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Powering A Sustainable Future – The Role for Agriculture

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Rationale – what? why? & who?

This unit, for high school students, will explore the many roles the agriculture, food and natural resources realm can play in required shifts in energy use, renewable energy production, reduction of greenhouse gas emissions and sequestration.

Figure 1 Imagining a near future where all students learn to grow, share and eat food using regenerative practices, make and use alternative energy at school.

Most people have a general understanding that fossil fuel use is “bad” for the environment. Many have some understanding that excess emissions of carbon dioxide, and other greenhouse gasses (GHG), are causing climate change. The perils seem to be ever clearer, as we experience and/or read about record high temperatures and catastrophic weather events. These are caused by the many human activities which have, and continue to, spew GHG into the air.[1]   Between writing the first and second draft of this paper, the earth has broken the global average surface temperature ever recorded two days in a row.[2] We can all look with horror at the temperature anomaly map video that NASA has produced, to visualize the planet’s long-term warming trend from 1880 to early 2024. As this video timeline progresses, the earth’s surface, starts out appearing white and blue. These colors represent average temperatures of the baseline period from 1951-1980. As time progresses, the map becomes ever more yellow, then orange, then red - indicating an almost 2 degree increase in temperatures from the baseline. June, July, and August of 2023 combined were 0.41 degrees Fahrenheit (0.23 degrees Celsius) warmer than any other summer in NASA’s record.[3] Heat, storms, wildfires, floods. Human caused climate catastrophe can no longer be ignored, and the only time left to work on this problem is now.

What seems less clear is how we humans, living in distinct places – interconnected by air, water and weather patterns – but politically separate, will pull off making the many changes that are so obviously required to coordinate reductions in GHG emissions. We need to onboard proven technologies, innovate and coordinate research and implementation at the scale required to solve this huge problem. We want temperature regulated homes, and the freedom to drive where we want in cars we can afford. We expect cold ice cream and hot coffee, and for the most part do not want to know how much methane the cow that provided the cream belched into the atmosphere, nor whether the coffee beans came from shade grown permaculture plantations. The scope of the problems feels so vast, and the impact of any of our individual actions so limited.

Education is potentially the most powerful tool to address climate change. One of the main requirements of change is understanding what is possible, and having the tools to implement, evaluate and iterate new technologies. Having a community of support, in the form of classmates and colleagues with whom to collaborate, navigate and instigate change is also an important key to changemaking. "The current global challenges need strategic, creative optimists who are willing to demand more radical approaches and identify pathways for action."[4]

High school students are not (yet) decision makers at either the household or political level. Even if they were, they are no more equipped than the average politician to decide when or whether to install solar panels or a heat pump, whether to support investment in hydrogen cell technology or biofuel. But decisions are being made that impact our collective future, and more decisions need to be made. Political will, start-up funding, and research and implementation priorities will need to be influenced by expertise. Given how complex and interconnected the issues of climate change and the challenges of making change are, it is imperative to build expertise in renewable energy technologies and climate mitigation strategies.

The goals for this unit are to help students to consider themselves stakeholders in our shared future. When armed with knowledge, ideas and problem-solving practice they can then take on an active role in designing, building and advocating for greener and cleaner future.

The "what" of this unit is to co-create with students a practical toolkit for reducing GHG emissions within the food and agriculture sector. They will be invited to explore and demonstrate understandings of several ways to reduce fossil fuel energy use, produce alternative energy, and shift agricultural practices to be part of the solution, rather than part of the problem.

Who Needs to Know?

The U School is a comprehensive laboratory high school with just under 300 students in the Philadelphia School district. Founded in 2014 through a grant from the Carnegie Corporation of New York to re-imagine schools to prepare youth for college and career, The U School is a competency-based model that requires young people to demonstrate their learning through tangible performance tasks. We leverage strong relationships with our students to grant students the agency and support needed to successfully make the college and career leap. This unit is designed for our Agriculture, Food & Natural Resources (AFNR) Career and Technical Education (CTE) program, which has evolved to be the primary class for almost all our U School 12th graders. In addition to science, social studies and agriculture CTE competencies, students explore what we call "Green Collar Careers" and "Sustainability Studies." The program is meant to grow citizens who understand complex interconnected issues and participate in community improvement. This is CTE for the 21st century, teaching a range of problem solving, technical, and academic skills which are transferable to a range of post-secondary pathways.

Many of the lessons, labs and activities from this unit would fit well in high school science courses, while other activities from this unit might better align with social studies or civics classes.

An overview of how agriculture (and the rest of society) has been using energy, and what options there are for changes to energy production and consumption, will fill an important gap in our current offerings. It will also offer students several optional opportunities for additional certifications, credentials, and internships.

Sustainability, Educators for Sustainability

Sustainability can be defined as a “process of continually and actively moving in the direction that promotes ecological health, social equity, quality of life, cooperation and compassion.”[5]

The UN Sustainability framework outlines a set of goals which are meant to be a “blueprint for peace and prosperity for people and the planet, now and into the future.”[6] Signatories to the UN sustainability goals list – which were unanimously adopted by member nations – have all agreed that affordable, sustainable clean energy for all and climate action are among the top 17 goals.

Sustainability is generally conceived as encompassing three equally important pillars: social, environmental and economic. These are often in tension, and determining whether a business or practice is sustainable is often not clear. A farm that grows delicious food and pays its workers well, but pollutes the drinking water downstream of its fields, could not be considered sustainable. A food processor with strong circular economy standards, little waste, using renewable energy and compostable packaging, earning a good profit who fails to pay workers a living wage would also fail this sustainability test. These goals can be hard to meet, and there are many tradeoffs along the way to reaching these goals.

As an educator, I am committed to the collective practice of educating for a sustainable future, as defined by The Cloud Institute’s Education for Sustainability (EfS). “EfS is an approach to teaching and learning that equips students, teachers, and school systems with the new knowledge and ways of thinking we need to achieve economic prosperity and responsible citizenship while restoring the health of the living systems upon which our lives depend.”[7] Along with three other teachers at the U School, we spent almost two years participating in a cohort of secondary and post-secondary institutions and individuals building on work of a wider network to establish best practices, and initiatives to implement a set of sustainability content standards. This is relevant, as educating for sustainability asks educators and students to consider themselves responsible for the world while offering a framework for evaluating and navigating choices. These content standards differ from Common Core, and the Career and Technical Education skills and task lists that also frame teaching. EfS standards provide a set of valuable tools to assist in creating a *process towards* goals which are as valuable as any specific content. Four of the nine sustainability standards that directly speak to this unit on energy and agriculture are:

> *Healthy Commons* Healthy Commons are that upon which we all depend and for which we are all responsible (i.e., air, trust, biodiversity, climate regulation, our collective future, water, libraries, public health, heritage sites, topsoil, etc.). Students will be able to recognize and value the vital importance of the Commons in our lives and for our future. They will assume the rights,

responsibilities, and actions to care for the Commons. *Natural Laws & Ecological Principles* Students will see themselves as interdependent with each other, all living things, and natural systems. They will be able to put their knowledge and understanding to use in the service of their lives, their communities, and the places in which they live. *Inventing & Affecting the Future* The vital role of vision, imagination, and intention in creating the desired future. Students will design, implement, and assess actions in the service of their individual and collective visions. *Multiple Perspectives* The perspectives, life experiences, and cultures of others, as well as our own. Students will know, understand, value, and draw from multiple perspectives to co-create with diverse stakeholders shared and evolving visions and actions in the service of a healthy and sustainable future locally and globally.[8]

Implementing sustainability standards are an essential objective and serve as guideposts in determining expectations of student learning, student activities and student action as we explore specific content. In the unit that will precede this unit on energy, students will have learned to define sustainability, assess sustainability practices, and begun to build sustainable leadership skills. We will have just explored how to audit a process, business or practice using the three pillars of sustainability: People (Social), Planet (Environmental), and Profit (Economic). We will bring this lens to our study of sustainable energy.

The Food & Agriculture Energy Connection

Plants are Producers: Photosynthesis, The Food Web, & Energy Transfer

"Most human energy requirements are met by forming bonds between hydrogen and oxygen. This occurs when fuels are burned. The fuels may be foods which are burned (or respired) in the body, or materials like oil and coal which are consumed in engines or furnaces. Photosynthesis is the process that produces these fuels… Apart from nuclear fission and ocean tides this is the source of virtually all energy on earth."[9]

As the fundamental building block of energy, we will turn our attention to a brief review of photosynthesis. Plants have the unique ability to utilize solar energy (the photons, of *photo*synthesis) to break the strong bonds of water (H_2O), which plants take up from their roots, and carbon dioxide (CO_2) which has entered the leaf from the air to create a new substance which could be written as CH_2O or "hydrated carbon" -the building block for all carbohydrates. This light energy is now stored as chemical energy in the form of glucose: carbon-carbon, carbon-oxygen, oxygen-hydrogen, and carbon-hydrogen bonds. This is the synthesis part of photosynthesis. Oxygen (O_2), another essential requirement for many living creatures, is formed in this process.

Plants make a range of simple sugars and complexes of sugars (complex carbohydrates) namely starches and cellulose. The energy stored in carbohydrate molecules (sugars and starches) created during photosynthesis passes through the food web from producer to consumers and decomposers. Energy is lost at each trophic level along the food chain, and energy accumulates and is stored in the tissues of large plants, such as trees. It should be obvious at this point that carbo- in carbohydrate is carbon. When carbon remains as carbohydrate in plant tissue or in soil it is considered sequestered or stored. The energy has not yet been utilized, nor has the carbon been released back into the atmosphere in the form of CO_2. While a tree grows, much of this carbon is stored as chemical energy in the bonds of the carbohydrates formed each day during photosynthesis. This carbon is in its branches, trunk and leaves. Every year millions and millions of trees, plants, animals, fish, birds, insects and people die and decompose and become part of the earth's soil. Wood is burnt, food is eaten, and carbon is released into the air when animals breathe, expel gas, and when soil is tilled. Carbon cycles through the system – being turned into carbohydrates and back into gas. In proper balance, the CO_2 taken up by plants equals that which is liberated by other processes.

Many of the living things that died millions of years ago ended up buried far underground, or underwater, and were pressed down by the weight of the soil and rocks and turned into oil, coal and natural gas – which we call fossil fuels. This natural process took millions of years. Digging up and burning these long-buried sources of fuel (carbon from long ago sequestered carbohydrates) allowed for many innovations and productive human endeavors. It is also the source of the excess CO_2 in the air, as this long-stored carbon cannot be taken up by existing vegetation. The carbon cycle got way out of balance, greenhouse gasses built up, and a climate crisis has been the very unfortunate result.

In agriculture education, the energy transfer within the food web is tied into a topic we call feed conversion ratios – which are a method of quantifying how efficiently various animals convert feed to mass. This has been considered a useful measure of farm productivity. If the expense to feed a flock of hens till they reach egg laying maturity costs more than the value of eventual eggs, this project makes no economic sense. But if a farmer can also sell some hens for meat, and/or utilize the services of the chickens to scratch and peck insects and spread cow manure after the cows have been moved on to new pasture, this aids the bottom line. Better still if farm waste can be converted to a biofuel (discussed in more detail in the next section). These practices might be the difference between a polluting or profitable farm, offering different metrics for productivity.

Agriculture is at its heart the coordinated production of energy, in the form of calories – to feed people and animals and to grow biomass crops to burn directly or turn into biofuel. Agriculture has, over the last hundred years or so, become an industrial sector that consumes large quantities of energy, and releases excessive greenhouse gasses through industrial farming practices. "Over the brief span of the 20th century, agriculture underwent greater change than it had since it was first adopted some 13,000 years ago…farms were [once] diversified enterprises, producing crops and animals together on the same farm in complementary ways. Animals were typically raised with access to the outdoors and fed from the farm, their manure provided valuable natural fertilizer, and most of the farm work was done by human and animal labor."[10]

Large scale industrial farming practices have grown to rely on inputs of petrochemicals in the form of pesticides, and fertilizers. The relationship between fertilizers and climate change is a complex web of interactions. Emissions from the production and application of fertilizer contribute to a warmer, wetter climate, which affects how farmers use fertilizer—how much they apply, how often, and when in the growing cycle. At the same time, fertilizer overuse and climate change combine to degrade soils, leaving fields more prone to erosion and damaging the living organisms in healthy soils, causing farmers to compensate with ever more fertilizer.[11]

These fertilizers are produced by processes that were designed to manufacture munitions and poison gas. This direct capture of nitrogen from the air has come at a huge cost. "Scientists have estimated that producing the ammonia needed for fertilizer generates more CO_2 than any other industrial chemical reaction."[12] Commercial farming often uses heavy diesel-powered machinery. Most farm animals are no longer raised on diversified farms, and meat production is responsible for deforestation, to create pastures for grazing. When cows are moved to concentrated feedlots with huge manure pits, they contribute massive amounts of methane and CO_2 to the atmosphere. Worldwide, livestock accounts for between 14.5 percent and 18 percent of human-induced greenhouse gas emissions.[13]

There are many other places along the farm to table supply chain where the agriculture sector uses energy directly: fuel used to power machines, refrigerate, process, package and ship food and fiber. By some estimates the amount of energy used in agriculture has grown substantially, and currently, the agri-food chain accounts for 30 percent of the total energy used around the world.[14]

Agriculture has also played a large role in providing feedstock for biofuels, that is, fuels that utilize biological materials (biomass) such as plant residues, crops, algae or animal waste to make biodiesel, biogas (methane) and bioethanol. These products all retain energy that can trace its initial source to photosynthesis, and because plant matter and animal waste are replenishable, they are considered renewable. These will be discussed in detail in the next section, and all are essential components of moving towards a non-fossil fuel carbon neutral future, particularly for equipment that will rely on liquid or gas fuels. These fuels “burn cleaner” than fossil fuels but can only be considered carbon neutral if the growing of the biomass itself doesn’t produce more emissions that the biofuels save by displacing fossil fuels.

Alternative Farming - Carbon Farming

Clearly there is a role for agriculturalists, agriculture educators and agriculture students (and all eaters) to delve deeply into practical details and specific changes that can be implemented to reduce/eliminate fossil fuel causing emissions on farms, food processing facilities and adjacent industries related to food, agriculture and natural resources. We need land use regulations that support conservation and carbon sequestering practices, we need subsidies to align with emissions goals, not lobbyists’ clients. Some of this is work for influencers, advocates and graphic designers; some of this work is for researchers, practitioners and laborers.

In a very practical way, agriculture can be part of the solution to climate change by utilizing proven practices that eliminate fossil fuel use and increase carbon sequestration. Reduced tillage, better waste management, crop rotations, increased cover cropping practices, all increase soil carbon stores (with co-benefits of growing healthy delicious food). Fixing nitrogen from the air is also done successfully by planting any of the whole category of plants called legumes - alfalfa, beans, peanuts, lentils etc. Nitrogen fixing legumes when grown interspersed, or in rotation, bring nitrogen into the soil while utilizingCO_2, and are key crops on all regenerative farms.

There are many farmers, agronomists, climate scientists, permaculturists, regenerative agriculture theorists, working towards what is called agroecology or carbon farming.   These “carbon-smart” farmers engage in research and practical experience to bring answers to the question of “how can we feed and clothe an ever-growing population, while eliminating carbon emissions, and sequestering more of the carbon already in excess in our atmosphere?” This is a huge question, and there isn’t one answer, but regularly considering the question, and working towards a solution is the goal of the work. Geography plays a large role in what solutions can be implemented where. City residents may not manage large tracts of land, but we have purchasing power influence, and our proximity to each other and large research institutions, provides many opportunities for collaboration on incubation of innovation.

Using case studies, virtual and in-person field trips, (discussed in activities section to follow) students will learn from, and alongside, some of these experts which strategies to try and how to evaluate their impact.

One such case study is to learn more about an innovative Israeli seed producer, Groundwork BioAg, who sell agronomic seeds inoculated with carbon capturing mycelia that provide high crop yields, low inputs, and which sequesters enough GHG that the farmers who plant these seeds can get carbon credit payments which offset their farm expenses. Students will have an opportunity to purchase these seeds and go through the process of applying for carbon credits.

Farming Alternative Energy - focus on BIOFUEL

Despite federal and state programs to convert corn into ethanol and soybeans into biodiesel to fuel cars and trucks, the United States had never regarded farming as a primary energy producer. That changed when Congress in August passed the climate provisions of the Inflation Reduction Act, which provides $140 billion in tax incentives, loans and grants to replace fossil fuels with cleaner renewable energy that lowers emissions of carbon dioxide.[15]

There are a range of existing, and yet to be fully operationalized, energy sources which are categorized as alternative/renewable energy which students should be familiar with. As part of their learning students will investigate solar, wind power, hydrogen fuel cell, and hydropower. Students will also spend some time investigating how our school gets/uses energy. This overview of energy technologies will be a jumping off point for digging in deeper on the focus of our exploration. Many – if not all – of these alternatives to fossil fuels have some role to play in cleaning and greening the agriculture, food and natural resources sector's carbon footprint. Here I am focusing solely on fuels that are made directly from biomass, and specifically those that can utilize agricultural and food waste in their production. We will be making and analyzing three biofuels in our classroom, and urban ag lab (outdoors); bioethanol, biogas and biodiesel. We will, of course also be growing energy, in the form of food, and composting food and garden waste. Each of these biofuels offers different opportunities for production and use, as described below.

Bio-digestion: what? how? pros/cons

Bio-digestion is a process that mimics the process that occurs when a cow eats grass, and liberates the energy from cellulosic plant material such as hay and grass in their rumen. The bio-digestion process utilizes the same bacteria as cows in an anaerobic (oxygen free) environment to metabolize/digest a range of organic waste and to generate burnable bio-methane gas also called renewable natural gas. This gas can be used for cooking, heating, or energy generation. This can be done on a home, farm or industrial scale.

Bio-digestion be used to divert and productively utilize a significant amount of organic waste, from municipal waste streams and sewage treatment plants. We waste a lot of food. "…60 million metric tons of food waste is generated just in the US each year, amounting to about 30% of the total food supply," according to the US Department of Agriculture.[16]

Digesters have been used most widely on dairy farms, to convert manure to fuel, but also to measurably reduce the manure odor, GHG emissions, and to protect waterways. I have met several farmers who power their farms and surrounding communities with energy generated from the manure from their dairy herds. Their neighbors are happy about the low-cost energy, but thrilled that the air outside and inside their homes no longer smells like, well, manure. The American Biogas Council estimates a large increase in demand for bio digestion. They "count more than 15,000 new sites ripe for development today: 8,600 dairy, poultry, and swine farms; 4,000 water resource recovery facilities, 2,000 food scrap-only systems, and utilizing the gas at 470 landfills who are flaring their gas."[17]

We have invested in a home-scale biodigester, which once set up and running, should provide several hours of cooking gas each week. Students will learn how to set up and tend this biodigester, and track food and garden waste that is diverted from the waste stream and cook meals with vegetables and herbs grown in our garden, on gas produced with garden and food waste, and use the byproducts of the process to fertilize the garden again. These digesters require tending, and work most effectively at temperatures ranging from 10-18 °C, which will limit year-round use. Managing and maintaining the biodigester is a tangible illustration of the carbon cycle, and a proof of concept about some agriculture circular economy initiatives. Students will have opportunities to visit a larger demonstration project at a local university, and to compare the effort and efficiency of this energy production technology with another method of utilizing food waste, composting. Figuring out the logistics of storing food waste, scheduling time to attend to the system, and planning to use the gas and byproducts, will all be part of the learning experience. Evaluating this process and comparing/contrasting with composting will help guide our recommendations and information for our Bio-Energy toolkit.

Figure 2 picture of home scale biodigester, HomeBioGas 2

Biodiesel: what? how? pros/cons

They do say what goes around comes around. Rudolf Diesel invented the diesel engine in 1897. From the beginning, this engine could run on a variety of fuels, including vegetable oil. In 1900, one of the new diesel engines featured at the Paris Exposition was powered by peanut oil."[18]

Biodiesel is made from any of various vegetable oils including used cooking oils, or animal fats. The process of converting vegetable oil to a useful fuel is called transesterification. Adding an alcohol (methanol) and a catalyst (usually sodium or potassium hydroxide) converts the oil or fats into a biodiesel and glycerin. Biodiesel can be made on a small scale, to demonstrate the technology easily. One measures out the ingredients, mixes the alcohol with the catalyst, warms the oil slightly, mixes everything together well, and waits. After the glycerin separates out and is removed, the biodiesel is basically ready. Additional steps, called washing, where water is added to the biodiesel, stirred and let to separate again, will remove any residual glycerin and soap impurities. On an industrial scale the process is more precise, but for school demonstration purposes, the resulting biodiesel will power an oil lamp, or could be mixed with approximately 80-90% fossil fuel diesel to power a diesel vehicle. Maybe our program can source an old diesel van and convert it to run on fuel we make.

Biodiesel made commercially using vegetable oil, mostly from soybeans, must be grown on land that is then not being used for growing food or conservation efforts. Another concern, which is true of all food-based bio-feedstock for any biofuel (such as corn kernels used to produce ethanol, see below) is that it can lead to increased food prices. There are so many subsidies for clean energy which can shift the economic incentives for farmers away from food production towards biomass production.

Since biodiesel can be made effectively, albeit with more batch-to-batch adjustments, with used cooking oil, this fuel could be a way to reduce existing waste streams, and to capture energy that would otherwise end up in landfills. But even using virgin oil for biodiesel reduces the total life cycle GHG emissions because carbon dioxide released from biodiesel combustion is offset by the carbon dioxide absorbed from growing the oil plants used to produce the fuel.

Bioethanol: what? how? pros/cons

Ethanol is an alcohol made by fermenting the sugars (carbohydrates) found in biomass. Current ethanol production relies almost solely on sugars extracted from corn, sugar beets, and sugarcane. It is easier to make bioethanol with food grade feedstock, such as corn kernels rather than corn stalks. While the stalks and stems have fermentable sugars, they are in the form of complex carbohydrates bound up with cellulose and lignin. To be able to ferment the sugars, the biomass feedstock must be pre-treated with acids or enzymes, or in some cases fungi, to begin to break down the plant structure, to access the glucose. The lignin component, once separated from the rest of the biomass can be burned as a fuel for the ethanol production plants boilers.

The U.S. is the world leader in biofuel production – generating 47 percent of global output over the last decade. The ten-fold expansion in ethanol production in the U.S. from 2002 to 2019 has been driven by the Renewable Fuel Standard (RFS), a federal program that since 2005 has required transportation fuel to contain a minimum volume of renewable fuels.[19] So far, that has largely meant corn ethanol. According to the Department of Energy, 98 percent of gasoline in the U.S. contains some ethanol, most commonly 10 percent, or E10.[20]

The promise of ethanol production is "that with the right technology for making and using ethanol, the chemical and energy industries could break their reliance on petroleum and drastically cut their climate impact."[21] So far this has not been realized. These crops are being grown on farmland and are using the same industrial farming techniques utilizing fossil fuel fertilizers and fossil-fueled farm equipment. Transporting them requires still more fossil fuel to power trucks. The distillation following fermentation requires heating fuel. And carbon dioxide is a by-product of this process. One study, which claims to be among the first empirical assessments of ethanol production, found that the production of corn-based ethanol in the United States has failed to meet the US Renewable Fuel Standard policy's own greenhouse gas emissions targets. Their findings are that major technological and policy changes would be required to meet the targets and to achieve the sorts of environmental benefits of biofuel production and use intended by these policies.[22]

If, instead of using food crops, ethanol production focused on agricultural waste, this process would become much more sustainable. Cellulose, in the form of lignocellulosic biomass, is abundant in agricultural and forestry waste. Common agriculture waste examples include corn stover – the stalks, leaves, and husks left over after kernels are harvested, wheat straw, and sugar cane bagasse.

There have been major investments, and roadblocks to success, for lignocellulosic bioethanol production. There were problems with feedstock logistics, plant design, need for more research, and government regulations. These issues contributed to making it unprofitable to bring this technology on-line, especially with the increase in fracking, which brought the price of fossil fuels down. Despite the disbanding, or sale, of many of the initial startups who had invested in these technologies, there is renewed interest. Some industry watchers think that after decades of false starts, the global push toward net-zero carbon emissions is now poised to combine with an improved suite of cellulosic technologies to usher in a new era for ethanol.[23]

There are several major companies pursuing these technologies in 2024, and we can follow their successes and challenges in real time. It is a reminder that the science and technology do not always match up with economics or political will, and sometimes a good idea is ahead of its time, or not feasible at all. Time will tell.

Since bioenergy or biofuels are part of almost all proposed pathways to reduce human caused GHG emissions to limit global warming to 1.5 or 2 °C, these technologies need to be explored. Whether these biofuels are currently, or can be, sustainably produced is still an open question, and one that will be the heart of the work students will explore as they work on their contributions to an Agriculture can Reduce the Climate Crisis Toolkit.

Teaching Strategies

A balance of direct instruction, investigations, independent and group research, field trips and hands-on practice will be utilized through this unit.

Students will be introduced to the topic and provided a student facing unit guide that clearly lays out an overview of what we will cover, and the requirements for portfolio completion for this unit. During the month this is our primary unit, there will be a related lesson or activity planned during each class block.

The unit guide includes links and hard copies of guided lab notes, other required and "choice" assignments and assessment rubrics, and a schedule of when activities are planned. This one-stop document serves as curated resources, templates for completion, and includes vocabulary lists, and career connections options. Some of the tasks build on each other – and must be completed in sequence, but others can be done (or may have been done in another unit that a student completed over the summer, or in a workshop off-site). Students are each responsible to maintain their unit portfolio, and time during several class periods each week will be directed towards artifact creation/logging/captioning etc. The completed portfolio will have a due date.

Students will begin this unit by reviewing their foundational knowledge with an anticipation guide intro and google form on food web, energy transfer and photosynthesis basics. This quiz-like set of questions will help establish what review is required for all, and what might be tailored to specific students on an individualized basis. They will also have a “learning tracking” KWL (what I (already) **k**now, I (still) **w**onder, what I **l**earned)-guided notes doc to complete weekly.

There will be 4-5 hands-on renewable energy labs/demonstrations where students will work in cooperative groups, a formalized way to ensure that students share responsibilities and learn from and with each other. Team roles include Principal Investigator (PI) who will read and annotate the directions, ask questions on team’s behalf and checks the final work; the Maintenance director: tracks safety and organization of the space, handles cleanup; the Documenter/Reporter records data and observations and shares the results with group; and the Materials Manager who gathers supplies, sets up materials and returns the equipment and supplies. These jobs are rotated for each different activity.

Students will be expected to update their learning tracking KWL chart, and various guided lab and/or field trip notes for weekly review.

Weekly seasonal garden lab time is always focused on regenerative climate farming techniques – which are a balanced combination of short lesson/demonstration/direct instruction on a particular topic, such as cover crops, followed by hands-on field work such as weeding, planting, sign making and documenting the activity.

Each student will be responsible for a research question or direct action and presentation to the group as their contribution to the tool kit. This might take the form of a policy paper about urban agriculture’s impact on climate change, or an infographic about compost or bio digestion, or a stop motion video directions for making biodiesel.

Some aspects of the competency model at the U School are worth noting. It is the expectation that: students will be working at different places on a competency’s learning progression; instructional decisions are based on student needs in real time; learning assets – i.e. teacher support – are available “just in time” so students can self-pace; units are designed to be student-facing; assessment “*as* learning” – i.e. revision cycles are part of the learning process. There are multiple opportunities to explore, engage and practice specific competencies. Authentic performance-based assessments for some of these skills related to practice and repetition, and many of the teaching strategies and assessments are therefore individualized and not formulaic. Because each student is completing an overall portfolio that may vary from her classmates, the expectations for each student throughout this unit will also vary.

Classroom and Schoolyard Activities

The unit will start with consideration of potatoes. Each student will arrive to find a potato on their desk. Students will be asked to write down all the ways this potato has been used, or can be used for energy. The most obvious might be the chemical energy of calories. A second could be the gravitational potential energy in a potato held above the ground, and then the third might be kinetic energy if the potato is dropped or thrown. Several potatoes will have been sitting in a sunny windowsill, or atop the classroom radiator, and can be passed around to demonstrate thermal energy. We will consider where the potato might have been grown, and what sort of, and how much, energy was used to get it to our classroom. Some of these potatoes may have been grown in the school garden, and others with a less clear provenance, which can introduce the idea of food miles, fossil fuel use in the supply chain, and alternative agricultural practices.

Students will then be asked to brainstorm examples of each type of energy we haven't yet covered but is listed – guided to focus on food and agriculture. A set of slides depicting each energy use and a connection to food and agriculture will follow.

This will lead to a more detailed discussion of where the chemical energy/calories come from. Students will hopefully recall some prior knowledge of photosynthesis and energy transfer through food chains/webs. Students will finish this lesson by completing a pre-test/prior knowledge review of these topics to assess gaps in understanding and specific areas requiring review.

Lessons two and three will be direct instruction overview of the climate crisis including the role of photosynthesis in the formation of the carbon in the fossils of fossil fuels, how the carbon cycle has been/could be in balance, and the many ways the carbon cycle has become "out of balance" with excess carbon dioxide, methane, and nitrous oxide as humans utilize long sequestered carbon, and/or deforest and degrade soils to prevent sufficient sequestration. This lesson will include several videos, graphic images including a playing and discussion of the temperature anomaly map referenced earlier.

Lesson four is a demonstration of how carbon captured through photosynthesis – i.e. carbohydrates – can be metabolized. This demonstration will include an interactive group lab to introduce students to the relationship between food and energy. A series of flasks will be filled with various plant material such as: grated potato (from lesson 1), chopped grass or clover, small pieces of wood, minced corn, or mashed peas. Yeast and warm water will be mixed with a small amount of sugar and added to each flask, one flask will have just yeast and water (no sugar). Students are asked to predict which container(s) will be more active, how will they know if they are more active etc. and offer reasons for their predictions. The flasks are then covered by a ballon. See figure below:

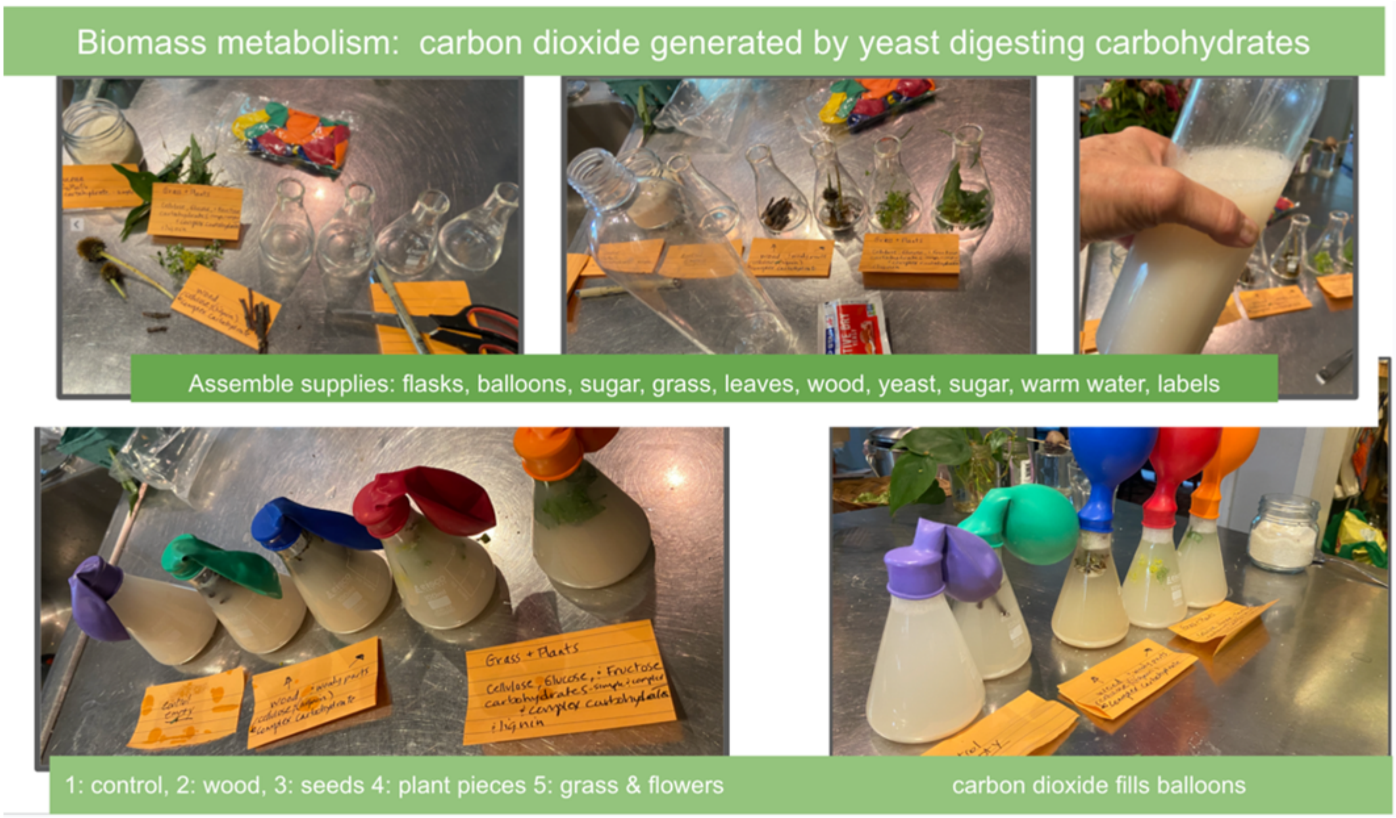

Figure 3 supplies and procedure for demonstrating metabolism of sugars

While students await balloons to be filled by carbon dioxide, they will work in small groups to observe yeast being fed sugar, becoming active (foaming), and measuring temperature increases due to this metabolic activity. Students will quantify the growth of the yeast, by measuring the height of the foam generated when yeast is given table sugar as a food source. Students will also be able to observe that the temperature of the water in which the yeast is growing will increase by between 1-3 ºF and graph this change over time. This one-hour lab requires only a vessel, water, sugar, and thermometer, to observe a key biologic process of liberating energy from carbohydrates created by photosynthesis. This process is also the foundation of brewing bioethanol, which will come up in another lab later in this unit.

As we progress through the unit activities, we will focus on hands-on projects that demonstrate and practice regenerative cycles, as we create, maintain and utilize renewable energy in our outdoor labs. Our focus will be to attempt school-scale strategies that would be similar enough in practice to be useful at larger scale. Students will participate in practical energy generation and use. First, by growing food, which is already a large part of our program, but hasn't yet been framed explicitly as an "energy source," and comparing our food growing practices to current commercial agricultural practices. Second, by taking food and garden residue and using a biodigester to convert this carbon rich resource into methane and fertilizer (reframing waste as a resource), and comparing this to the massive food waste/methane generation issue worldwide. Third, by using the gas from this biodigester to cook food. Fourth, by using what is left after bio digesting to fertilize crops on our "climate farming" regenerative food farm on the school property. We will also utilize food and garden residues (another reframing of waste) for creating compost, and the making of biochar, both of which when added to soil help sequester carbon, making these potent tools in a carbon farming toolkit. We will ferment and capture small amounts of bioethanol and attempt to make bioethanol from non-edible portions of plants (cellulosic bioethanol) to explore first-hand the challenges and opportunities inherent in using food crops and land that could grow food to grow fuel. We will make biodiesel from corn and soy oil –

after hopefully making our own oil by grinding soybeans and corn kernels. In addition, we just purchased several small solar generators and a solar fan kit to demonstrate how we can use sunlight to power some practical on-farm needs, such as irrigation pump, shed ventilation, and creating a phone/computer charging station for our outdoor classroom.

We will review the food supply chain through a series of lessons that trace key commodities along their route from different sorts of farms to different sorts of markets. We will have several lessons on how animal agriculture impacts climate, and what it means when feed conversion ratios are the key tool to measure farm productivity. We will focus these lessons on where fossil fuel energy is used and what alternatives exist or could be imagined to replace GHG emitting practices. We will schedule field trips to local regenerative food producers and sustainable food processors to deepen and reinforce students' understanding of all the intersecting parts within the global food supply chain. Each of these individual parts of this network who have been making contributions to greenhouse gasses emissions are an opportunity to learn how to shift to more sustainable/regenerative paths. Students will prepare for these field trips with advance research and guided notes which will be utilized before, during and after each trip and become a resource as they move towards their final projects.

Our students work in our garden weekly with school staff, with periodic technical assistance from the Pennsylvania Association of Sustainable Agriculture's Climate Smart Farming and Marketing Program, to grow food and to engage in citizen community science to implement and monitor a variety of recommended urban farming practices in our growing spaces. These weekly "in the field projects" will be tracked in garden notebook guided notes and maintained in student binders.

Students who are learning about the ideas and practices of "climate farming" can explore the many ways that food growing, and natural resource management practices, can sequester carbon, contribute to renewable energy, and reduce the energy consumption and GHG emissions. These hands-on experiences will be supplemented by case studies and independent research so students can explore stories and data from the likes of seed producers who sell agronomic seeds can earn extra carbon credit for sequestering carbon in the soil; and farmers partnering with energy producers to co-locate biofuel production to utilize farm waste. This unit will tie into existing lessons from other units on regenerative farming, reducing food waste and composting. Students might choose to demonstrate their learning by doing an audit on an agriculture entity (farm, food processing facility etc.) to identify areas where energy/climate friendly practice related improvements could be made, or by teaching younger students the value of these practices during garden club.

The unit will also explore how to advocate, communicate, agitate, and educate about sustainable energy, sustainable food and farming practices, and other climate change solutions in our community. These lessons on "changemaking" will not explicitly be part of this unit but will be reviewed as applicable.

Some Solution Based Tools to Consider:

- ☐ Step by Step Instructional Guide (Slide Show, Video, Photo Essay)
    - ☐ Food Growing Basics
    - ☐ Community Composting
    - ☐ Making Biodiesel
    - ☐ Anaerobic Biodigestion
    - ☐ Urban Climate Farming/Agroecology Basics (this is a big one, work on this in teams)
- ☐ Slide Presentation, Infographic or Photo Essay or Short Video explaining why & how to:
    - ☐ Compost
    - ☐ Make and use biodiesel or bioethanol
    - ☐ Biodigest food waste
    - ☐ Agroecology Matter
    - ☐ Explain photosynthesis and carbon cycle
    - ☐ Do something else that matters (get approval before you get too far)
    - ☐ Eat as though the Planet matters
- ☐ Well written letter with three facts about topic of your choice, with sources cited to:
    - ☐ Editor of local paper or Grid Magazine
    - ☐ You city council representative
    - ☐ You choose
- ☐ Create a Climate Impact Audit Tool
- ☐ Slide Show or Research Paper showing alternative ways to measure farm productivity using a sustainability lens and how specific agricultural practices contribute to carbon sequestration, and reduced energy use.
- ☐ Design &/or Build a Useful Project Using Alternative Energy/Climate Smart Thinking
    - ☐ Solar irrigation system
    - ☐ Biodigestor for Cooking

Figure 4 Our climate toolkit graphic and project choices for student capstone projects

Along with regular opportunities to demonstrate learning through assessments, projects and lab notes, students will each contribute to the *Agriculture Can Reduce the Climate Crisis Toolkit* by identifying an issue, a solution, and practical advice/details about implementation. These capstone projects will be combined into a shared slide deck, with links to each student's work, organized by category: climate farming solutions; energy reduction solutions; innovations & policy. As a work in progress, this toolkit will be both a resource for current and future students and partners, and a repository for new ideas and emerging strategies.

Endnotes

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A useful guide for teachers and students to understand Ethanol production

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This long, but easy to follow, book explains many complex scientific processes in clear and humorous ways. Many illustrations aid the reader. Each chapter is very well summarized.

Wheeler, Stephen M, and Christina Rosan. *Reimagining Sustainable Cities : Strategies for Designing Greener, Healthier, More Equitable Communities*. Oakland, California: University Of California Press, 2021.

Excellent overview and analysis of multiple practical and proven ways to create sustainable communities.

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Short history of how many of the agricultural “innovations” over time have led to dispossession and environmental degradation.

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Another set of data from a reliable source to demonstrate climate change impacts

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A clear explanation of why our current farming practice which rely on fossil fuels are problematic and should be changed.

Appendix on Implementing District Standards

AFNR CTE Standards:

AFNR 102	Identify major segments of the food production & processing industries.

AFNR 402	IPM - Distinguish between chemical, mechanical, cultural and biological methods of plant pest control.

AFNR 403	Discuss the major principles, advantages and disadvantages of integrated pest management.

AFNR 501	Discuss the environmental impacts of agricultural activities on soil, water and aerial systems.
AFNR 502	Analyze current agricultural environmental challenges.
AFNR 503	Understand how natural resources are used in agriculture.
AFNR 504	Contrast practices for conserving renewable and nonrenewable resources in agricultural systems.
AFNR 505	Understand how new energy sources are developed from agricultural products (e.g.: gas co-generation and ethanol).

AFNR 604	Discuss the reasons for and importance of soil conservation.

AFNR 607	Identify elements of a soil management plan for a natural resource management area.

AFNR 701	Discuss the government's role in regulating air, soil, and water use & management.
AFNR 702	Understand the difference between natural resource management conservation strategies and preservation strategies.
AFNR 703	Identify local, regional and global air and water conservation issues and conservation measures being employed in the region.
AFNR 704	Discuss major pieces of U.S. policy designed to protect and conserve natural resources.
AFNR 705	Identify non-governmental stakeholders (state, national & regional) in natural resource management.

AFNR 706	Analyze the ways in which human needs and environmental considerations interrelate.

AFNR 1001	Discuss the environmental impacts of agricultural activities on soil, water and aerial systems with an environmental justice lens; paying attention to racism and the effects of poverty.
AFNR 1002	Analyze current agricultural environmental challenges including food access, land access, culturally relevant food production, water access/rights, large industry, and obesity.
AFNR 1003	Understand how natural resources are used in agriculture with a focus on environmental justice.
AFNR 1004	Contrast practices for conserving renewable and nonrenewable resources in agricultural systems.
AFNR 1005	Understand how new energy sources are developed from agricultural products (e.g.: gas co-generation and ethanol).

AFNR 1101	Define sustainable agriculture, food justice, food equity, environmental racism, and related terms.
AFNR 1102	Discuss the three "E's" of sustainability (environment, economics & equity) and the importance of each. Understand the relevance in urban vs. rural settings.
AFNR 1103	Compare and contrast conventional and sustainable agricultural practices. Investigate its effects on vulnerable populations.
AFNR 1104	Evaluate the role of soil fertility in an ecological production system.

AFNR 1105	Discuss the principles and strategies of sustainable agriculture focusing on food access and environmental justice.
AFNR 1106	Identify and describe local examples of enterprises using sustainable agricultural practices.
AFNR 1107	Evaluate and implement methods to protect and enhance soil productivity.
AFNR 1108	Describe the principles and practices used to enhance and maintain biological diversity in an agricultural environment.
AFNR 1109	Describe strategies that combine management methods for integrated pest control.
AFNR 1110	Discuss key principles and practices related to sustainable vegetable production.
AFNR 1111	Discuss regulations and implement production of crops for organic certification.

Educator for Sustainability Standards – discussed within content sections

Common Core:

Science

SCI.2.1	Make meaning of data collected

SCI.3.1	Create a model to represent a system
SCI.3.2	Use the model to communicate ideas
SCI.3.3	Evaluate and refine models

Social Studies

SS.2.2	Analyze multiple perspectives
SS 2.3	Evaluate the importance of people's actions in shaping outcomes

SS 3.1	Examine Enduring Problems
SS 3.2	Build Civic Knowledge
SS 3.3	Take Action

SS 4.2	Apply geographic tools
SS 4.3	Analyze relationships between human and environmental systems
SS 4.4	Evaluate the impacts of human activity on environmental systems