and provision of vehicle fuel) by scaling up the technology to a regional scale. This development was made possible by commitment and support provided by local and central government bodies and driven by growing global climate change concerns. This switch to biogas is credited with reducing Kristianstad's carbon dioxide emissions by 25% over 10 years and decreasing fossil fuel usage by half (Rosenthal 2010).

Summary and Commentary: Biogas in Context

Biogas in Nepal focuses on rural household energy self-sufficiency. Biogas in the United States focuses on industrial-scale waste management application, with the generated energy being used directly by the facility or transferred into a regional grid. In Sweden, biogas is part of a new energy strategy to make a municipality and its surrounding region fossil fuel free and energy independent. These three examples demonstrate how one renewable energy technology can be modified and adapted across scale and cultural/social contexts, from developing to developed countries, and from rural to more urban-type areas.

Biogas in Nepal has been dependent upon funding from developed countries to help establish the biogas sector and supplement the subsidy program. With biogas now a registered CDM, if the petition for CER credits is approved, the government will be able to generate revenue from the sale of carbon credits to global North companies and use those funds to sustain the renewable energy program. Use of the carbon market in this way does raise questions of neo-colonial practices as a result of which the global North may not need to change energy behaviors; rather developed countries would pay those living in the global South to change theirs (Bachram 2004). However, biogas is being adapted and used in diverse, if limited, global North applications as outlined in the examples of the United States and Sweden above. While this does not negate arguments of imperfect power relationships in the global energy marketplace, nor does it herald a substantial shift in energy behaviors in the United States, it does demonstrate that energy behaviors in developed countries are malleable. The same technology used to promote sustainable development by non-governmental organizations, international non-governmental organizations, and governments in the developing world is also applicable to solving energy problems in developed countries. Furthermore, biogas usage at any scale in any locale -- from the family to a community -- creates a localized resiliency to the volatility of global fossil fuel markets while buffering biogas users from the vulnerability created by reliance on depleting fossil fuel reserves.

In the rural areas of developing countries, including Nepal, India, China, Vietnam, and Indonesia, biogas is about equipping rural households with the ability to create their own renewable energy (largely for cooking fuel) that will enhance environmental protection, family health, and quality of life while providing a localized energy resiliency. In the United States, biogas is often a by-product of industrial-scale waste management that is sometimes put to productive energy use, and sometimes simply flared to reduce methane emissions. Biogas digesters at livestock facilities in rural areas are more about managing waste and odor associated with thousands of animals in a concentrated area. The energy generated from such facilities is used both on-location and sold into electric grids for use by a wider constituency who may not even realize that their electricity is provided by a range of sources including biogas. Biogas is even being explored as a potential energy source for localized operations that require substantial amounts of energy to operate, such as the example of data centers explored above. In Sweden, biogas is being used to help meet the energy needs for an entire metropolitan area, thus crossing the boundary from serving as an isolated rural energy system to being an integral part of a metropolitan regional energy network. The scale of biogas systems and service areas ranges from a household in Nepal to a city in Sweden, but energy capture and use is based upon the same basic precept – renewable energy can be locally generated through everyday waste.

Classroom Application: Sustainability in Context

While teaching an introductory college course on geographic perspectives on sustainability and human-environment systems, I did a series of lectures and readings on energy. During one lecture where I explained biogas in Nepal, my students got into a discussion about whether or not biogas technology could be adapted for use in the United States. The predominant stance among the students was that, no, given the established infrastructure, such a thing was not possible. Their discussion was based on imperfect information – before their spontaneous inquisitive outburst, I had not provided them with any case studies in the global North. However, biogas *is* being used in the global North as the examples of the United States and Sweden show. Not only that, but the case of Kristianstad demonstrates biogas' role in helping a region shift to renewable energy reliance. I brought the example of Kristianstad to the classroom, and it began to shift the students' notions of biogas as a curious oddity relevant only to rural, global South projects to understanding its potential across scale and culture. It was this classroom discussion that taught me the importance of bringing diverse examples of biogas application into the classroom; otherwise, biogas was seen as something that "people over there" could do, but that could not possibly be adapted to "our" advanced energy infrastructure in the U.S.

Biogas provides the educator with an example that can be taught in class about issues of scale and cultural context in sustainability. With this kind of example serving as a guide for students, a number of assignments and exercises can be designed to explore scale and cultural context in sustainability. For example, students can select another sustainability technology or method and research how it is currently used and adapted in different cultural contexts or scales. Alternatively, students can be asked to prepare a proposal for how a specific sustainability practice could be adapted to different scales and cultural contexts. Such an exercise requires students to have a solid understanding of their chosen technology or practice as applied within a specific context of community needs and culture. In either exercise, the technology or practice studied could be any approach that seeks to engender sustainability, including another alternative energy form, alternative farming practices, or alternative economic opportunities (fair trade, buy local, etc.).

For a course that is more applied in focus and centered on issues of energy, students could conduct group projects where each group researches the social, environmental, and economic viability of an alternative energy system for a specific place and context, perhaps the surrounding college community. There could be groups for wind energy, solar energy, biomass, biogas, and micro-hydropower. Such an exercise requires research into the energy needs, existing infrastructure, local economy, local industries, and environment of the place in question. For example, are there existing sewage treatment plants or landfills that produce methane? Are there old water-powered mills that could be retrofitted? Is there a local farming or food processing industry that produces waste that can be used for biogas generation? Is wind energy viable, and if so where would be the best place to build a windmill? The groups can present a portfolio outlining their feasibility study based upon their knowledge of the technology and their understandings of the scale and context in which it could be implemented.

By engaging in such comparative projects rooted in place, students can learn that there is more than one way to achieve sustainable living. What works in one place may not work in another. Any solution that is proposed as a pathway to sustainability needs to be rooted in the social, environmental, and economic realities of place. Teaching sustainability across scale and culture is one way to critically engage students in a dialogue that is key to changing thinking and sustainable life choices.

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