Full Recovery Agriculture™ for the Energy Transition

Biofuel, Liquid H2, and Electro-Fuel Processes Included

ABSTRACT

Arid rangeland is an underused resource. Insufficient freshwater availability limits the productivity of this land, which is typically used for low intensity agriculture (animal grazing). The high solar resource makes this land valuable as a renewable energy resource for hybrid (mixed) Photovoltaic (PV) and wind turbines. The high solar resource also makes this land especially valuable for biofuels and electro-fuels (E-Fuels) based on water electrolysis and atmospheric CO2 production, if sufficient fresh water can be made available.

Currently, agriculture produces biofuels such as ethanol (gasoline additive) from corn, sugarcane, and renewable diesel (diesel blend component) from plant oils (soybean oil and palm oil). However, current biofuel production is inefficient, making poor use of the available land and solar resource. Less than 1% of the solar energy is converted into vehicle propulsion energy (sun-to-wheels) with corn-based ethanol versus approximately 20% of the solar energy with state-of-the-art PV modules and Electric Vehicles (EVs) and state-of-the-art bifacial PV solar efficiency exceeds 25% and average EV efficiency is over 77% (US DOE 2023, PV Magazine 2023).

A more efficient agricultural biofuel system is needed with the following characteristics:

- Overall solar energy efficiency equivalent to competing PVs
- Maximum capture of both CO2 and solar energy
- Maximum freshwater efficiency (kg biomass/m3 fresh water)
- Co-production of food, biofuels, and E-fuels
- Elimination of CO2 and other Global Warming Potential (GWP) emissions from food, biofuels, and electro-fuels production

Enviro Water Minerals (EWM) has developed the Full Recovery Agriculture™ system for arid rangeland as an extension to its Full Recovery Desalination® process. The Full Recovery Agriculture™ system produces food, biofuels, and E-fuels. Seawater, brackish groundwater, and highly intermittent stormwater (multi-year drought with flash floods) are fed into EWM's desalination process to provide low cost, high purity water that can meet zero purge, continuous fertigation requirements. The Full Recovery Desalination® process integrates EWM's recently developed Thermal Energy Storage (TES) and Liquid Air Energy Storage (LAES) systems with the Full Recovery Agriculture System™ to allow heat to be optimally managed between the two systems.

A PVC-glass composite fabric (produced from the Full Recovery Desalination® products) made in a shadehouse (SH) covers the agricultural area. This traps moisture, collects stormwater, and allows a Controlled Atmosphere (CA) to be used to optimize crop production. A Subsurface Drip Irrigation (SDI) system provides both fertilizer and irrigation. Both soil and air temperature are

controlled. Air humidity and CO2 content also are controlled. Diffused sunlight and high efficiency, next generation LED lighting optimized for agricultural applications provide the agricultural energy source. An air circulation system is used to provide cooling and ensure optimal CO2 concentration is available for maximum photosynthesis. A CO2 capture system is integrated into the air circulation system and TES system to capture CO2 for the electro-fuels and provide CO2 enriched air in the SH.

Three high efficiency biofuel crops (corn, sugarcane, and alfalfa) are grown in the SH. Sugarcane is fed to an ethanol-based biofuel plant. Corn is fed to an ethanol-based biofuel plant and to dairy and beef cattle. Alfalfa also is fed to the dairy and beef cattle, which convert it to digested biomass, beef, and dairy products. All the byproducts (e.g., distillers grain) from the biofuel plant are fed to the dairy and beef cattle or used to produce high value biochar and biogenic CO2. The dairy and beef cattle urine and manure are collected and routed together with all the non-edible crop residue (including corn stover) to an onsite anaerobic digestor and biosolids torrefaction system (biochar production). Methane, hydrogen sulfide, ammonia, and CO2 are scrubbed from the cattle and dairy barn eliminating the GWP emissions and producing valuable biogas, high purity CO2, and liquid fertilizers. State-of-the-art TES heating and cooling, heat pumps, EV, drone cultivation and harvesting, robotic feeding and manure collection, CA cattle and dairy barn, and CA corn, sugar cane, and alfalfa storage systems are used in the cultivation and harvesting of biofuel production, beef production, dairy production with the anaerobic digestor and torrefaction system.

This allows the combination of the Full Recovery Desalination® and the Full Recovery Agriculture™ system to achieve the biofuels objectives above. Both the Full Recovery Desalination® process and the Full Recovery Agriculture™ system are capital and energy intensive. However, the additional revenue from the full recovery byproducts and the higher yield of food products, biofuels, and E-Fuels more than offset the higher costs, making the Full Recovery Agriculture™ process both efficient and profitable.

The Full Recovery Agriculture™ process allows agriculture to play an ever-increasing role in the energy transition for food production, biofuels, and E-fuels production. EWM's Full Recovery Agriculture™ converts low productivity arid lands into a high productivity resource for the energy transition.

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INTRODUCTION

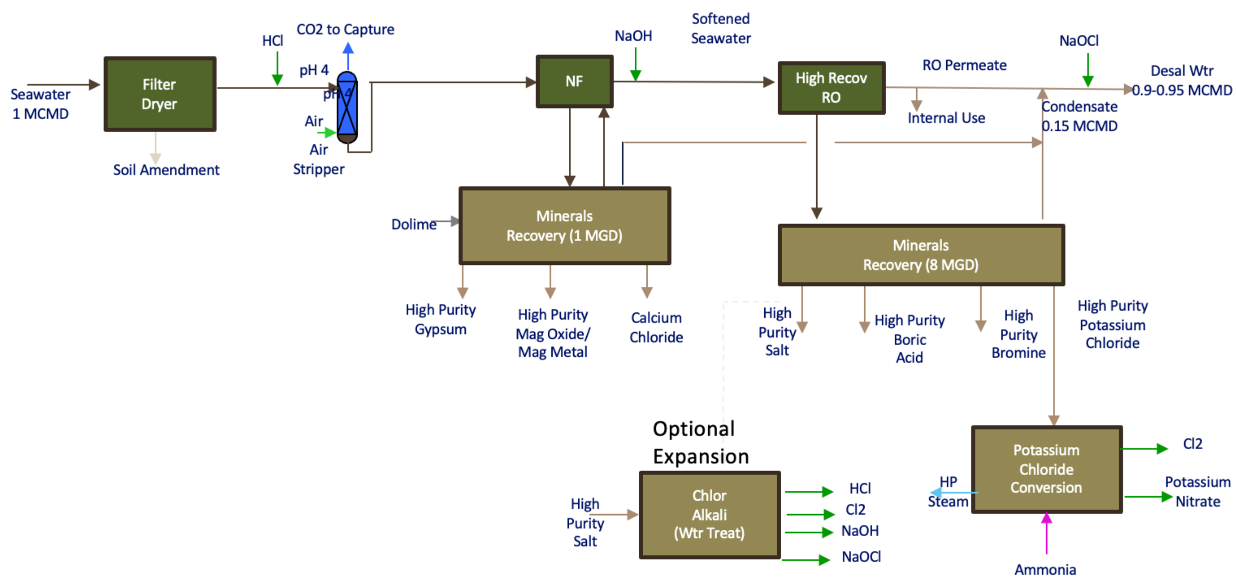
The U.S. is the world leader in biofuels, mainly turning corn into ethanol. This has made corn the most planted crop in the U.S. with 40% of all U.S. corn production being used to make ethanol for gasoline (USDA 2022). Brazil, the largest global producer of sugar cane and the second largest global producer of corn, is significantly increasing its corn to ethanol (biofuel) production because of its high profitability. Sugarcane plantings are being reduced to accommodate the corn growth because of the limited agricultural land. This has caused the shutdown of 30% of the ethanol refineries due to lack of sugarcane (Reuters 2022, 2023, Ethanol Producer 2022). High consumption of fossil fuel-based fertilizer is required for corn and sugarcane. There also is significant economic incentive to shift land use from savannahs and rainforest to fossil fuel intensive sugarcane and corn to ethanol production. Brazil's land use transition to sugarcane and corn for ethanol has negatively impacted net CO2 emissions (Resources, Conservation and Recycling 2022).

In addition to ethanol biofuel production, corn is used as livestock feed. In the U.S., approximately 40% of the corn production is used for livestock feed, 10% is used for seed and food, and 10% is exported (USDA 2022). Soybeans, used to make renewable diesel, compete with corn for U.S. cropland planting. The U.S. renewable diesel production is projected to more than double by 2024 based on projects currently under development, which will further reduce U.S. cropland available for food production (Reuters 2022). Sustainable Aviation Fuel (SAF), produced from both ethanol and vegetable oils, is a potential large growth biofuel market. For biofuels to significantly impact global warming without impacting global food supply, non-crop sources of biomass are required to decrease the land use and fossil fuel impacts that offset the CO2 savings from the biofuels (IEA 2022).

Typically, arid rangeland is used for cattle grazing at a low stocking density. Beef cattle use nearly 60% of the world's agricultural land but account for less than 2% of global calories and 5% of global protein; greenhouse gas emissions are high per kilogram of protein due to methane release (Grazing Facts 2023). In the arid western part of the U.S., overgrazing is the most widespread cause of species endangerment because it irreparably harms the ecosystems they depend on (Center for Biological Diversity 2023).

There is significant arid land with outstanding solar resources available for biofuels and PV production. Due to climate change, desertification is increasing because of higher temperatures and more variable rainfall, which causes more droughts and flooding (IPCC 2019). Overgrazing can occur during drought conditions because cattle herd populations cannot be rapidly increased or decreased to adapt to the more variable drought and flood conditions and overgrazing leads to habitat destruction and additional desertification (Texas Parks and Wildlife Department 2023). Optimizing water and land management for these arid areas provides a significant opportunity for food production, biofuels production, E-fuels production, PV power, wind power, and reducing desertification (IPCC 2019).

EWM has been developing its Full Recovery Desalination® process technology for over 10 years. EWM's expertise is in integrating state-of-the-art electrochemical, membranes, ion exchange, evaporation, crystallization, and precipitation systems with renewable energy. The Full Recovery Desalination® process uses existing process equipment to separate the feed salty (high dissolved solids) water into high value commodity grade minerals. The water is essentially a byproduct of profitably recovering all the minerals.



EWM Full Recovery Desalination® for Seawater. EWM integrates commercially proven technologies from multiple industries – no "unproven technologies" and no waste streams.

Figure 1 -- EWM Full Recovery Desalination® Process Block Flow Diagram

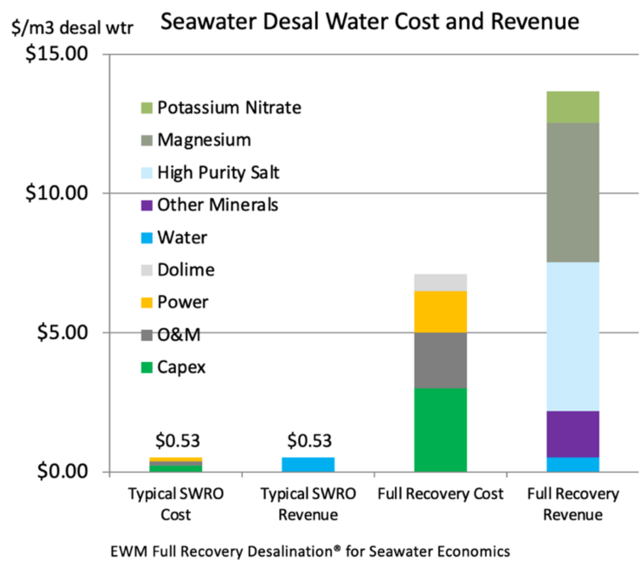


Figure 2 -- EWM Full Recovery Desalination® Sample Seawater Economics

The economics shown in Figure 2 include magnesium metal production but do not include high purity chemical grade salt production Hence, the potentially significant added value for renewable energy powered salt to chlor-alkali, green PVC, and glass production is not included. The Full Recovery Desalination® economics shown are favorable because the revenue from recovering the minerals offsets the additional capital as well as the operating and energy costs. EWM also has developed optimized Thermal Energy Storage (TES) and Liquid Air Energy Storage (LAES) systems to supply low-cost baseload heat and power to the Full Recovery Desalination® process from intermittent renewable energy.

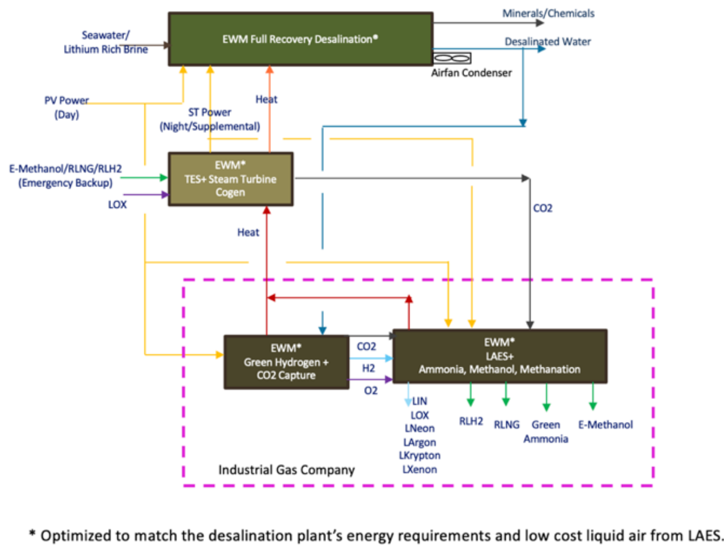


Figure 3 -- EWM's Optimized TES and LAES System for EWM Full Recovery Desalination®

A low-cost, optimized energy storage system is an important design feature of EWM's Full Recovery Desalination® process. This design feature allows for cost effective low-cost intermittent PV and wind power. Full recovery is an energy and capital intense process and, therefore, EWM has developed a customized high reliability, high efficiency system to be able to use 100% renewable energy. Using 100% renewable energy in capital intensive industrial processes such as EWM's process is challenging because the processes must operate the baseload (24/7/365) for full capital utilization.

The same state-of-the-art brine processes and energy systems can be used to provide water, heat, and cooling in agriculture and biofuel applications. EWM has recently modified the process flow scheme for its Full Recovery Desalination® process to support agriculture and biofuel production as follows:

- Economical use of desalinated seawater and brackish groundwater for agriculture
- Capture and storage of intermittent stormwater (seasonal and yearly)
- Utilization of byproduct SH heat for desalination (summer cooling)
- Utilization of byproduct desal heat for SH CO2 capture
- Utilization of byproduct desal heat for SH (emergency winter heating)
- 100% intermittent renewable energy supply (no fossil fuels)

In addition, EWM has developed the Full Recovery Agriculture™ system as an add-on to the desalination process. The Full Recovery Agriculture™ system is designed to integrate with the modified Full Recovery Desalination® to monetize the low-cost water and byproduct heat in arid regions.

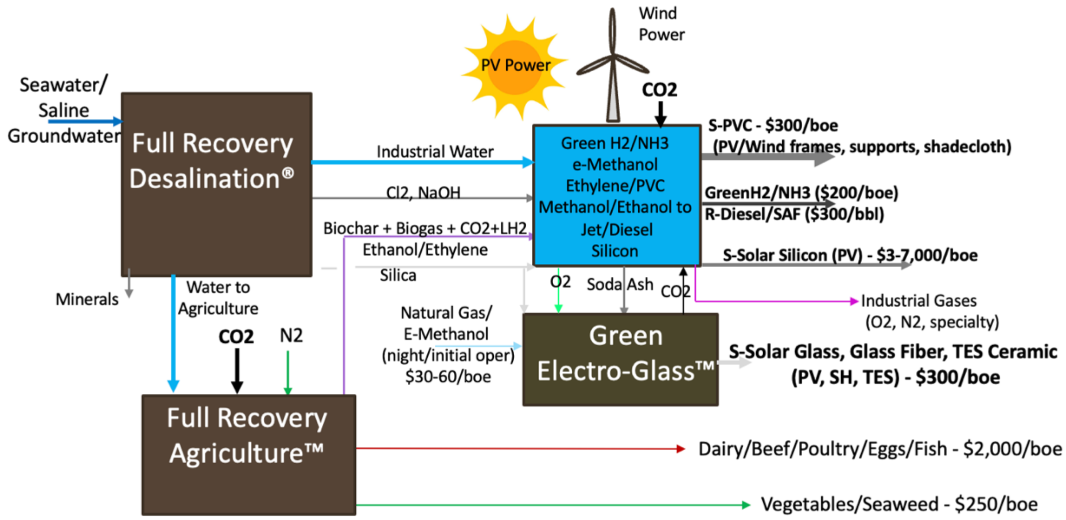


Figure 4 -- Integration of Full Recovery Desalination® with Full Recovery Agriculture™

The combined system is designed to provide food, biofuel, E-fuels, and intermediates to an offsite or adjacent green energy transition materials plant (PV module production). These are discussed further in the Non-Metals section of EWM's "Green Mining for the Energy Transition" paper.

EWM Food and Biofuels Ranch™

The EWM Food and Biofuels Ranch™ is a food and biofuel system that is designed to provide food and biofuels in arid regions of the world by using various underutilized water resources. The ideal regions and water resources include the following:

- US/Mexico southwest region (Gulf of California, brackish groundwater, and stormwater)
- Atacama desert region of Chile, Bolivia, and Argentina (Pacific ocean)
- Kalahari desert region of Namibia and South Africa (Atlantic ocean)
- Arabian Peninsula and Egypt (Red Sea, Arabian Gulf)
- North Africa (Mediterranean Sea)
- Australia (Indian Ocean and Southern Ocean)
- Northwestern India and Pakistan (Indian Ocean)

The ranch consists of six areas:

1) Managed wildlife rangeland
2) PV and wind farm with stormwater collection
3) Shadehouse crop production system
4) Cattle and dairy barn
5) Beef and dairy processing
6) Biofuels plant

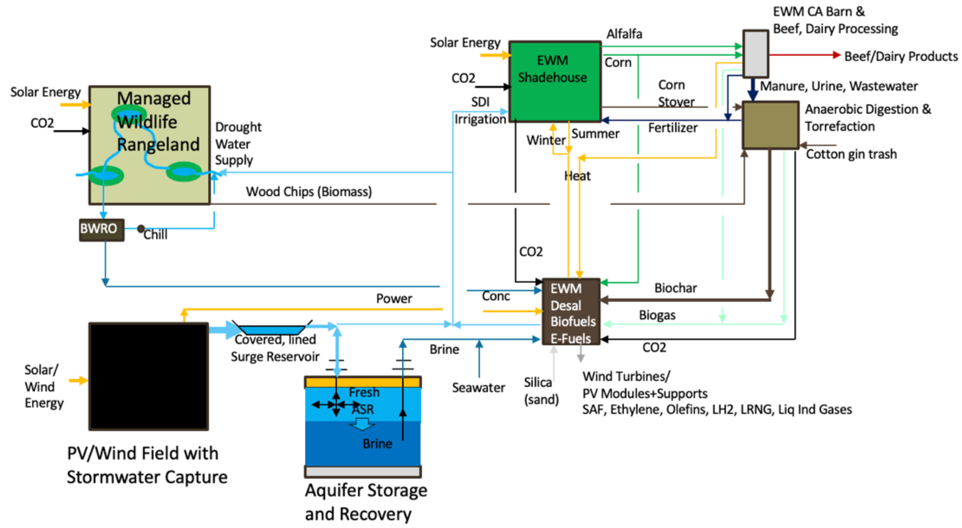


Figure 5 -- EWM Food and Biofuels Ranch™

EWM expects that an initial phase and a final world-scale (multiple phases) ranch would consist of the following land use breakdown:

	Initial Phase	World Scale (multi-phase)
Managed wildlife rangeland	2,000 acres	10,000 acres
PV/wind farm with stormwater collection	4,000 acres (700 MW)	20,000 acres (3.5 GW)
Shadehouse Crop Production System	3,000 acres	15,000 acres
Cattle and dairy barn	100 acres	500 acres
Cattle and dairy processing	40 acres	100 acres
Biofuels plant	40 acres	100 acres
Total world scale ranch	9,180 acres (3,700 ha)	45,700 acres (18,500 ha)

The area would need to be regional but not necessarily contiguous because PV/wind power transmission is economically viable for distances less than 10 miles (16 km). All the food, biofuel, and E-fuel products can be cost effectively shipped by rail or road (high value food products only). No or limited external grid power transmission capacity is required because the PV and wind power is converted onsite to higher value food, biofuels, and E-fuels. A smaller scale ranch is also economically viable; however, the significant infrastructure costs (rail terminal, cattle and dairy processing, biofuels plant) cause reduced profitability at a smaller scale.

Managed Wildlife Rangeland

At its core, the EWM Food and Biofuels Ranch™ is a high efficiency arid land use system. The system repurposes existing low efficiency cattle grazing land to ultrahigh efficiency food, biofuel, and E-fuel production. The EWM Food and Biofuels Ranch™ also improves the environmental footprint. The ultrahigh efficiency food, biofuel, and E-fuel production allows a significant fraction of the total ranch area (20-30%) to be repurposed from grazing to a managed wildlife rangeland.

Managed Water System

A portion of the low-cost desalinated water provided by the Full Recovery Desalination® process is used to ensure that an optimized wetland microsystem is available throughout the managed wildlife rangeland area. During times of long-term drought, water from the managed wildlife rangeland area is recirculated back to the Full Recovery Desalination® to ensure that dissolved salt or organic toxin buildup does not occur. In hot summer months, the TES chilling system is used to cool the water, minimizing evaporation losses, and preventing toxic algae formation. Makeup water from the desalination system is added to maintain minimum flows and levels in the creeks, ponds, and lakes contained in the managed wildlife rangeland area. Uncontaminated freshwater available to wildlife in arid regions during drought conditions creates an oasis, preserving essential wildlife habitat.

Managed Invasive Vegetation

Invasive vegetation (e.g., salt cedar) and overgrown areas need to be managed within the managed wildlife rangeland area. This maximizes wildlife habitat and avoids buildup of dry biomass fuel, which can cause wildfires. The excess and invasive vegetation is removed mechanically and monetized as biomass. This biomass is valuable because it can be co-processed in the anaerobic digestion and torrefaction systems with fresh manure to generate high value biochar with smaller amounts of biogas and biogenic CO_2. Biochar is becoming an important, high value energy transition resource because it is used to replace coal in the production of solar grade silicon.

Controlled burns to clear vegetations are avoided because they waste the biomass resource and produce CO_2 and other toxic emissions. Wildfires should rarely occur in the managed wildlife rangeland area due to the mechanical brush clearing and presence of water during long term drought. Soil carbon sequestration should be significant in the managed wildlife rangeland area because of the reduced wildfire risk and the continuous presence of water during drought conditions. A key management goal for the managed wildlife rangeland area is to maintain a carbon rich soil, which maximizes wildlife habitat and sequestering carbon.

Managed Endangered and Invasive Species

No cattle will be allowed to graze within the managed wildlife rangeland area. Invasive species will be removed and endangered species will be reintroduced. Hunting of game animals during the appropriate seasons can be used to control the game animal populations to healthy numbers and to provide revenue for maintenance of the managed wildlife rangeland area. The continuous presence of water during drought is a key factor in maintaining species diversity in the managed wildlife rangeland area and the surrounding region.

Protection of Birds

Bird populations suffer from pesticide use, which reduces insects available to birdlife. Pesticide use (including overspray) along with habitat destruction has caused a decline in the Texas rangeland bird population and has had a much more significant impact on bird populations than wind turbines, especially if bird collision countermeasures (blade markings and collision avoidance cameras) are used (Audubon Texas 2022, Univ of East Anglia 2022, Wind 2021, Sierra Club 2023). Healthy populations of insects and birdlife will be maintained in a balanced ecosystem in the managed wildlife rangeland. No wind turbines will be located in the managed wildlife rangeland to minimize interaction of birds with the wind turbines. Wind turbines will be interspersed within the PV field where there is no water, bird habitat, insects, or other food sources to attract birds.

The SH will provide a barrier to rapid insect infestation of the crops. This prevents insects in the managed wildlife rangeland from significantly reducing crop yield. Natural predator insects are used in the SH to manage insects yield loss, avoiding pesticide use and release to the managed wildlife rangeland.

Treatment chemical (nutrients, disease control) use in the SH is minimized due to the high biosecurity provided by the SH. No treatment chemicals will be released from the SH because the ventilation system is turned off during spraying. Drones using targeted downdraft, controlled droplet size spray nozzles essentially eliminate drift from drone spraying in the wind-free SH conditions (Ohio State Univ 2023).

PV Solar Farm with Stormwater Collection

A significant source of revenue required for a favorable EWM Food and Biofuels Ranch™ is the PV solar and wind farm. EWM's design maximizes efficient solar energy collection mechanisms, therefore, its footprint should be maximized in these arid regions. In typical open field corn to ethanol biofuel systems, less than 1% of the solar energy is converted to fuel; typical PV panel has a 25% solar energy efficiency, and the corresponding EV has 5 times the efficiency of a standard internal combustion engine without a hybrid battery and regenerative braking; and, therefore, the PV – EV combination has over a hundred times higher solar efficiency than open field corn-based ethanol used in a conventional internal combustion engine (PV magazine 2022).

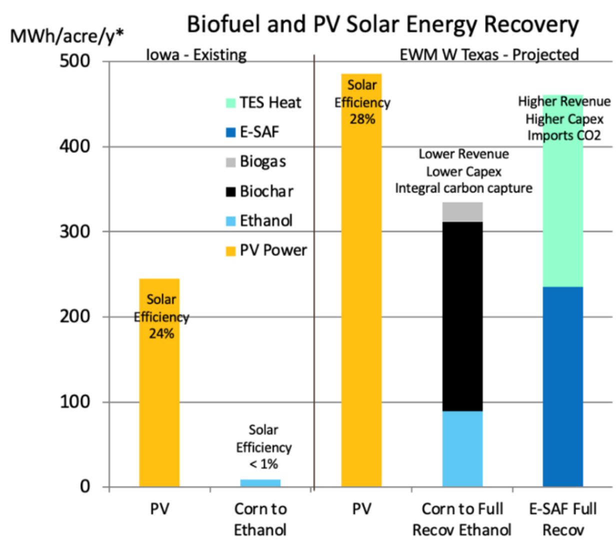


Figure 6 -- PV and Biofuel Efficiency

Corn based ethanol is produced in two steps. First by enzymatically converting the corn starch to glucose and then fermenting the glucose to ethanol. The starch to ethanol conversion efficiency is typically 88% (Journal of Agricultural Food Chemicals 2013). During this process at 100% conversion efficiency, 40% of the carbon in the corn starch is lost to CO2. During typical starch to ethanol conversion, only 50% of the carbon in the starch is converted to ethanol. In EWM's Corn to Ethanol process, all the carbon in the corn, including the stover, is recovered and solid as valuable biofuel or captured biogenic CO2.

As explained below in EWM's Shadehouse Crop Production System, the solar energy efficiency and revenue generation from corn can be significantly improved so that agricultural corn production is more competitive with PV solar fields. In the design of the EWM Food and Biofuels Ranch,™ the PV field and the Shadehouse Crop Production System complement each other. As explained below, the PV field collects stormwater because it does not need water. The crop production system captures carbon, which when combined with green H2 produced from PV power, produces valuable SAF and PVC for PV module frames and supports. Biochar also is produced from captured carbon, which is needed for green solar silicon for PV modules.

PV efficiencies continue to improve. Further cost reduction, however, is dependent on low-cost, abundant green raw materials (glass, silicon, and composite PVC-glass frames and supports). EWM's target product slate for the biofuels includes these raw materials to ensure low-cost, local, or regional production of PV modules.

The largest portion of the ranch area in EWM's system is to be used by the PV solar farm (40-50%). In addition to maximizing solar energy capture efficiency, the PV solar farm is used to collect stormwater. This avoids flooding the PV field during large storm events and provides low-cost fresh water for the drought periods.

The PV solar farm in the EWM system will use a combined ground albedo sunlight diffuser and water collection system. This system is well suited to inland locations where there is access to a brackish groundwater aquifer. West Texas and the southwest U.S. have many locations that have this type of geology. Other locations may need to use larger lined and covered reservoirs for storage of the stormwater.

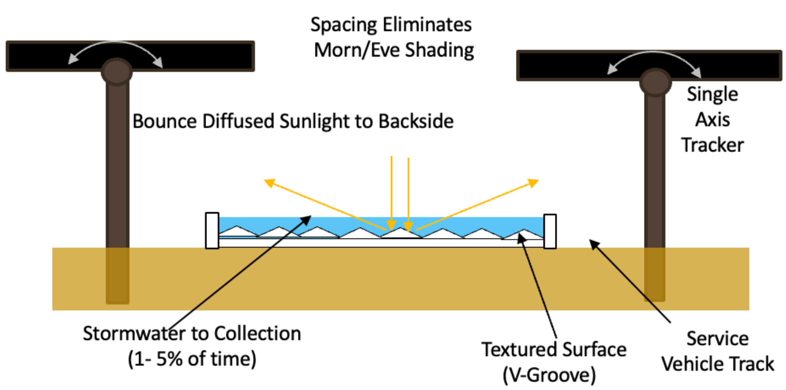


Figure 7 -- PVC Bifacial Reflector External V-Groove with Stormwater Collection

The Full Recovery Desalination® plant to be used in the system continuously extracts brackish water from the aquifer producing minerals for sale and desalinated water for use at the ranch. During storm events, the vacant pore space is refilled with stormwater, thereby converting the brackish water aquifer to a freshwater aquifer without creating the overpressure condition frequently encountered with produced water disposal wells. Based on San Antonio Water Services' Aquifer Storage and Recovery (ASR) system, the native groundwater does not mix with the injected fresh water. The freshwater injection wells also are above the brackish water source wells, which allows the halocline (density difference) to maintain fresh and brackish water separation.

White V-groove PVC water collection trays are to be placed between the single axis tracking PV rows. During stormwater events, the water will run off the PV panel surface and be collected in the tray system. The collected stormwater drains into a lined covered reservoir, which fills during the storm event. The covered reservoir is then pumped into an aquifer storage and recovery system (optional). This water supplements the desalinated brackish groundwater or desalinated seawater.

The white V-groove water collection trays that are to be used also maximize the efficiency of the PV modules. Bifacial (dual pane glass) PVs are the state-of-the-art PV modules. The white V-groove water collection trays act as a light diffuser, redirecting the sunlight that is not collected by the top of the PV module to the back side. To maximize PV efficiency, single axis tracking systems are used with large spacing between rows to eliminate one PV row being able to shade the adjacent row during dawn and dusk conditions. Typically, only 50% of the sunlight is captured by the front side of the PV panel when the sun is overhead (mid-day). The diffusers maximize the collection of the remaining sunlight by directing it to the back side of the PV. The white V-groove diffusers provide significantly more sunlight to the back side of the PV module than the typical brown desert sand. Up to 3 times more reflected light is supplied to the back side of the PV modules because of the V groove surface pattern and the white color (Energies 2018). Maximizing PV sunlight collection and power output per acre or hectare is an important part of the EWM Food and Biofuels Ranch design because it maximizes energy production and minimizes footprint.

Shadehouse Crop Production System

An advanced shadehouse system is used in the EWM system for high efficiency crop production. Because of its significantly higher yield of cattle feed than typical arid rangeland, a smaller portion of the ranch is used (20-30%). The storm water from the larger PV Solar Farm, together with supplemental seawater and brackish groundwater, provides the water required for the shadehouse crop production system. Composite PVC-glass fiber cloth is used to provide diffused omnidirectional sunlight and to provide a barrier between the ambient air and the shadehouse controlled atmosphere. PVC-glass composite micropiles and beams are used to support the PVC-glass fiber cloth. The system is designed with a high strength wind fence and has a gabled structure to channel hail and stormwater to an underground stormwater collection system. This prevents hail and flood damage to the crops and collects the stormwater for storage and use during drought conditions.

Crops and Projected Yields

For biofuels to be competitive with PV energy, yields must significantly increase. Producing PV energy, biofuels, and food for the energy transition without rainforest, grassland, and sensitive desert habitat destruction requires higher crop yields. As discussed above, current open field biofuel solar efficiency is very low, indicating that there is significant solar resource that the crops are not recovering nor using to capture CO2 and convert it to biomass.

Greenhouse tomato yield has been highly optimized because it is one of the most common greenhouse crops. Fully optimized greenhouse tomato yields are 16 times higher than open field tomatoes for arid high solar resource regions (Univ. of Arizona 2016). Although this increase may be achievable for corn and alfalfa, EWM has more conservatively estimated the yield improvements that are to come from using many of the same techniques used to increase the greenhouse tomato yield.

It is becoming economically viable to re-convert excess PV power to targeted colors of light at night with high efficiency LEDs, and essentially use the crops as a low incremental cost long term chemical battery. This requires high efficiency LEDs, which are discussed in the Lighting section below.

Under feedlot conditions, beef cattle gain 1.5 kg per day and consume 6 kg of high-quality feed per kg of gain (Successful Farming 2017, Canadian Gov't 2023). Thus approximately 3.3 tonne/y of feed are required per cow.

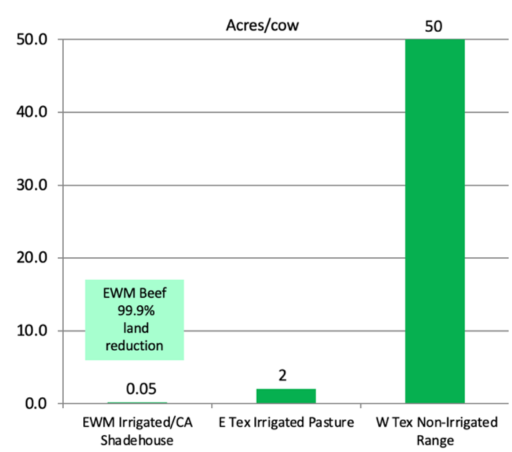


Figure 8 -- Cow Acreage Requirement

With EWM's optimized Shadehouse Crop Production System, the amount of combined corn and alfalfa feed needed can be produced in less than 0.1 acres. In East Texas with plentiful rainfall and irrigation, 2 acres of managed pasture support 1 cow. Typically, 50 acres per cow of West Texas non-irrigated rangeland is required to reliably support 1 cow because of the arid conditions and periodic droughts (Texas Landowners Association 2020). Therefore, with EWM's optimized Shadehouse Crop Production system, 0.2% of the current ranch land is required to support the current cattle population. Even with the reduced land allocation to crops, the EWM system supports more than 100 times the existing cattle population.

Alfalfa

High quality alfalfa is an important component of beef and dairy cattle feed. It provides protein and fiber for good cattle nutrition. Alfalfa promotes cattle growth and produces significant digested cellulose in the manure, which is an important feedstock for anaerobic digestion. The biological activity in the digested cellulose helps convert the supplemental woody and cellulose waste (corn stover, cotton gin waste, salt cedar, and other invasive and excessive biomass harvested from the Managed Wildlife Rangeland) into high value biogas, biogenic CO_2, liquid fertilizer, and biosolids (biochar feedstock) in the anaerobic digestor.

Irrigated East Texas pasture typically yields the equivalent of 1.4 tonne/acre/y of supreme quality alfalfa and the best open field Alfalfa yield is 14.4 tonne/acre/y in the Imperial Valley of California (UC Davis 2018).

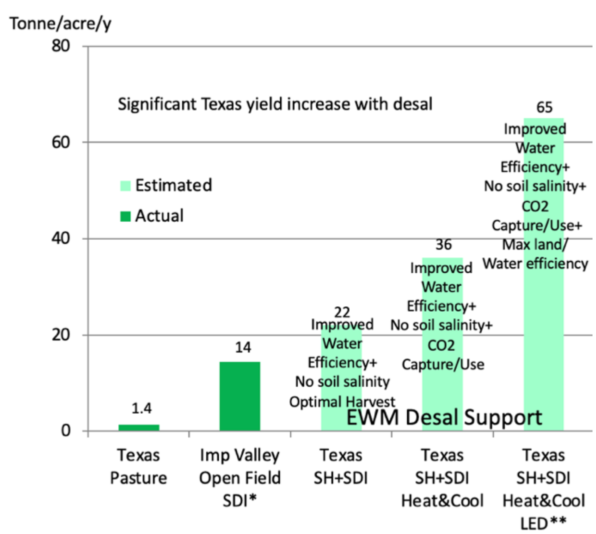
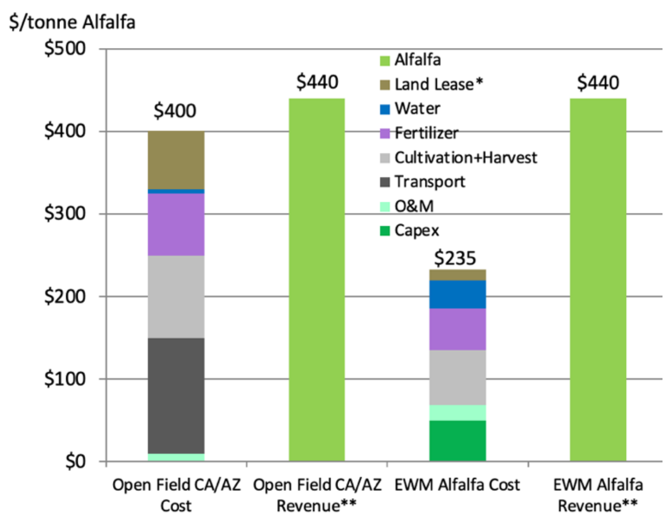


Figure 9 -- Alfalfa Yields

With EWM's SH (omnidirectional light with less summer heat stress) and optimized irrigation water chemistry, EWM projects that the yield will increase 20%. EWM's high efficiency harvesting and CA storage essentially eliminates harvesting and drying losses. The nutritional and mechanical losses from typical open field multi-pass mowing, raking, drying, and gathering are 30% (Hay and Forage 2017; Univ of Mass 2022; Penn State Univ 2022). Therefore, the SH, high efficiency harvesting, and CA storage increases the equivalent dry alfalfa hay yield to 22 tonne/acre/y.

With the addition of the integral CO2 capture and recycle system (increases SH CO2 from 350 ppm - ambient to 1000 ppm) and the heating and cooling system, the yield further increases to 36 tonne/acre/y. The elevated CO2 typically increases yield 50% (Bayer 2019) and the optimized temperature and humidity are estimated to provide another 10% increase.

If the optional high efficiency LEDs are used for 10 h/d, then the maximum potential yield is 65 tonne/acre/y because of the increased photosynthesis time with optimized color LED light. The incremental economics of adding LED lights to the SH are further discussed below in the Lighting section.



*Includes freshwater rights for CA/AZ
** Revenue based on delivered cost to Texas feedlots
(EWM Non-LED case)

Figure 10 -- Alfalfa Sample Economics

The economics of EWM's high efficiency, high yield SH alfalfa production is estimated to be very favorable compared with California and Arizona open field alfalfa production. The ultrahigh yields from the SH, CO2, SDI, temperature, and humidity control more than offsets the increased capital recovery and operating and maintenance cost. The ultrahigh yield, automated EV harvesting, and onsite feeding systems eliminate transportation cost and reduce cultivation and harvest cost per tonne. The high efficiency SDI system also reduces fertilizer cost per tonne of alfalfa because no fertilizer is lost to the environment. Onsite potassium nitrate (main crop nutrient) production along with recycle? from anaerobic digestion reduce the per tonne cost of fertilizer.

The EWM case also has several currently under-monetized benefits, including:

1) Reduced water consumption and no wastewater. The SH shading and cooling system and the high yield minimize freshwater consumption per tonne of alfalfa. The existing California and Arizona open field alfalfa production use underpriced (essentially free) Colorado River water. If the open field California and Arizona alfalfa farms paid market price for the water for their alfalfa, production costs would be over $200/tonne higher. The Colorado River water has an elevated content of dissolved salt, which requires a significant salty wastewater purge stream to maintain soil health. This creates an environmental issue from the mixed waste salt and lost crop nutrients, which are turned into toxic dust when the wastewater evaporates in the Salton Sea (UC Riverside 2022).

2) Reduced land use. Arid land is currently undervalued because its price does not reflect its value in producing green solar and wind power and biofuels. EWM's estimated ultrahigh yields free up over 99% of the existing rangeland because of much higher solar energy efficiency. This makes room for the large PV farm and managed wildlife area. The reduced water consumption, high efficiency stormwater collection and storage system, and low-cost desalinated water from Full Recovery Desalination® allow high purity water to be supplied to the managed wildlife area, maximizing its value as a drought proof wildlife habitat oasis.

3) Reduced GWP emission agriculture. The cost for agriculture GWP emissions is currently underpriced. Regulation and tax incentives or penalties reflecting the total GWP cost are not yet in place. EWM's Full Recovery Agriculture™ system does not produce CO2 or GWP emissions from cultivation, harvest, fertilizers (i.e., N2O), and crop transportation (explained below). The irrigated managed wildlife area (with profitable selective biomass harvesting and no routine controlled burns) will more than offset the land use impacts of the PV/wind field and SH. The ultrahigh yield SH includes an integral CO2 Direct Air Capture (DAC) system, which also offsets its land use impacts.

Corn

High quality corn is the other main component of beef and dairy cattle feed. It provides the calories (energy) needed for the cow's biological functions. Corn also increases the fat content (energy content) in meat and dairy products. Higher energy and fat content in the beef and dairy products increases their value and price by providing more biologically available energy to the global population.

Most of the U.S. corn production occurs in the Midwest cornbelt where there is plentiful rainfall (Iowa and Illinois are the leading U.S. corn producers) (USDA 2022). Corn is a warm season crop and has optimal germination and growth at a soil temperature of 86° F; it does not germinate at soil temperatures below 50° F; and growth is much slower when the soil temperature is below the optimum and is also reduced when the soil temperature is above the optimum (Purdue Univ 2020).

The soil temperature requirement causes most of the solar resource in the Midwest cornbelt to be unused. The active high biomass production phase only occurs from June to September. Planting in Iowa typically occurs in early May and harvesting occurs in late October (USDA 2010). The first month of growth is slow due to low soil temperature with minimal solar energy collection with the small plant size. During the last month, the corn uses the solar energy to reduce the corn moisture content (drying) with limited new biomass production. Cool fall conditions extend the field drying interval. (Purdue Univ 2018).

Corn used for biofuels and cattle feed is typically dried in the field to approximately 15 wt% moisture before harvesting to minimize transportation cost to remote feedlots (i.e., Iowa corn to Texas feedlots) and biofuel refineries. The reduced moisture also allows long term storage with minimal spoilage. The dried corn is then rewetted (steamed and flaked) prior to cattle feeding or slurried prior to biofuel ethanol production. The corn field drying and rewetting process make inefficient use of the solar resource but is necessary with the current production and consumption locations and with the high rail transportation costs for shipping water.

Brazil has recently overtaken the U.S. as the world's leading corn exporter (Univ of Illinois 2023). A key advantage for Brazilian corn is two crops per season. Brazil's tropical climate provides higher soil temperature year-round, which provides a sufficiently long growing season for two crops (Univ of Illinois 2023). Its lower latitude provides sufficient sunlight in the winter months to accommodate two crops. However, land use issues are occurring in Brazil because new corn acreage is replacing native savannahs and rainforests, which compete for the same rainfall and sunlight resource (Reuters 2023).

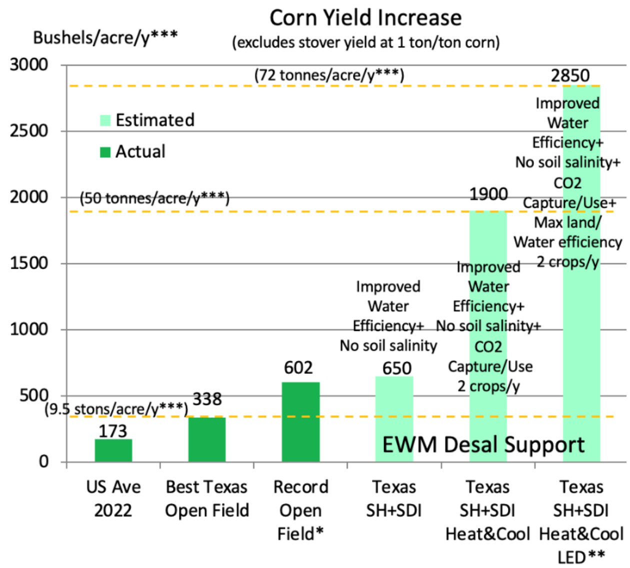


Figure 11 -- Corn Yields

With EWM's SH (omnidirectional light and less summer heat stress) and optimized irrigation water chemistry, EWM projects that the yield will increase 10% over the current record open field yield to 650 bushels/acre/year. EWM's high efficiency system will produce High Moisture Corn (HMC) with 30 wt% moisture, increasing the nutritional value (North Dakota State Univ 2018). Producing HMC essentially eliminates drying and rewetting energy losses.

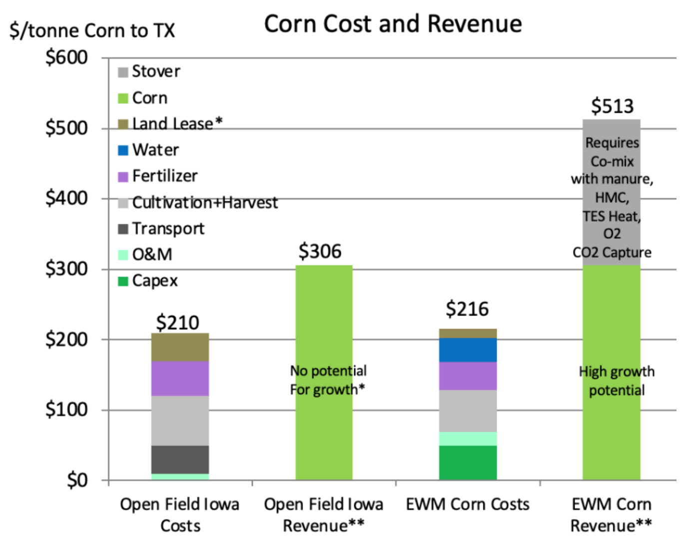
Yield is significantly increased with the addition of the integral CO2 capture and recycle system (increases SH CO2 from 350 ppm -ambient to 1000 ppm) and heating and cooling system. The elevated CO2 typically increases yield 50% (Bayer 2019) and the optimized soil and air temperature and humidity provide another 10% increase, as well as allowing two corn crops per year. This increases corn yield to approximately 1900 bushels/acre/year (50 tonnes/acre/y).

If the optional high efficiency LEDs are used for 10 h/d then the maximum potential yield is 2850 bushels/acre/year (72 tonne/acre/y) due to the increased photosynthesis time with optimized color LED light. The incremental economics of adding LED lights to the SH are further discussed below in the Lighting section.

The corn crop and alfalfa crops are to be intercropped so that the alfalfa can be grown year-round. Even with two corn crops per year, corn is not grown in the winter. The rapid germination, early growth, and minimal drying allow a 2 month reduction in time required from corn planting to harvest. The northern hemisphere corn crop seasons are as follows:

- First crop late Feb to late June
- Second crop late June to late October

No corn will be grown from November to late February so that the reduced winter solar resource is used exclusively by the alfalfa. This allows a levelized year-round continuous harvest of alfalfa, minimizing alfalfa CA storage requirements. The corn is to be used as a biological "peaker" providing additional solar energy recovery during the increased summer solar energy period. The double corn crops also reduce corn CA storage requirements compared to the typical single annual crop, which must be stored for twice as long (12 month storage versus 6 months).



*Based on farmland with sufficient rainfall to support 1 crop/year, no additional land with sufficient rainfall
** Revenue based on delivered cost to Texas feedlots

Figure 12 -- Sample Corn Economics

Ultrahigh yields from the SH, CO_2, SDI, temperature, and humidity control will offset the increased capital recovery and operating and maintenance cost. The ultrahigh yield, automated EV harvesting, and onsite feeding systems eliminate transportation cost and reduce cultivation and harvest cost per tonne. The high efficiency SDI system also reduces fertilizer cost per tonne of alfalfa because no fertilizer is lost to the environment. Onsite potassium nitrate (main crop nutrient) production along with recycle from anaerobic digestion will reduce the per tonne cost of fertilizer.

The revenue is significantly enhanced because the stover can be cost effectively harvested as valuable biomass feedstock for the onsite anaerobic digestor. The undried stover can be co-digested with the biologically active cow manure. Typically, 1 dry tonne of stover is produced per tonne of dried corn. The stover represents a valuable biomass resource, which currently remains in the corn fields as nutrient containing mulch (Purdue Univ 2015).

Corn typically produces 3 times more residual non-crop biomass than soybeans. Up to 70% of the non-crop corn biomass can be harvested as biomass without impacting soil quality (organic carbon content) but harvesting non-crop soybean biomass is not recommended because of the much smaller yield of non-crop biomass (Univ of Nebraska 2018). The availability of the non-crop biomass gives corn a significant revenue advantage over soybeans for biofuels production.

Midwest corn production is remote from cattle feedlots and, therefore, the stover cannot be cost effectively shipped to the feedlots to be mixed with fresh manure. Additionally, biologically active fresh manure is not captured in the feedlots, which limits the efficiency of anaerobic co-digestion with cellulosic corn stover biomass. Shipping the anaerobic digestor fertilizer rich liquid back to the corn would not be cost effective because of the high-water content. EWM's process that includes wet corn harvesting, integrated cattle feeding, and anaerobic digestion all at one site is the critical factor for the stover biomass monetization to be possible.

The EWM process has several currently under-monetized benefits, including:

1) Optimized water consumption and no wastewater. The Midwest cornbelt farms use uncontrolled rainwater for irrigation. Although this is a low-cost water source, stormwater flooding can occur, which washes fertilizer into the Mississippi river and creates a hypoxic zone at the mouth of the river in the Gulf of Mexico; there are several other rivers globally that have similar storm caused fertilizer runoff and downstream hypoxic zones (Michigan State Univ 2021, Heinrich-Boell Foundation 2017). EWM's SH system captures and stores stormwater for use during droughts. No nutrients are lost to the environment and SDI fertilization is managed so that no nitrogen is lost to N2O.

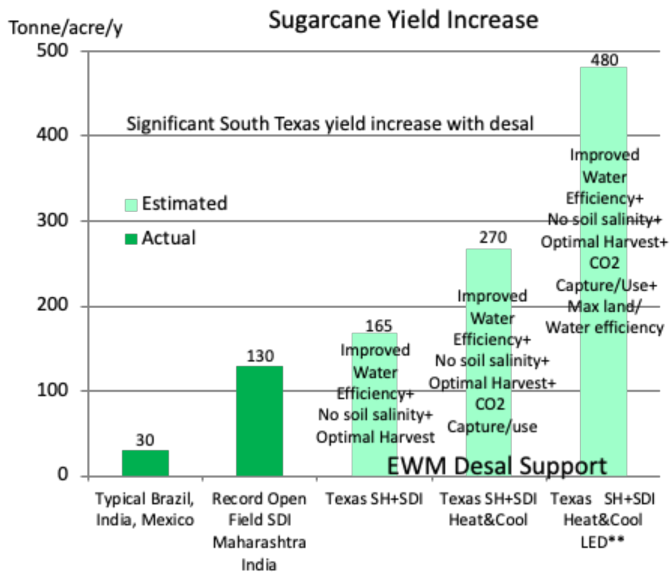
2) Reduced land use. Cornbelt farmland with sufficient rainfall to support agriculture is currently fully utilized and no expansion for additional biofuel production is possible. Arid land is plentiful and currently undervalued, because its price does not reflect its value in producing green solar and wind power and biofuels. EWM's process that can create ultrahigh yields frees up over 99% of the existing rangeland due to the much higher solar energy efficiency. This makes room for the large PV farm and managed wildlife area. The reduced water consumption, high efficiency collection and storage system, and low-cost desalinated water

from Full Recovery Desalination® allow high purity water for the managed wildlife area, maximizing its value as a drought resistant wildlife habitat oasis.

3) Reduced GWP emission agriculture. The cost for agriculture GWP emissions is currently underpriced because regulation and tax incentives or penalties reflecting the total GWP cost are not yet in place. The midwestern cornbelt stormwater flooding washes nitrogen rich fertilizers out of the soil into rivers and streams where microbes convert the nitrogen to N_2O, a potent GWP gas (NSF 2021). EWM's Full Recovery Agriculture™ system does not produce CO_2 or GWP emissions from cultivation, harvest, fertilizers, and crop transportation (explained below). The irrigated managed wildlife area with profitable selective biomass harvesting and no routine-controlled burns, will more than offset the land use impacts of the PV field and the SH. The ultrahigh yield SH includes an integral CO_2 DAC system, which will more than offset its land use impacts.

Sugarcane

Brazil and India are the global leaders in sugarcane production, and, between them, they produce 50% of the global sugarcane. Sugarcane is a fast growing, high biomass perennial crop that can grow year round in tropical climates. Sugarcane's optimal daytime temperature is 86-93^0 F (30-34^0 C), which can be maintained year round in parts of Brazil and India (Soil Science Society of America Journal 2009).. Brazil and India have lower latitudes that provide sufficient sunlight in the winter months to accommodate year round growth. However, land use issues are occurring in Brazil because new corn acreage is replacing sugarcane, putting pressure on native savannahs and rainforests, which compete for the same rainfall and sunlight resource (Reuters 2023). India does not have agricultural land available with sufficient rainfall or irrigation to expand sugarcane production and must look to increased yields on existing agricultural land (Wageningen University 2022).



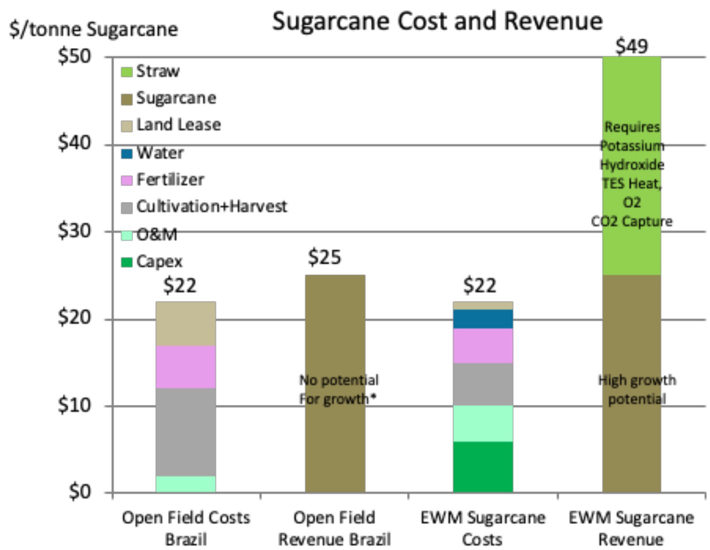
* Optimal weather conditions 9months/y (3 month/y high temperature) with elevated TDS irrigation water (river water)
** Requires high efficiency low cost LED or high cost sugarcane

Figure 13 – Sugarcane Yields

With EWM's SH (omnidirectional light and less summer heat stress) and with optimized irrigation water chemistry, EWM projects that the yield will increase 10% over the current record open field yield. EWM's CA harvesting and storage (discussed below) essentially eliminates sugar losses to microbes during harvesting and storage, providing an additional 15% equivalent yield increase. Typical sugarcane sugar loss from harvesting and storage are 20-30% (Saudi Journal of Biological Sciences 2019). The combined impact increases the yield 25% over the current open field yield to 165 tonnes/acre/year.

Yield is significantly increased with the addition of the integral CO_2 capture and recycle system (increases SH CO_2 from 350 ppm -ambient to 1000 ppm) and heating and cooling system. The elevated CO_2 typically increases yield 50% (Bayer 2019), and the optimized soil and air temperature and humidity provide another 10% increase. This increases sugarcane yield to 270 tonnes/acre/year.

If the optional high efficiency LED's are used for 10 h/d hen the maximum potential yield is 480/acre/year because of the increased photosynthesis time with optimized color LED light. The incremental economics of adding LED lights to the SH are further discussed below in the Lighting section.



*Based on tropical farmland with sufficient rainfall to support perennial continuous growth, no additional land without rainforest/savannah destruction

Figure 14 -- Sample Sugarcane Economics

Ultrahigh yields from the SH, CO2, SDI, temperature, and humidity control offset the increased capital recovery and operating and maintenance cost. The ultrahigh yield and autonomous EV harvesting reduce cultivation and harvest cost per tonne. The high efficiency SDI system also reduces fertilizer cost per tonne of sugarcane because no fertilizer is lost to the environment. Onsite potassium nitrate (main crop nutrient) production along with the recycle from anaerobic digestion reduce the per tonne cost of fertilizer.

The revenue is expected to be significantly enhanced because the straw can be cost effectively harvested as valuable biomass feedstock for the onsite anaerobic digestor. The undried straw can be pretreated with potassium hydroxide (produced onsite) and TES heat to allow cost effective anaerobic digestion. The straw represents an undervalued biomass resource, most of which is currently used as a low nutrient content mulch fertilizer, which produces CO2 and N2O emissions from surface microbial degradation (Bioenergy Research 2019).

The EWM process has several currently under-monetized benefits these are:

1) Optimized water consumption and no wastewater. Tropical sugarcane farms use uncontrolled rainwater for irrigation. Although this is a low-cost water source, stormwater

flooding can occur which washes fertilizer into the rivers and creating hypoxic zones. There are several rivers globally that have storm caused fertilizer runoff and downstream hypoxic zones (Michigan State Univ 2021, Heinrich-Boell Foundation 2017). The SH system captures and stores stormwater for use during droughts. No nutrients are lost to the environment and SDI fertilization is managed so that no nitrogen is lost to N_2O.

2) Reduced land use. Tropical farmland with sufficient rainfall to support agriculture is fully utilized, and no expansion for additional biofuel production is possible. Arid land is plentiful and currently undervalued, because its price does not reflect its value in producing green solar and wind power and biofuels. EWM's expected ultrahigh yields free up over 99% of the existing rangeland because of the much higher solar energy efficiency. This makes room for the large PV farm and managed wildlife area. The reduced water consumption, high efficiency collection and storage system, and low-cost desalinated water from Full Recovery Desalination® allow high purity water supply to the managed wildlife area, maximizing its value as a drought proof wildlife habitat oasis.

3) Reduced GWP emission agriculture. The cost for agriculture GWP emissions is currently underpriced. Regulation and tax incentives or penalties reflecting the total GWP cost are not yet in place. With typical open field agriculture, stormwater flooding washes nitrogen rich fertilizers out of the soil into rivers and streams where microbes convert the nitrogen to N_2O, a potent GWP gas (NSF 2021). EWM's Full Recovery Agriculture™ system does not produce CO_2 or GWP emissions from cultivation, harvest, fertilizers, and crop transportation (explained below). The irrigated managed wildlife area with profitable selective biomass harvesting and no routine, controlled burns, should more than offset the land use impacts of the PV field and the SH. The ultrahigh yield SH includes an integral CO_2 DAC system, which again should more than offsets its land use impacts.

Aquaculture (Optional)

High intensity, small footprint aquaculture can be optionally added to the EWM Full Recovery Agriculture™ system. In this case, CA seaweed system (similar to the PVC-glass SH system) is used together with a Recirculating Aquaculture System (RAS), which monetizes the effluent ammonia from the RAS system. Artificial seawater or high purity freshwater makeup is provided by the onsite Full Recovery Desalination® process, and the purge water is returned. Residual organic biomass from the RAS is fed to the anaerobic digestor for recovery of nutrients and production of biogas, CO_2, and biochar.

In this process, fish food is generated onsite from a combination of beef byproducts (rendered beef processing byproducts), ethanol biofuel byproducts (distillers grain), corn meal, alfalfa protein extract, seaweed protein, oil extracts, and low cost imported soybean meal from renewable diesel production (Hay Forage Grower 2020, University of Florida 2019, Fishes 2021, Food Navigator 2020).

EWM's seaweed system has the following advantages that make it economically competitive:

- Low-cost shared PV powered TES systems for heating and cooling
- Excellent solar resource for maximum seaweed yield
- Onsite supply of nutrients and water (desalination, aquaculture, and fertilizer)
- Onsite customer for seaweed products (aquaculture feed)

EWM's aquaculture system has the following advantages that make it economically competitive:

- Low cost, high purity fresh water and synthetic seawater supply
- Low-cost feed supplied from onsite production
- Monetization of byproduct biomass (fish manure)
- Minimal water treatment and chemical cost (onsite desalination and integrated seaweed production)

Harvesting and CA Storage

Typical alfalfa and corn harvesting, and their storage systems, are inefficient because crop production is located remotely from consumers. This requires energy intensive drying, which is performed in the field, reducing available solar energy for biomass production.

Alfalfa

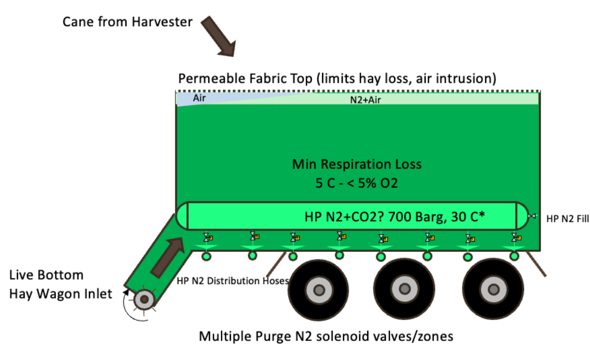
EWM's process avoids the field drying step of converting fresh alfalfa (85% moisture) to transportable alfalfa hay (15% moisture). During this step, the cut alfalfa blocks the sunlight available to the remaining alfalfa, which minimizes biomass production. 5-7 days of field drying are typically required. Multiple passes of heavy tractors are required (mowing, raking, and baling), which mechanically damages the remaining alfalfa and slows regrowth. Leaf shatter, mainly from raking, occurs at less than 50% moisture causing hay loss. Respiration (breakdown of the 100% digestible starch and sugars by microbes) occurs during drying and results in 5-10% loss in digestible dry matter. There is also the potential for the entire alfalfa hay cutting to be lost if rain occurs during field drying. (Hay and Forage 2017, Univ of Massachusetts 2022, Penn State Univ 2022).

The total average alfalfa annual yield loss of typical production is approximately 30% due to the following:

- loss of sunlight during drying
- loss of irrigation during drying
- potential full cutting loss with rain during drying
- slow regrowth due to multi-pass wheel traffic
- leaf shatter loss during mechanical handling of dried hay
- respiration loss of 100% digestible starch and sugar
  (Hay and Forage 2017, Univ of Massachusetts 2022, Penn State Univ 2022)

EWM's system uses a CA storage system to maximize the nutritional value of the alfalfa and prevent respiration losses (spoilage). The EWM TES and LAES systems provide low-cost nitrogen and chilling to make CA storage more cost effective than drying and rehydrating the alfalfa.

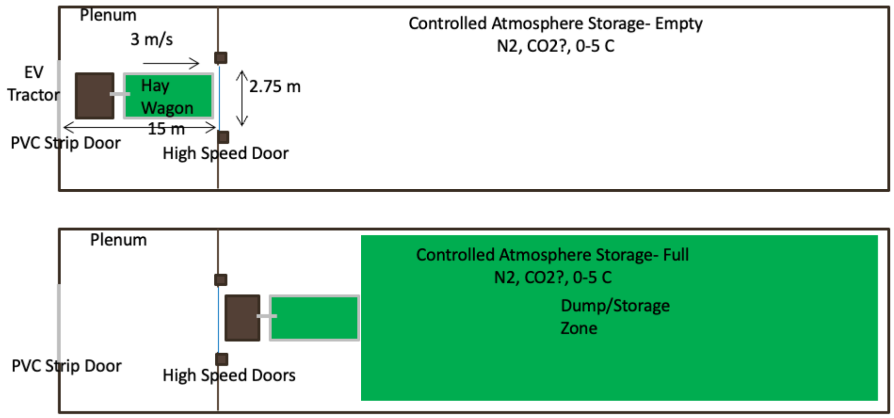
The EWM alfalfa harvesting system uses lower weight autonomous EV tractors (John Deere 2023) with a front mower (Poettinger 2023) and a live bottom hay wagon (Poettinger 2023) to mow and collect the wet hay in a single pass. The mechanical damage from the single pass is minimal because the alfalfa that remains immediately after cutting is mechanically resilient. There will be no cut alfalfa on top of the remaining alfalfa and regrowth with optimized solar energy and fertigation can occur immediately after the single pass of cutting.



*Based on composite tanks used for HP GH2 fuel cell systems

Figure 15 -- EWM Nitrogen Purged Forage Wagon

In the EWM process, the cut alfalfa is collected in a nitrogen purged forage wagon. High pressure (700 bar), lightweight composite tanks filled with nitrogen and potentially CO2 are used to continuously purge the wet alfalfa. This purges the oxygen and cools the alfalfa to approximately 5^{o} C, immediately providing the optimal CA and preventing respiration losses.



EWM CA Hay Wagon Transfer to CA Storage

Figure 16 -- EWM CA Hay Wagon Transfer to CA Storage

When the hay wagon in the EWM system is full, the autonomous EV tractor takes the wagon inside the CA enclosure, which is equipped with a PVC strip door and high-speed cold food storage door. An intermediate plenum minimizes loss of CA storage nitrogen to the atmosphere. Once inside the CA storage area, the live bottom forage wagon will unload the purged, cooled alfalfa. The EV tractor with forage wagon will then leave the CA storage area and resume single pass alfalfa cutting. An autonomous EV loader/stacker (Bobcat 2023) then stacks the newly delivered fresh alfalfa within the CA enclosure to maximize the CA enclosure utilization.

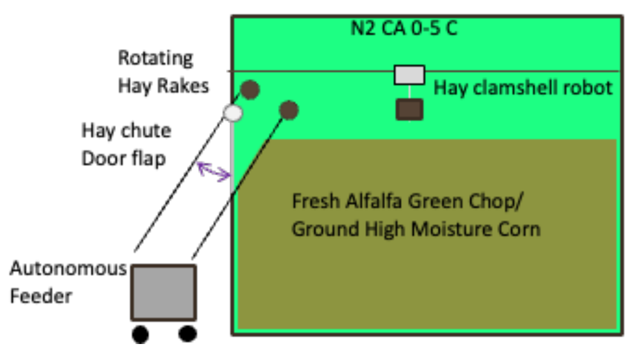


Figure 17 -- EWM CA Storage Feed Recovery

Alfalfa feeding from the CA enclosure in the EWM system will use an autonomous clamshell and feeding robot. The clamshell loads the appropriate amount of alfalfa into the feeding robot (Lely 2020). It loads ground High Moisture Corn (HMC) and mixes the alfalfa and distillers grain. The robot then delivers the feed mixture to the cows.

Corn

EWM's system uses a CA storage system to maximize the nutritional value of the corn and prevent respiration losses (spoilage). The EWM TES and LAES systems provide low-cost nitrogen and chilling to make CA storage more cost effective than drying and rehydrating the corn.

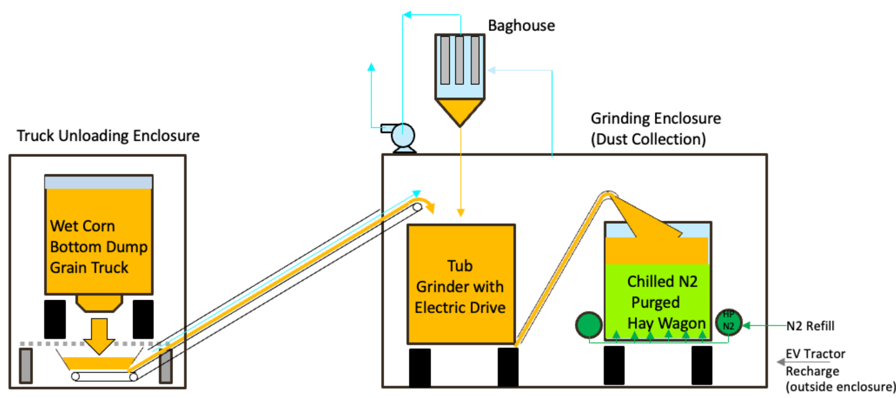


Figure 18 -- EWM High Moisture Corn Grinding

Corn is harvested as in the EWM system as HMC (30 wt% moisture). The HMC is then ground in a tub grinder (Roto Grind – Burroughs Enterprises 2023). The ground HMC is collected in a nitrogen purged forage wagon. High pressure (700 bar), lightweight composite tanks filled with nitrogen and potentially CO_2 are used to continuously purge the wet HMC. This purges the oxygen and cools the HMC to approximately 5^{o} C, immediately providing the optimal CA and preventing respiration losses.

The forage wagon emptying and recovery for cow feeding in the EWM system is the same as described above for the cut alfalfa. For biofuels production, the feed clamshell is used to transfer HMC from the CA storage to a covered belt conveyor, which delivers the ground HMC to the biofuel plant.

Sugarcane

EWM's process uses a CA storage system to prevent respiration losses (spoilage) and maximize the bioavailable sugar in the sugarcane. The EWM TES and LAES system provides low-cost nitrogen, oxygen, and chilling to make CA storage more cost effective at maximizing ethanol yield.

Sugarcane is harvested as a chopped and topped sugarcane with 70 wt% moisture. The chopped and topped sugarcane is to be collected in a nitrogen purged live bottom forage wagon. High pressure (700 bar), lightweight composite tanks filled with nitrogen and potentially CO_2 are used to continuously purge the moist sugarcane. This purges the oxygen and water vapor and cools the HMC to approximately 5^o C, immediately after cutting providing the optimal CA and minimizing microbial respiration losses.

When the hay wagon is full, the autonomous EV tractor takes the wagon inside the CA enclosure. The live bottom empties the wagon of the purged and chilled sugarcane into the CA storage enclosure.

The sugarcane is rapidly processed after harvest, but a small amount of CA storage time (<48 hours) is necessary to allow harvesting and processing activities to be decoupled. Ozone is used in addition to nitrogen, CO_2, and chilling in the storage enclosure. Oxygen from the LAES system is supplied to an onsite ozone generator that is used in the CA storage for microbial destruction. Apples (similar sugar storage issues) have successfully used this system to minimize microbial decomposition (Good Fruit Grower 2019). Stored sugarcane juice has shown significant reduction in sucrose loss when treated with low concentrations of ozone (Journal of Food Processing Engineering 2020). A feed clamshell is used to transfer the chopped and topped sugarcane from the CA storage to a covered belt conveyor that delivers the sugarcane to the biofuel plant.

Heating and Cooling

A separate humidifier enclosure is to be used in the EWM system to contact softened brackish water or brine from a Full Recovery Desalination® plant with the filtered and coil cooled air. The air is further cooled and humidified, and the brackish water or brine is pre-concentrated for lower cost minerals recovery. Chilled, cooled, or heated water from the TES system is used in the air mover coil to control the inlet air temperature and the brackish water/brine humidifier is used to control inlet air humidity. The combination of TES pre-cooling and softened brackish water/brine humidification provides low energy cooling of the large SH. All the heat from the SH is captured as warm return water to the TES system or as concentrated brackish water/brine.

Except for extremely cold ambient conditions, air in the EWM process will flow once through the SH providing feed air to an integral CO_2 capture system. During ambient conditions (below -5^o C), an underground PVC recirculation duct will be used to maintain SH temperatures above damaging frost conditions for the alfalfa. If necessary, all the byproduct heat from the desalination plant and biofuels plant and the stored TES system heat is used to heat the SH, minimizing the need to use backup biofuel or liquid hydrogen for emergency winter heating. Heat integration between the SH and the TES, LAES, desalination, and biofuels plant is to provide a significant energy efficiency advantage allowing the cost-effective operation of the SH. Other greenhouses and SHs exist in arid high temperature environments (Pure Harvest – UAE/KSA 2023), but the high energy cost for standalone heating and cooling significantly impacts economics.

Irrigation and Fertilizer

An SDI system is to be used in the EWM process to provide near continuous irrigation to the corn and alfalfa. This system provides the highest efficiency water distribution of the high purity water from the desalination plant. Using high purity water eliminates the need for a wastewater purge, minimizing water and nutrient loss. Soluble fertilizers and nutrients (mainly self-produced potassium nitrate and ammonium nitrate) are continuously fed with the irrigation water to the crops. A closed fertigation system with no purge saves up to 35% of the nitrogen fertilizer, reducing cost and preventing downstream hypoxic zones and N2O emissions (Purdue Univ 2017).

Self-production of green ammonia and recovery of potassium from the brackish groundwater and seawater reduces fertilizer costs by avoiding transportation costs and distributor margins. In addition, the fertilizers do not carry a potential CO2 cost, because they are produced from low-cost onsite PV/wind power and not fossil fuel-based hydrogen.

CO2 Capture and Recirculation

The near continuous, large flow of filtered cooled air from the SH is an ideal air source for sorbent-based CO2 DAC and for airfan coolers required to reject heat from the overall ranch system. EWM has designed an optimized mechanical solid sorbent absorber that integrates with these two systems. The sorbent is continuously loaded with CO2 and stripped, minimizing the amount of solid sorbent required and providing a continuous flow of captured CO2. The cooled airflow in the EWM system will deliver low-cost air to the absorber system. Heat from the TES system is to be used to regenerate the sorbent and produce a wet CO2 stream. The CO2 is dried, compressed, liquified, and purified using low-cost cooling from the TES system, which uses low-cost onsite PV/wind power. The integration of the CO2 DAC with the SH air flow system, airfan cooler air flow system, and TES systems in the EWM design significantly reduces the overall CO2 capture, purification, and liquefaction cost. This is critical to the economics of SAF production from CO2 and green hydrogen.

The CO2 DAC system in EWM's design mainly produces a high purity liquid CO2, but there also is a small low purity vaporized CO2 purge stream that contains the air impurity from the absorber. This low purity purge stream is then to be recirculated back to the SH to provide elevated CO2 in the SH. Typically, 1000 ppm (vs 350 ppm ambient) is maintained in the SH to maximize photosynthesis and biomass production. During daytime operation, some of the high purity liquid CO2 is added to the low purity purge stream to maintain the optimal amount of CO2. Multiple CO2 injection points are then used to maintain the optimal CO2 level throughout the SH without creating a health hazard (OSHA 8 hour Permitted Exposure Limit - PEL for CO2 is 5000 ppm). The CO2 in the SH effluent downstream of the last CO2 injection point is elevated (400-600 ppm) in the EWM system to maximize photosynthesis in the last zone. The enriched CO2 in the SH effluent maximizes the CO2 capture of the CO2 DAC system. Combining CO2 DAC with SH operation maximizes crop yield and minimizes CO2 capture cost for onsite biofuels and E-Fuels production.

The DAC CO2 in EWM's design is supplemented with the byproduct CO2 from the bioethanol and the CO2 recovered from the anaerobic digestor and torrefaction (biochar) system. However, the ultimate source of all the CO2 is the atmosphere and, therefore, should qualify for significant CO2 credits (green olefins for PVC production) or its use allowed as SAF (meets regulatory or tax incentive requirements).

Lighting

High efficiency LED lighting is under development for greenhouse and SH applications. Greenhouse fluorescent lighting is being replaced by new high efficiency LEDs. However, less than 5% of greenhouses use supplemental lighting and less than 1% use LEDs (Osram 2022). LED for human lighting systems focus on white light; however, plants need mainly blue and red light for photosynthesis. Therefore, the U.S. DOE has developed an agricultural lighting LED roadmap that focuses on blue and red LED's (DOE 2022).

Currently the best commercially available white light LEDs (Phosphor Converter LED, PC-LED) have an efficacy of 200 lumens per watt. However, blue and red LEDs have a much higher power to light conversion efficiency than green and amber LEDs. Therefore, Color Mixed (CM-LED) blue and red LEDs for supplemental agriculture lighting have a higher potential efficacy of over 300 lumens/watt. DOE projects that by 2030 the higher efficiency blue-red CM-LED will be available (DOE 2022).

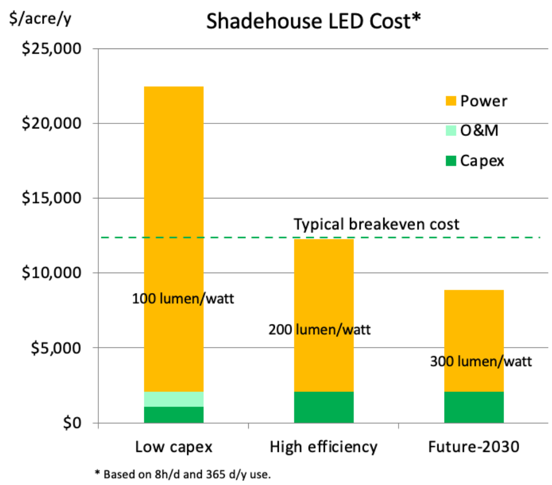


Figure 19 -- Shadehouse LED Cost

Adding LEDs to the SH at the current LED efficacy of 200 lumens per watt to increase the daily growth time by 8 hours per day has breakeven economics because of the high yields achieved in the EWM SH design. When the higher efficiency supplemental agricultural CM-LEDs become available in 2030, the additional revenue from the crops and biomass is expected to exceed the cost of the CM-LED's.

The major cost of supplemental lighting LEDs is the cost of storing the onsite generated PV power for the 8 hour night operating period. EWM's optimized TES and LAES system is used instead of Lithium Ion Batteries (LIBs), because of the extended period of operation required. This system minimizes energy storage cost because the byproduct heat generated from power conversion is then efficiently used in the desalination and CO2 DAC systems.

There are significant underpriced land use benefits from supplemental LED lighting, which are not included in the breakeven cost analysis. The higher yield reduces land required for crop production and arid land is currently underpriced.

There also are underpriced water efficiency benefits of using supplemental LED lighting. LEDs efficiently target just the wavelengths of light required for photosynthesis; no infrared and other unused heat gain wavelengths are emitted. This essentially eliminates the heat load associated with sunlight and the previously used fluorescent lights. The lower heat load reduces water requirements and agricultural water currently is underpriced.

The PVC-glass SH structure supports can be used as an integral LED lighting system. The hollow PVC-glass SH support beams act as an insulating housing and, therefore, wiring, transformers, and LED strip lights can be installed within the SH support beams.

Cattle and Dairy Barn

High value beef (Black Angus) and dairy (Holstein) cows originated in northern Europe and were imported to the U.S. in the 1600s. These cows produce the economically optimum ratio of high value fat to protein when temperatures are below 60° F (15° C) as an adaption to the colder northern European winters. Heat stress begins to occur in cattle at lower temperatures (75° F, 24° C), because cows produce significant internal heat during rumination. Heat stress causes cows to eat less food and compromises their uterine environment, reducing weight gain and milk production, and increasing infertility. (Holstein Assoc 2016, Univ of Missouri 2022, UC Davis 2020, San Diego State Univ 2020). By 2050, global warming effects are projected to cause 12% reduction in U.S. beef production, 30% reduction in Brazil's beef production, and 25% reduction in India's milk production (global leader in milk production) (Lancet 2022).

A cow generates 40 times more manure and urine compared to a human because cows have a high cellulose diet (Cornell Univ. 2017). Texas has a population of approximately 30 million people and approximately 15 million cows. Unlike human waste, cow manure in Texas is typically not immediately collected and routed to treatment plants. Dried cow manure from Texas dairies and feedlots is collected and composted in open air; however, limited local markets and high transportation costs for the low value dried manure limit its recovery (Manure Manager 2008). In addition, open air handling and composting of manure releases significant amounts of methane and N2O, which have high GWP factors (Environmental Science and Technology 2023).

Manure and urine from outdoor cattle feedlots produce ammonia and methane emissions and can increase water pollution from nutrient and pathogens runoff to water bodies during significant stormwater events. This leads to eutrophication, algal blooms, and hypoxia. Despite the significant environmental benefits of recovering these organic materials, the recovery of value-added products from livestock waste is not a current practice. The historically low market value of products from the cattle waste (pre-2019) has not justified the high investment and energy costs for cattle waste processing (Univ of Wisconsin 2019). The emerging high value biofuels market, however, makes conversion of the fresh cattle waste to biofuel products economically viable.

EWM's solution to the heat stress and cattle waste management problems is to provide a full recovery CA cattle and dairy barn. This maximizes beef and dairy revenue (maximum volume and maximum product quality/price) and monetizes the wastes as high value biofuel products in the emerging biofuels market. In the CA cattle and dairy barn, the fresh manure and urine is immediately collected to minimize offgassing and maximize byproduct manure and urine value as high value biofuel products (biogas, biogenic CO2, and internally utilized SDI fertilizer liquids). No cattle manure or urine is discharged to any of the ranch water systems, even during severe storms (floodwater conditions). No GWP air emissions are released from EWM's manure and urine processing system.

A typical free stall dairy barn needs 100 square feet per cow (Texas A&M 2012). Based on a high yield SH feed area of 0.05-0.1 acres/cow (2,178-4,356 square feet), the barn area required is less than 5% of the SH area, or < 1.5% of the total ranch area.

The EWM barn design consists of a bedding area (individual silica sand covered mattresses), a common feeding area, a common brushing area (automated brushing system – Lely 2020), milking parlor (dairy only), and common calf birthing, impregnation, and health care areas. A CA system provides the optimal environmental conditions (typically less than 60^o F, 15^o C), and recovers methane (biogas product), H2S, ammonia, and CO2.

Although there are high capital and energy costs associated with the CA cattle and dairy barn, the higher beef quality (higher fat content), growth rate, milk quality (higher fat content), and milk productivity are expected to provide more than enough additional revenue to cover the increased costs.

The low chilling cost provided by EWM's TES and LAES system minimizes energy cost and allows a recirculated air system to be used for the barn, which facilitates scrubbing and methane capture. Oxygen enriched air is used to minimize makeup air requirements. This minimizes cooling losses and provides additional biosecurity, because the lower volume of makeup oxygen enriched air can be filtered and disinfected before entering the barn.

Maximum Beef and Milk Quality

Beef quality is determined by fat content. The highest value beef is Certified Black Angus USDA Prime beef, which is typically 250% of the price of USDA Choice beef. The supply of this exceptionally high-quality beef, however, is limited. In the U.S., typically only 2% of the beef is graded as Prime (Certified Angus Beef 2022).

Specialty beef producers, however, are able to achieve 12% Prime using open feedlots with uncontrolled shading and temperature at locations with summer temperatures significantly above the optimum (typically 90-100^o F, 32-38^o C). Feedlot quality fodder (purchased dried corn, and dried hay) are used as feeds. Purchased heifers are used, which are selected by pedigree. (Marubeni 2022).

EWM's process uses several improvements to the specialty feedlots:

- CA system provides optimum temperature and humidity conditions
- higher quality fresh cut alfalfa feed, CA stored
- higher quality ground HMC, CA stored
- onsite breeding and calf production to slaughter and packaging control
- maximum biosecurity with no airborne or imported cattle-based disease sources

Therefore, EWM projects a significantly higher percentage of prime grade beef (target 40%).

Milk quality (protein and fat content), as well as quantity, is negatively impacted by higher temperatures (Animals 2022). Temperatures below 65^{o} F (18^{o} C) are ideal for dairy cows. Above this temperature, dairy cattle reduce feed intake impacting quality and quantity of milk (Univ of Missouri 2022, Animals 2022).

Automated Feed and Manure System

As described in the Harvest and CA Storage section above, for the EWM process, feeding robots are filled with an optimized mixed ration of fresh cut alfalfa, ground HMC, and distillers grain. The robot delivers the mixed feed ration to the beef and dairy cows. Multiple daily feedings are used to create a Pavlovian response, maximizing feed intake, growth, milk production, and fertility.

A manure collection robot (Lely 2020) continuously collects fresh manure, dilutes it with water, and transports it to a covered manure slurry sewer, which transports the manure slurry together with the urine to the onsite anaerobic digestion plants. In the EWM system, the urine drains to trapped, water purged floor drains. The manure and urine alley also are periodically flushed with water from the manure collection robots that contain a water bladder as well as a manure slurry collection bladder (Lely 2020).

Scrubbing, and Cooling

An air circulation system is to be used in the EWM system barn to maintain the atmosphere to the optimal conditions (temperature, humidity, CO2, methane, ammonia, H2S, and O2). Exhaust air from the barn is to be routed to a multistage aqueous scrubber, which uses acid, hydroxide, hyprochlorites, and chilled water to scrub, disinfect, and cool the recirculating air. This removes nearly all the water vapor, H2S, ammonia, and CO2. The H2S is oxidized to sulfate and combined with the ammonia and water as a recycle fertilizer stream. The CO2 is routed separately to the common CO2 purification system (see SH CO2 Capture and Recirculation).

The cooled recirculating air from the aqueous scrubber is routed to EWM's proprietary methane scrubbing system, which integrates cooling from the TES and LAES system with carbon-based sorbents developed for methane removal from coal mine Ventilation Air Methane (VAM) (Adsorption 2021). Integration of the TES, LAES, and VAM systems with the circulated cooled, scrubbed air allows cost effective recovery of the methane as liquified biogas that is suitable for rail transportation (cryogenic double wall rail car) or high-pressure regasification and pipeline transport.

After methane scrubbing, most of the chilled air in the EWM process is recirculated to the barn after the addition of makeup O_2 enriched air. The makeup O_2 enriched air is provided by the LAES system, which combines filtered air with byproduct O_2 from green H_2 production. A small purge is taken from the barn recirculating air to prevent buildup of any trace gases.

Anaerobic Digestor and Torrefaction

In the EWM process, the byproduct manure and urine slurry are routed to an anaerobic digestor system. A pretreatment hydroclone and plate and frame filter remove entrained bedding sand as a washed and dried filter cake, which is reused in the barn or transported by rail or conveyor to an onsite or offsite silicon production facility. The pretreated manure and urine slurry is then mixed with caustic pretreated supplemental biomass (ground woody waste from the managed wildlife rangeland, high moisture corn stover, and imported cotton gin waste) and organic rich, concentrated dairy effluent water and pumped to a commercially available complete mix anaerobic digestor system, suitable for the 5-10 wt% solids slurry produced from the barn manure and urine recovery systems.

The anaerobic digestor produces biogas containing CO_2 and methane. The biogas is compressed and chilled methanol is used to scrub the CO_2 from the biogas. A heated stripper is then used to separate the CO_2 and recycle the methanol. The CO_2 is routed to the common CO_2 purification system (see SH CO_2 Capture and Recirculation). Heating and chilling are provided by the TES and LAES systems.

The anaerobic digestor produces a fertilizer liquid that is recycled to the irrigation and fertilizer system for crop production. The anaerobic digestor also produces biosolids which are routed to a commercial torrefaction unit.

The torrefaction unit in EWM's process heats the biosolids with heated recirculating effluent gas. The effluent gas first dries the solids (producing water vapor) and then carbonizes (cokes) the solids at higher temperatures (350^o C). At the higher temperature, the biosolids emit CO_2, water vapor, and Volatile Organic Carbon (VOC) compounds. The effluent gas from the hot biosolids is heated with TES heat and then oxygen is added to combust the VOCs at high temperature, converting them to CO_2. The hot CO_2 and water vapor are then recycled to the torrefaction unit to provide the heat needed for coking and drying. A vapor purge is taken from the cooler drying section and the CO2 and water vapor mixture is cooled (TES system) to condense out the water (ThyssenKrupp 2014). The wet CO2 is routed to the common CO2 purification system (see SH CO2 Capture and Recirculation).

Beef Economics

The economics of EWM's high quality Full Recovery Beef Production™ are very favorable compared with typical Texas open field and open feed lot beef production.

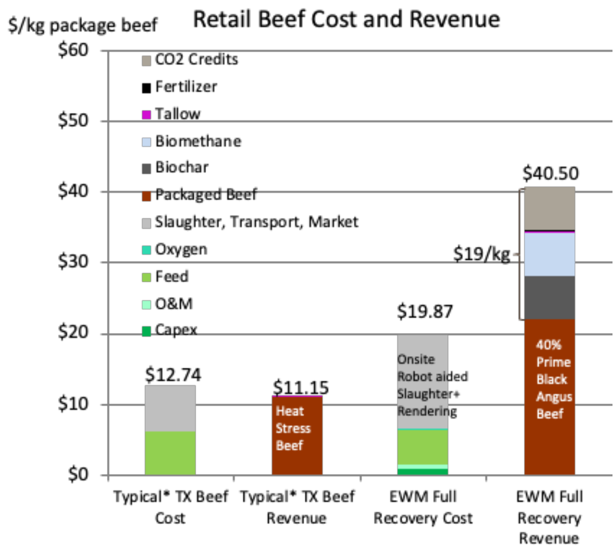


Figure 20 -- EWM Full Recovery Beef Production™ Sample Economics

EWM's process including the optimized environment in the CA barn, optimized self-produced and controlled feed, end to end beef control (conception to slaughter and packaging), maximum biosecurity, and controlled genetics produces the highest possible grade of beef (40% Prime Certified Angus Beef) and maximizes beef revenue. Full control of the entire value chain reduces the revenue fluctuation risk.

Significant heat stress in Texas, and other arid regions of the world, limits beef quality to an average prime grade of 2%. Feed costs per ton are high due to transportation costs of corn from Iowa (cornbelt) and alfalfa from California (Imperial Valley). The dried corn must be steamed and flaked before feeding. No shade or cooling is provided, and the hot Texas summers cause near heat stroke conditions for cattle bred for northern European conditions. In 2022, thousands of cattle died from heat stroke where temperatures were 104° F (42° C). Texas is experiencing a heat wave in 2023 where temperatures in

West Texas reached 114º F (46º C). As discussed above, global warming is expected to further increase the frequency and peak values of these extreme heat waves. This creates variable beef quality and quantity based on the frequency and severity of heat waves, droughts, and floods.

The biofuel byproducts produced in the EWM process are highly valuable due to the advent of the energy transition market and tax incentives for biofuels and CO2 capture. Biomethane is a premium fuel because it is based on captured biogenic methane and is compatible with the existing natural gas infrastructure. Biochar is another important fuel because it replaces high carbon footprint fossil fuel coal in silicon production. Solar silicon production for PVs also requires a high purity carbon source as well as green PV power to convert silica sand to silicon.

Beef and Dairy Processing

The U.S. is the world's largest producer of beef, especially prime and choice grade corn and alfalfa fed beef. U.S. commercial slaughter in 2022 was 31 million cows. Large plants with capacity over 50,000 cows/y account for > 96% of the cattle slaughter. The big four (JBS, Tyson, Cargill, and Marfrig) account for 85% of fed cattle slaughter. (Packer and Processor 2023).

Approximately 35% of the beef live cattle weight is dressing losses (head, hide, feet, blood, and viscera) and an additional 20% is carcass trimming loss (bone, cartilage, and tallow) giving a typical final take home yield of 45% of the live cattle weight (Univ. of Wisconsin 2022). Rendering plants use low level heat-based processing to kill bacteria and convert the residual beef products into valuable aquaculture feed (cooked protein, fat, and bone meal), biofuel (tallow), and leather (Tyson 2020).

Unlike the electronics and automotive industry, limited automation is used in beef processing. Robot assisted beef slaughter systems using modified equipment and techniques from these industries are being developed to improve productivity and workplace safety (Journal of Food Engineering 2022). Therefore, existing beef processing plants using exclusively manual labor are expected to be replaced with new plants using state-of-the-art processing techniques.

Co-location of a new state-of-the-art beef slaughter and rendering plant at the ranch site allows onsite full recovery of all the beef byproducts. Vertical integration ensures a firm, controlled supply of beef cattle and a matching firm-controlled capacity of high recovery beef processing. Low-cost heating and chilling from an onsite, low-cost PV based TES and LAES system minimizes energy costs and carbon footprint. Only the product beef is transported as refrigerated or frozen beef products, using PV or LH2 fueled trucks or trains (onsite fuel supply). This minimizes transportation costs and CO2 emissions.

Dairy processing plants (cheese, yogurt, etc.) are built near or adjacent to milk producing dairies to minimize transportation cost of the milk. Dairy processing plants, however, generate up to 60 tonnes of wastewater per tonne of milk processed. Producing 1 kg of cheese leaves 9 kg of whey, which contains valuable sugars, fats, proteins, minerals, and water but is typically disposed of as a wastewater stream with negative environmental impacts due to its high biological oxygen demand (BOD) and chemical oxygen demand (COD). High energy and capital costs to separate the whey into transportable food (i.e., dried whey powder) and energy (i.e., lactose) products limit whey utilization. (Biomass Conversion and Biorefinery 2021, Fluence Corp 2020, Dairy Processing Handbook 2022, New Food Magazine 2023).

Co-location of the dairy processing plants at the ranch site will allow full recovery of the whey and wastewater. EWM's Full Recovery Desalination® plant design is modified to use the low-cost PV based TES and LAES system to cost effectively monetize the wastewater and the whey effluent stream. Adding the incremental water processing units to the desalination plant reduces the capital cost as compared to a stand-alone whey recovery and wastewater treatment facility. The energy cost is reduced by using EWM's TES and LAES system, which is optimized for the energy intensive evaporation and drying processes required for dairy processing plant whey and wastewater.

Biofuel Production

A typical biofuel plant requires approximately 20 acres. For a world scale biofuel plant, which includes ethanol to ethylene conversion, Electro-Methanol (E-Methanol), and conversion to olefins, approximately 100 acres would be required. To support this facility a minimum 10,000 acre total ranch area (potentially multiple regional sites) would be required. In this scenario, < 1% of the total ranch area would be used for biofuel production.

Corn Biofuel Production

Implementation of ethanol from corn has several advantages using EWM's process, which includes onsite SH corn production system and CA storage.

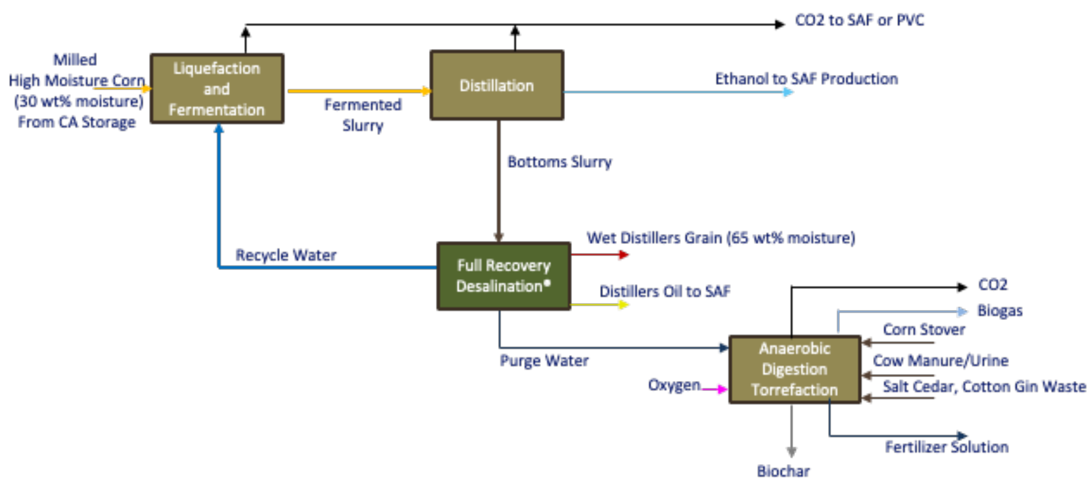


Figure 21 -- EWM Corn to Ethanol Process

These advantages for converting corn into ethanol, include:

- Corn transportation storage and grinding can be eliminated because ground HMC CA storage is provided as part of the cattle feeding system
- EWM's HMC CA stored corn has a higher yield versus dried, ground, and reconstituted corn and ore of the sugar content is bioavailable in the fermentation process
- Low-cost PV based TES heating is used for cooking the ground corn slurry in the enzyme cooking and liquefaction step (85° C) and cooling for the fermentation step (34° C)
- Byproduct wet CO2 from the fermentation step is routed to the common CO2 purification system (see SH CO2 Capture and Recirculation)
- TES heating and cooling is used in the ethanol distillation step
- Wet ethanol is sent to the onsite ethanol to ethylene step
  (molecular sieve drying for gasoline additive grade ethanol eliminated)
- Wet distillers grain is directly mixed with the feed corn and alfalfa with minimal CA storage requirements, and the forage wagon system used for fresh cut alfalfa and ground HMC is used to transfer the wet distiller grain to a similar CA storage system (distillers grain drying system eliminated)
- TES heat is used to evaporate the byproduct corn syrup
- High BOD and fines containing wastewater is routed to the anaerobic digestor for monetization of the biomass and dissolved organics
- Transportation and intermediate storage for the ethanol and dried distillers grain is minimized

The use of PV based TES heat and cooling eliminates any fossil fuel CO2 emissions that typically occur in the energy intensive corn to ethanol process. The corn to ethanol process is similar to the EWM Full Recovery Desalination® because many of the steps involve vaporizing and condensing water to separate the various organic components.

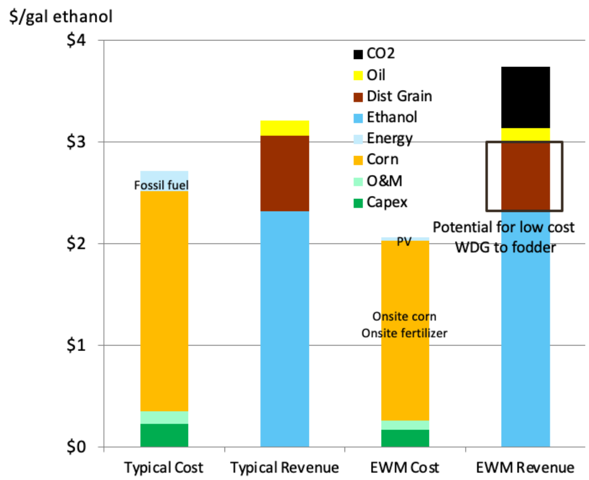


Figure 22 -- EWM Corn to Ethanol Sample Economics

The economics of EWM's Corn to Ethanol process are estimated to be very favorable compared with typical corn to ethanol used as a gasoline additive. EWM's HMC delivered corn price from its process is lower and the CA stored HMC provides a higher yield. Energy and capital costs are lower due to the deletions listed above. Byproduct CO2 is captured onsite and converted to E-Fuels with green H2. This avoids the CO2 pipeline and sequestration issues that limit the current midwest cornbelt plants from recovering the CO2 from fermentation. EWM does not require CO2 offsets, because fossil fuel energy is replaced with PV based TES heating and cooling.

Sugarcane Biofuel Production

Implementation of ethanol from sugarcane has several advantages using EWM's process, which include onsite SH corn production system and CA storage.

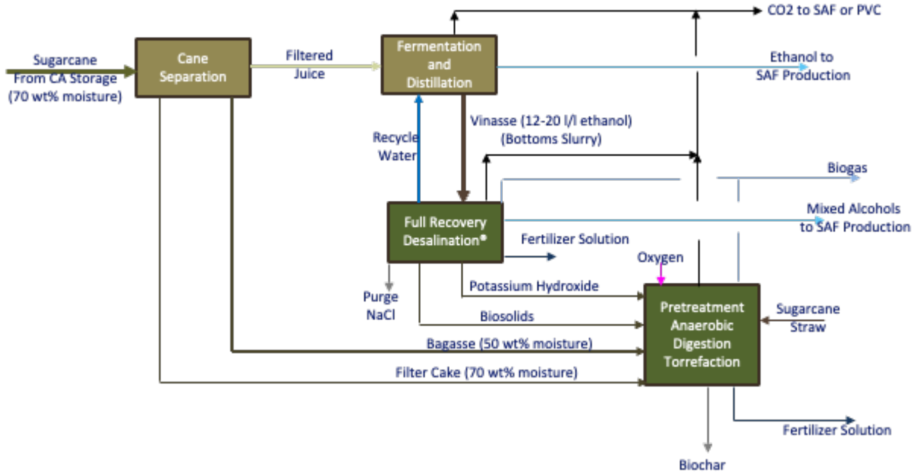


Figure 23 -- EWM Sugarcane to Ethanol Process

The advantages for converting sugarcane into ethanol, include:

- The Bagasse and filter cake high moisture biomass byproducts (50 wt% and 70 wt% moisture) are typically combusted in low efficiency boilers (< 70% efficient), producing medium pressure steam (40 bar). High efficiency congeneration is not used (National Conference on Technological Developments in Civil and Mechanical Engineering, India 2018). High particulate emissions (flyash) result from bagasse boiler operation, which require significant investment in scrubbers, electrostatic precipitators, or fabric filters (US EPA 2020). These emissions control systems are not always implemented resulting in local air pollution. EWM converts the bagasse and filter cake to high value biochar, biogas, and biogenic CO2, with no emissions.

- The high volume Vinasse wastewater stream (ethanol distillation bottoms) is typically returned to the sugarcane field as a fertilizer stream. It is a dark brown, acidic (pH 4), liquid slurry with an unpleasant odor and high organic matter content. The COD is >100,000 mg/L and the BOD is > 30,000 mg/L. Vinasse contains valuable macronutrients (N, P, K). However, the high organic content and low pH of the untreated Vinasse causes soil toxicity 100 times more than domestic wastewater (Sustainability 2022). EWM's process separates and treats the Vinasse, producing organic-free recycle water, low organics fertilizer solution, biogas, biogenic CO2, mixed alcohols (suitable for SAF production), and a pH neutral biosolids slurry that stimulates microbial activity in anaerobic digestion.

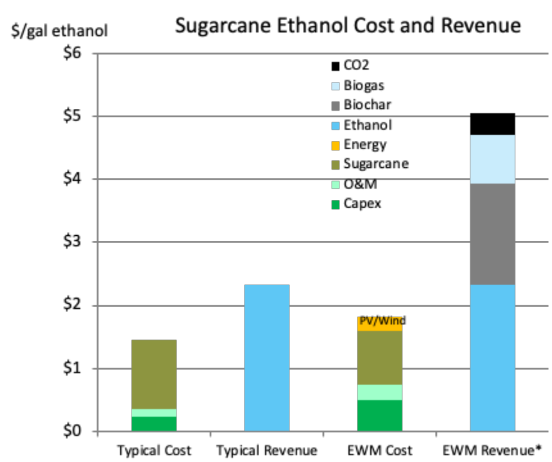
- The organic-free recycle water limits the ethanol content in the fermentation section avoiding yeast sensitivity and maximizing sugar conversion to ethanol. The typical makeup water addition is not required and there is a net water export in the recovered fertilizer solution.

- EWM's CA stored sugarcane has a higher yield compared to typical harvested and stored sugarcane. Essentially all the sugar produced by the sugarcane is bioavailable in the fermentation process, and fewer organic acids are in the Vinasse bottoms stream.

- Byproduct wet CO2 from the fermentation and distillation step, Full Recovery Desalination® step, and the anaerobic digestion and torrefaction step is routed to the common CO2 purification system (see SH CO2 Capture and Recirculation).

- Wet ethanol is sent to the onsite ethanol to ethylene step (molecular sieve drying for gasoline additive grade ethanol eliminated)

EWM has developed a high efficiency PV/wind based TES heating and cooling system for its Full Recovery Desalination® step. This system is also used to supply the energy for the entire energy intensive Full Recovery Sugarcane to Ethanol™ Process. The TES system replaces the low efficiency, high moisture content bagasse and filter cake combustion. The high volume biomass streams (4 tonnes dry matter/tonne ethanol) are used to produce high value biogas, biochar, and biogenic CO2. CO2 and particulate emissions are eliminated and the water in the biomass is recovered as fertilizer solution.



*Excludes biochar, biogas and CO2 produced from straw

Figure 24 -- EWM Sugarcane to Ethanol Sample Economics

The sample economics of EWM's Full Recovery Sugarcane™ process are very favorable compared with typical sugarcane to ethanol used as a gasoline additive or replacement. EWM's CA stored sugarcane provides a higher ethanol yield. Energy and capital costs are higher because the various biomass streams are refined and sold as high value biofuels and not combusted onsite. The additional revenue from the high value biofuels plus the captured biogenic CO2 are to more than offset the higher capital, operating and energy costs. Byproduct CO2 can be shipped as liquid using TES chilling or converted onsite to E-Methanol with green H2. This avoids the CO2 pipeline and sequestration issues that limit the current sugarcane to ethanol plants from recovering the CO2 from fermentation. EWM does not require CO2 offsets, because fossil fuel energy is replaced with PV based TES heating and cooling.

Ethanol to Ethylene

The highest priced, largest growth biofuel today is SAF. Ethanol to gasoline is not a good long term growth market because it faces competition from higher efficiency PV power and EVs. The first ethanol to SAF project is under construction in Georgia using Technip's ethanol to ethylene technology to produce ethylene as a first intermediate. The conversion of ethanol to ethylene occurs at mild temperatures and pressures - 20 bar and 240^{o} C (Lanzajet 2023, Technip 2023). Heat is required for the feed ethanol vaporization and superheating and for the distillation system used to separate the reaction products (ethylene, C3+ impurities, recycle ethanol, and byproduct water). Cryogenic level cooling is required to produce liquid ethylene for rail transport. The EWM LAES system will produce liquid nitrogen, which can liquify the ethylene for storage and rail transport.

Transporting cryogenic (liquid) ethylene recovers a significant amount of water from the ethanol because ethanol chemically contains 40 wt% water. Onsite ethanol to ethylene conversion also reduces the rail transport cost because the water (valuable at the arid ranch site) is not transported. Significant heating and cooling is required in the feed vaporization and superheating and in the reactor product distillation. The low-cost PV based TES and LAES systems in EWM's design are best suited to provide this heating and cooling.

In addition to SAF, ethylene can be used as a green polymer feedstock in the EWM process. This provides future optionality for the bio-ethylene because no fossil fuel CO2 is emitted in its production and the only source of carbon used in the production of the ethylene is atmospheric CO2 biogenically captured CO2 by the corn.

PVC Production (optional)

Green PVC can be produced onsite because the Full Recovery Desalination® plant will be producing chlorine. Chlorine is combined with ethylene to produce PVC. TES heating and cooling would be used to eliminate the need for fossil fuel-based heating and cooling.

Green Liquid H2

The Inflation Reduction Act (IRA) Tax Credit definition of Green Hydrogen (electrolysis hydrogen eligible for IRA Tax Credit) is currently being developed by the U.S. Treasury Department. A coalition of academics, energy companies, and environmental organizations has proposed a stringent definition of green hydrogen based on three pillars: additionality (new, expanded, or reduced curtailment of renewable power generating capacity), deliverability (the new renewable power capacity is connected to the electrolyzers), and hourly time-matching (renewable power production matches consumption on an hour-by-hour basis) (Center for Strategic and International Studies 2023).

The most controversial of the proposed pillars is the hourly time-matching. The American Clean Power industry organization has made a counterproposal that annual time-matching be used for projects under construction before January 1, 2029 to facilitate the construction of the first generation of green hydrogen plants. The more rigorous hourly time-matching standard would then be implemented after January 1, 2029 (American Clean Power 2023). This, however, could result in the increased construction of both fossil fuel plants (night hydrolyzer power) and PV plants (day hydrolyzer power). A Natural Resource Defense Council (NRDC) sponsored study concluded that the hourly time-matching standard would allow economical construction of the new green hydrogen plants. However, the first-generation locations would be where hybrid PV and wind power could be used in conjunction with each other to increase the hourly availability of the new renewable power, maximizing the capital utilization of the electrolyzers (NRDC 2023).

The EWM ranch design co-locates the renewable power (PV and wind) at the same location as the green hydrogen production. This meets the more stringent hourly-matching time standard, and also allows a high efficiency direct DC-DC connection (voltage converters only) with lower cost DC transmission for non-contiguous regional PV solar farms. The cost of transmission for the intermittent PV and wind power can exceed the cost of PV and wind power generation, depending on distance from generation to consumption. Therefore, the EWM ranch design minimizes the cost of transmission.

EWM's green H2 production design uses Proton Exchange Membranes (PEM's) to generate green H2. EWM's TES and LAES system is used to convert the medium pressure hydrogen from the PEMs into liquid hydrogen. EWM's TES and LAES system has been optimized to allow the significant byproduct heat produced from electrolysis and hydrogen liquefaction to be beneficially used in the desalination and CO2 DAC processes. The green liquid hydrogen can be shipped by rail as a green fuel or chemical intermediate. EWM has developed a liquid hydrogen pumping and vaporization system with refrigeration recovery. This eliminates the need for expensive and inefficient high pressure hydrogen compression and allows the liquid hydrogen to be an ideal chemical intermediate product or green fuel that can be shipped by rail or deep-sea vessel.

EWM's process also has a high efficiency liquid hydrogen fueled peaking turbine design under development that could allow liquid hydrogen conversion to fully dispatchable peaking power at a high efficiency (approximately 95% LHV efficiency). EWM also has a derivative design under development that could allow liquid hydrogen conversion to maritime power (similar to the GE LM 2500 maritime turbine) and aviation power (next generation hydrogen fueled turbofan engine). This version has a lower efficiency but allows an approximately 15% less fuel consumption (LHV basis) versus conventional fossil fuel-based diesel and jet fuel. Alternatively, fuel cells can be used to convert vaporized liquid hydrogen to power trucks and trains in a hybrid configuration with batteries (Toyota 2023, Alstom 2022).

Fuel cell's current low stack capacity (typically less than 1 MW per stack) limits their use in large scale maritime power applications (e.g., 50 MW world class container ship). The larger scale maritime power applications have larger space available for propulsion and can use high temperature turbine exhaust heat in a combined cycle to increase efficiency above fuel cells.

Byproduct oxygen from the PEM electrolysis is liquified as part of EWM's LAES system and stored for use as low pressure oxygen for the cattle barn, torrefaction unit, and optional PVC production.

Methanol Production

Significant CO2 is produced by the SH CO2 DAC system and from the ethanol, anaerobic digestor, and the torrefaction unit in the EWM process. The CO2 is purified and liquified as part of the TES and LAES system. The high purity liquid CO2 can be shipped by rail as a cryogenic liquid or converted onsite with green H2 to E-methanol. The onsite conversion is simplified because both feeds are liquids and can be pumped to the high pressure required for methanol synthesis. TES and LAES heat and cooling can be used, and the refrigeration recovered into the TES system.

EWM also has developed an optimized methanol production process that uses the liquid hydrogen and liquid CO2 produced as part of the LAES system. This system reduces cost by eliminating the compression system and by using the TES and LAES systems to provide low-cost PV based heating and cooling.

The advantages of onsite conversion are:

- Byproduct water from methanol conversion is recovered and reduces the rail shipping cost
- A low-pressure ambient temperature liquid (E-Methanol) is shipped instead of cryogenic H2 and CO2
- The TES and LAES can utilize the refrigeration and byproduct heat from liquid hydrogen and liquid CO2 conversion to methanol

Methanol to Olefins

There is a potentially large market for E-methanol as a maritime fuel, because it is compatible with existing reciprocating diesel engines (modifications required). It, however, is not yet clear if liquid green hydrogen, green ammonia, or E-methanol will be the favored fuel for large scale maritime engines.

The highest value and current largest growth market for E-methanol is SAF. Exxon's or UOP's Methanol to Olefins (MTO) process is first used to convert the methanol to a mixed olefin stream (either C2= to C4= for UOP, or C3= to C7= for Exxon).

EWM's design of transporting olefins (cryogenic liquid) instead of methanol recovers a significant amount of water from the methanol because methanol chemically contains 56 wt% water. Onsite methanol to olefins conversion as part of EWM's process reduces rail transport cost because the water (valuable at the arid ranch site) is not transported. Oxygen is required for MTO catalyst regeneration and CO2 is produced, which can be routed to the designed onsite CO2 purification and liquefaction system and heat from the MTO reactor effluent cooling can be used in the TES system.

In addition to SAF, the olefins could be used as a green polymer feedstock. This provides future optionality for the bio-olefins because no fossil fuel CO2 is emitted in its production and the only source of carbon used in the production of the ethylene is atmospheric CO2 (DAC and biogenically captured CO2 by the alfalfa and corn).

SAF Production

SAF production is projected to increase significantly from 25,000 bbl/day in 2022 to 2,500,000 bbl/d by 2040 (31% of total jet fuel consumption) (UOP 2022). This is primarily driven by EU mandates and U.S. incentives. There are four options available to produce SAF, including:

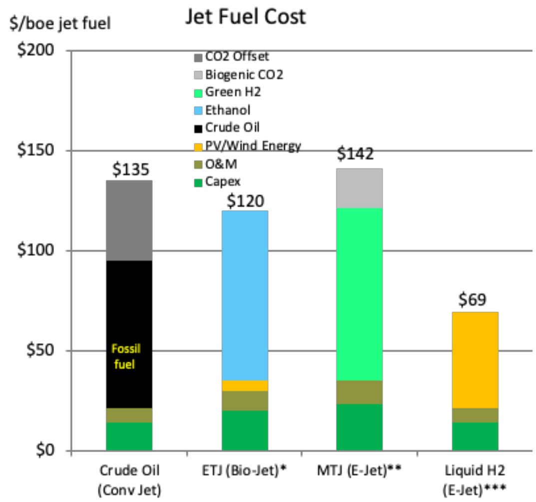
- Hydrotreated vegetable oils (HVO, Bio-Jet)

- Ethanol to jet (ETJ, Bio-Jet)
- Methanol to jet (MTJ, E-Jet)
- Biomass to jet (Hydroprocessed Pyrolysis Oil, Bio-Jet)

For each SAF option, a biogenic or DAC CO2 source is required to meet the evolving EU SAF standard. Fossil fuel-based CO2 for SAF is currently being evaluated in the US; however, producing SAF from fossil fuel-based CO2 has a net release of CO2 to the atmosphere. Land use is also a limitation in the evolving EU standard. Biomass from forestland, peatlands, wetlands, and other land that is currently sequestering significant carbon cannot be used to make SAF, because this also would result in a net release of CO2 to the atmosphere. (European Parliament Research Service 2022; International Council on Clean Transportation 2022).

EWM's Full Recovery Agriculture™ design converts biomass produced on arid land that currently has very low biological carbon sequestration due to limited water for plant growth. EWM's process harvests only invasive biomass from the managed wildlife rangeland and significantly improves the carbon capture of the native plant by providing water during drought. This avoids range fires and loss of both carbon sequestration and wildlife habitat. The additional carbon sequestration in the managed wildlife rangeland offsets the low land use impact of the PV field with stormwater capture and the ultrahigh yield SH agriculture.

EWM's process converts the mixed biomass sources (manure, urine, wood chips from managed wildlife rangeland, corn stover, and imported cotton gin waste) to high value biogas, CO2, and biochar using anaerobic digestion and torrefaction. The biogas is routed to a natural gas pipeline or shipped as renewable LNG by rail or ship. The CO2 from DAC and the biomass from ethanol production is used to convert green hydrogen to methanol and SAF. The biochar (biogenic carbon) is used to produce silicon and the offgas from silicon production (CO rich syngas) is used to produce additional methanol and SAF with green hydrogen addition.



*Includes ethanol byproduct credits to decrease cost of internally supplied ethanol (excludes corn byproduct benefit – market price corn)
** Includes IRA green H2 credit
*** Includes IRA green H2 credit, H2 byproduct heat credit, and improved jet engine LHV efficiency (15% fuel reduction) for LH2.

Figure 25 – Sample SAF Economics

Bio-Jet (ETJ) has a lower cost of production than E-Jet (MTJ). The corn price used in the ETJ economics does not consider the savings from EWM's Full Recovery Agriculture™ process because the corn is sold internally at current market price. If the corn transfer price to ethanol is set to the break-even cost of production, then the ETJ price would be below the current fossil fuel-based jet fuel price (< $95/bbl) and would be similar to the Liquid H2 price.

The lowest E-Jet price is liquid hydrogen because it avoids the costs and efficiency loss of capturing CO2 and converting it back to jet fuel with green H2. As discussed above in the Green Liquid Hydrogen section, there are potential efficiency gains from using liquid hydrogen, both in its production and in the conversion of the liquid H2 to peaking, maritime, and aviation power.

All the carbon from EWM's Full Recovery Agriculture™ process leaves as either food, SAF intermediates (ethylene and olefins), or optionally as CO2 to sequestration. No carbon is emitted, no carbon originates from fossil fuels, and there is no net carbon impact from land use. Initially all the captured CO2 would be converted to SAF using green hydrogen through the MTJ pathway. When green H2 replaces carbon based SAF, however, the following options would be available to maintain revenue:

- Increased corn to cattle feed (no corn to ETJ)

- Captured CO2 to underground sequestration
- Ethylene and olefins used to produce PVC and other recyclable polymers

SAF feedstock optionality is an important design feature of EWM's Full Recovery Agriculture™ process to ensure long term profitability. It is difficult to predict timing of the multi-phase energy transition (i.e., jet from crude oil to Bio-jet and E-jet to liquid hydrogen).

Ammonia Production

Green ammonia is a valuable fertilizer and potentially a green maritime fuel. EWM has developed an optimized ammonia production process that uses the liquid hydrogen and liquid nitrogen produced as part of the LAES system. This system reduces cost by eliminating the compression systems and by using the TES and LAES system to provide low-cost PV based heating and cooling for the ammonia production system.

Ammonia is also converted to nitric acid in the EWM process to produce potassium nitrate and ammonium nitrate fertilizers. The byproduct heat is used in the TES system.

Potassium Nitrate Production

Potassium chloride is converted in the EWM process to potassium hydroxide, chlorine, and green hydrogen using a PV powered chlor alkali unit. The green hydrogen is captured and combined with the green hydrogen from PEM electrolysis. Chlorine is shipped as a product by rail or used to produce PVC as discussed above. The potassium hydroxide is mixed with the nitric acid above to produce potassium nitrate, the key fertilizer used by the SH crops.

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