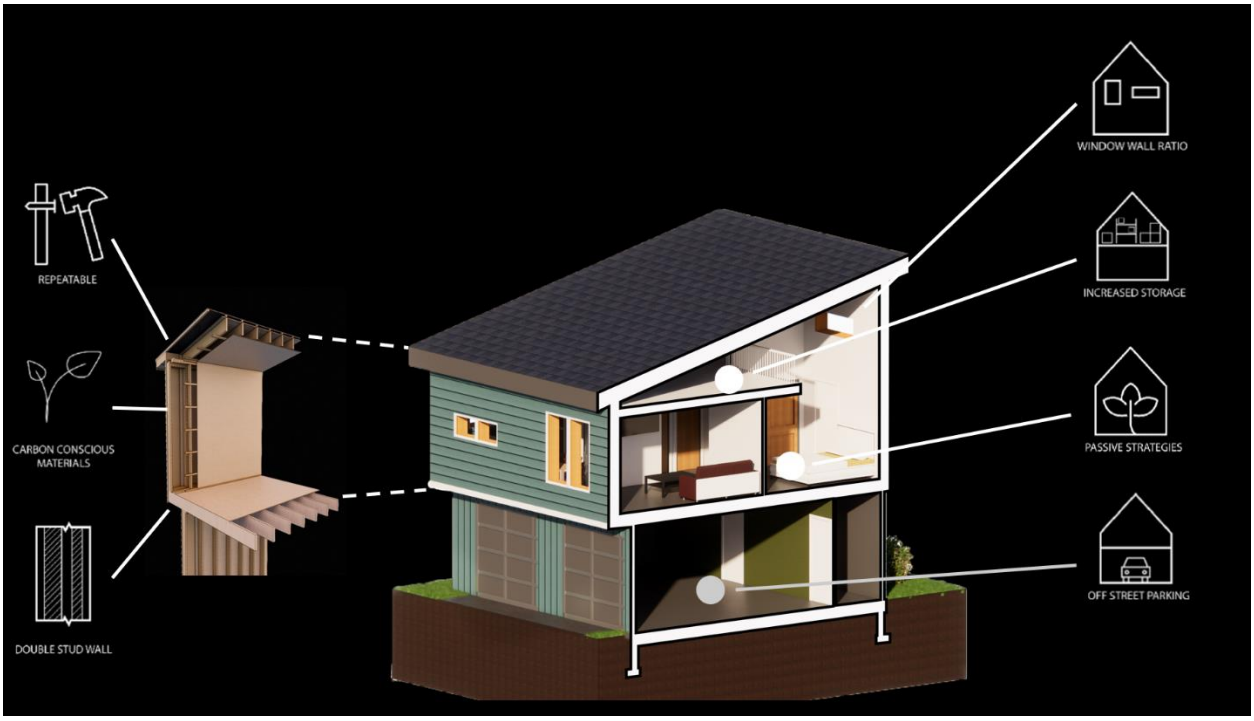
Durability & Resilience

U.S Department of Energy

Solar Decathlon 2023

Build Competition



University of Colorado Boulder Team

03/28/2023

Introduction

As Americans, around 90% of our lives are spent indoors, and as such we believe that our buildings should be both healthy to its occupants and low impact to the environment. The effects of climate change over the last two decades have brought increasing awareness of the impact our everyday actions and consumption patterns have. Additionally, global insecurity, extreme weather events, and unforeseen challenges like global pandemics are on the rise. In many ways it seems the world is at an inflection point and that the changes we make today will have tremendous effect on the future. With the ever-growing demand for energy, there is a need for solutions of all forms —and faster.

Approach

The design of the Canopy is centered around independence, free from increasing energy prices, extreme weather events, or public policy. Resilience and durability go hand in hand as resilience is durability with the ability to be prepared. Within buildings, this comes in various forms. A building must be resilient to the climate, society, and environment, while being durable with its choice of materials and longevity.

Enclosure Resilience

The building enclosure is the primary defense against the outside world providing shelter to the home. The durability of an envelope is essential for the longevity of the building. Since our building materials encompass embodied carbon, it is essential that our materials are long-lasting to prolong their life cycle. We focused to build a resilient enclosure based on:

- Thermal Comfort
- Controlling Indoor Air Quality
- Energy Efficiency
- Embodied Carbon

Moisture Control

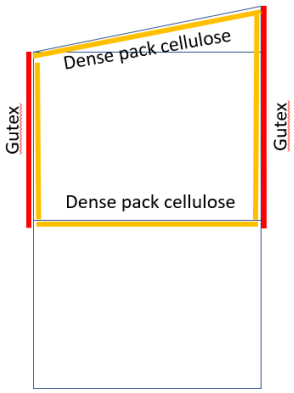
One of the biggest detriments to a building envelope is the accumulation of mold. This can lead to problems with indoor air quality, as well as more drastic problems like structural damage. To build a resilient envelope, a robust weather resistant barrier (WRB) is needed. We chose to incorporate the Solitex Mento 1000, which is a 3-layer monolithic membrane that is both incredibly waterproof as well as vapor open to allow drying of the envelope outwards.

Air Sealing

A high performance and airtight envelope has a few primary benefits. First of course, it reduces infiltration which in heating dominated climates can contribute to a large portion of heat loss. Second, it helps insulation work better by reducing convection within the insulation materials. Third, it promotes better indoor air quality by limiting outdoor air contaminants and dust.

Continuous Exterior Insulation

Continuous exterior insulation helps to control moisture by reducing condensation from occurring within the enclosure. It helps to mitigate the harsh effects of outdoor air conditions to promote a long-lasting structural framing system. Although the entire envelope is not continuous, we have a continuous blanket of Gutex which surrounds the walls of our home.



Energy Resilience

In the last year, a global energy crisis triggered by Russia's invasion of Ukraine has caused profound volatility on the global energy market. These changes could dampen the transition to decarbonize our world and have lasting effects on the price of energy and policy. Additionally, there has been an increase in extreme weather events due to climate change, increased risk due to cyber security, and general societal unrest.

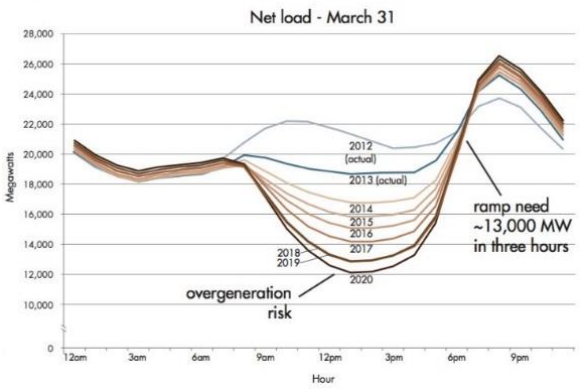
Challenges

The exponential increase of Renewable Energy Supply both BTM (Behind-The-Meter) and Utility-Scale Generation has stirred a global rush to changing how we use, think, and interact with Energy. Additionally, it has come with unforeseen challenges that require immediate solutions.

The Duck Curve

The intermittency of renewables is an increasing challenge which is often referred to as the "duck curve" due to its resemblance of a duck as shown below [2].

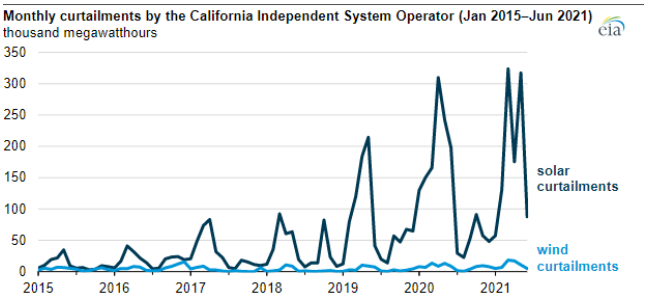
The figure depicts the CAISO and the net load curves they have experienced over the last decade. As seen the duck has been getting "fatter" which requires sudden ramping and slowing down of the power generation on the grid. This has tremendous challenges for both the cost of electricity and meeting demand with both an overgeneration and under generation affecting the delicate balance of the grid. Although accurate forecasting for both wind and solar production are continually refined, the unpredictability and variability still pose significant difficulties.



Furthermore, as seen in California and Hawaii in recent years, the amount of BTM solar growth adversely affects the grid by not being able to predict the amount of DERs (Distributed Energy Resources). Before widespread solar adoption occurred, this challenge was less significant but as policies and regulation for Residential Solar change so does the adoption. Hawaii was the first state to stop Net-Metering for residential solar customers in 2015 with Hawaii Electric Industries stating the infrastructure was not ready to handle the demand. Instead they incentivized on-site utilization and energy storage along with demand shifting [3], In many states renewable saturation is still very low; however recently the California Public Utilities Commission's proposal for NEM 3.0, has sparked the conversation around Asymmetric Net-Metering [4].

Energy Curtailment

One of the significant downsides of excess renewable generation without storage is curtailment—the deliberate reduction in output below what could be supplied [5] . In recent years Wind and Solar Curtailment in California is on the rise as shown below:



This typically occurs in the shoulder seasons like Fall and Winter. In 2021, solar accounted for 17% of California's utility-scale generation with 8% wind. In the same year, CAISO curtailed 1,400 GWh of Solar and 80 GWh of wind—estimated to be enough to power 220,000 homes in California.

One of the enormous benefits of Hydrogen is its ability to store energy seasonally without degradation. Instead of curtailing energy, excess energy could be used to produce Hydrogen that could be stored until the Summer or Winter when it is needed the most. Critics of Green Hydrogen often say that the efficiency could not compare to batteries, however with excess energy needing to be curtailed and current battery technology not suitable for long term storage, Hydrogen is debated as a plausible energy carrier. Instead of curtailment, Green Hydrogen could be produced or distributed for other uses besides just power generation. This could help advance the Hydrogen economy for uses such as ammonia, decarbonizing steel and cement production, and transportation.

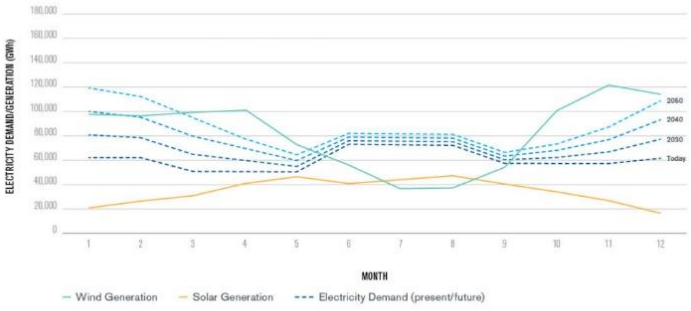
If instead of curtailment, the 1,480 MWh were used to produce hydrogen through electrolysis, around 28,150 kgs of Green Hydrogen could be produced. If all of that energy could be stored that equates to around 350,000 metric tons of CO2 that would have otherwise been emitted [6].

Energy Shift in Cold Climates

For the last century, energy has been cheap, it has been on demand, and it has been readily available. As such, when fuels proved to be a sufficient heating source for buildings, efficiency was not of great importance. With the adoption of air-conditioning in homes and buildings, the peak electricity demand traditionally occurred in the Summer since most of the building heating was done with fuel. The growth of building integrated photovoltaics has aligned with cooling dominated climates which have seen exponential adoption and financial incentives along with increased reduction in price.

As demonstrated by the PJM interconnection, currently seasonal electricity peaks in the summer [7]. It is forecasted though that with the electrification of space and water heating that the wintertime electricity demand will spike, worsening seasonal variation and misaligning with solar peak production.

FIGURE 1: SEASONAL VARIATION IN WIND/SOLAR GENERATION AND ELECTRICITY DEMAND (AS HEATING IS ELECTRIFIED)



As heating demand is electrified, annual peak demand is shifted from June(6), July(7), and August(8), to December(12) and January(1). This shift brings the annual demand curve closer in line with regional wind generation variability.

Although wind energy often peaks in Winter, residential wind power has many limitations that solar does not offer. As homeowners become more aware about energy and it's increasing cost, energy efficient and demand response measures can help to dampen the peaks and flatten the curve

Energy Independence

Residential rooftop solar has allowed the opportunity for homeowners to take back some control over their energy use. It adds resiliency to changing energy prices and enables power to be produced rather than solely dependent on a centralized energy provider. In order to have a self-sufficient home three things are crucial:

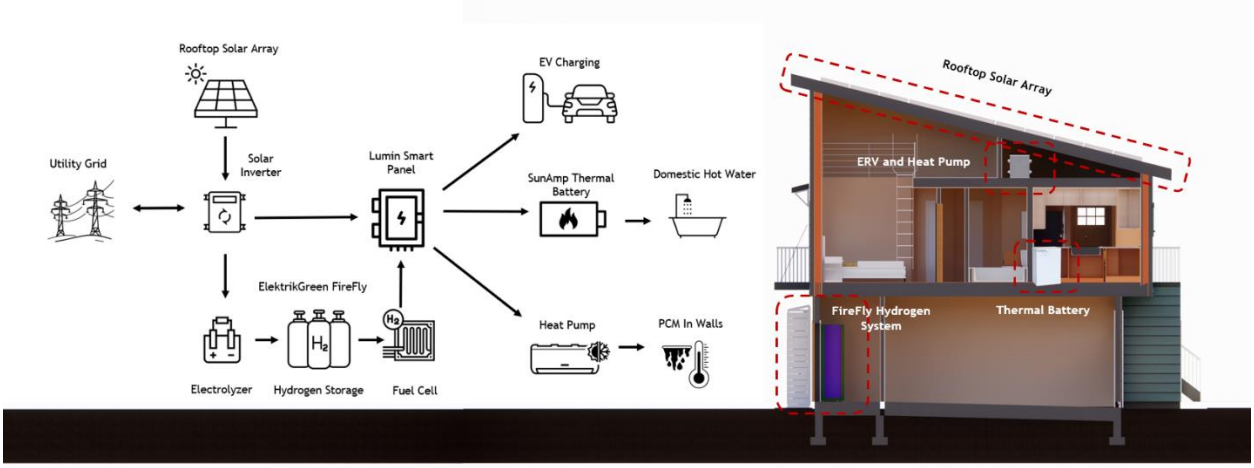
1. Renewable Energy Production
2. Flexible Energy Storage
3. Energy Efficiency

Flexible Energy Storage

The Canopy incorporates diverse energy storage to meet the loads of the home. Since many of the loads within the home are thermal, Phase Change Material (PCM) Energy Storage can help to provide affordable and low embodied carbon storage as compared to batteries.

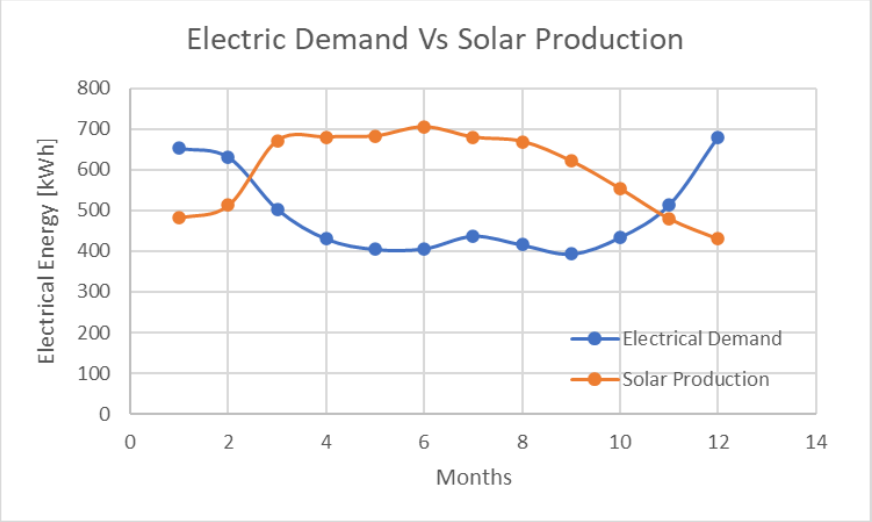
Phase Change Material within our walls help promote resiliency by reducing and storing heat flux that would otherwise move through the wall assembly. This helps to increase the passive potential of the home and helps the home itself act as a battery to store heating or cooling potential and to dampen large temperature swings.

A PCM Thermal battery allows high density energy storage with very low heat loss. Using an oversized thermal battery which can store 10.5 kWh of hot water heating potential, we are able to store 2-3 days of hot water at any given time for when there is less solar production or when energy storage is critical.



Seasonal Energy Storage

For BTM solar, one of the primary challenges is that in heating dominated climates there is a mismatch between the electrical demand and the solar production. In the summer there is a surplus of solar production while the demand is minimized. Given fixed building massing, roof pitch, and orientation the home was limited to improving the performance of the rooftop solar array. The tilt angle of the panels is only 14 degrees which leads to a greater discrepancy between the high summer sun and low winter sun.

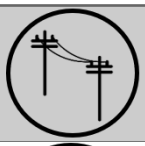
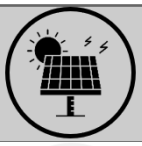
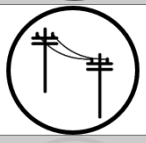
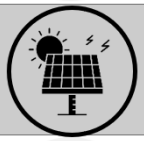
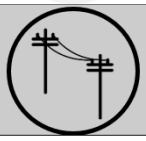
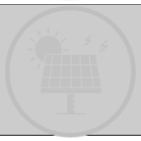


One of the primary benefits of Green Hydrogen over traditional electrical storage is its ability to store energy without degradation for days, weeks, or months at a time. Although we do not have the hydrogen storage capacity to store excess energy from the Summer until the Winter, we do have seasonal storage in the form of 5-7 days. This is especially helpful in the Fall when excess hydrogen can be produced and stored to help mitigate reliance on the grid in the Winter when there is less solar production. With 55kWh of max hydrogen capacity, this equates to around 3-5 days of daily energy storage or 5-8 days of storage to last the nighttime.

Energy Independent but Grid-Connected

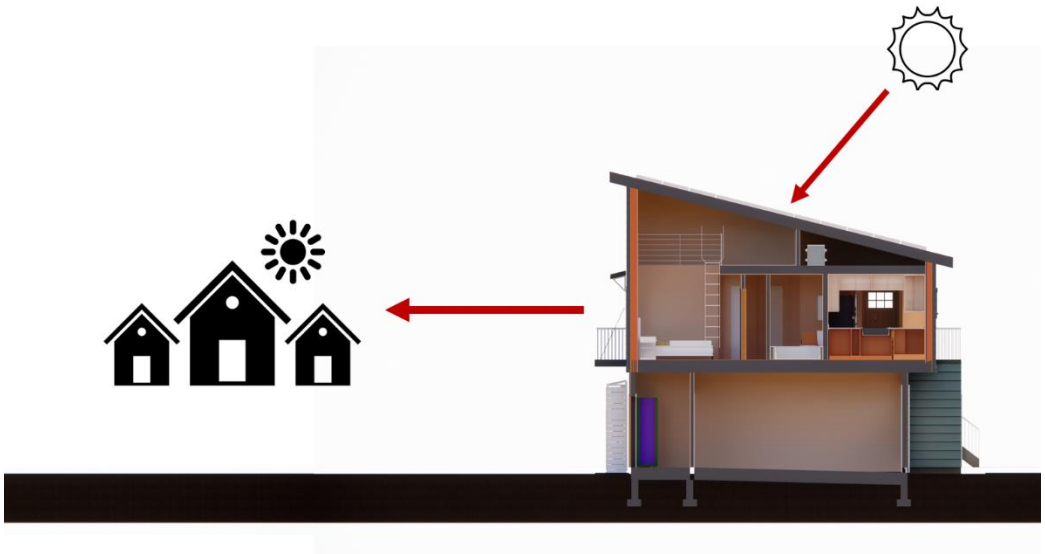
The Canopy will be the first grid-connected home in Colorado powered through solar and hydrogen storage. Being grid-connected allows for flexibility, future proofing, and net-metering while still having the benefits of a self-sufficient energy storage system. Using a smart panel board from Lumin Smart, we can automatically shed loads whenever there is an interruption in the grid power to prevent discharging all our energy storage. These loads can be prioritized and individually controlled allowing for advanced flexibility and monitoring to balance the home energy demand and our energy storage.

The FireFly system can operate in 5 separate modes:

#	Mode	Utility Grid	Solar	FireFly
1	**NORMAL OPERATION** Typical operation for the FireFly system. The Utility Grid, Solar System, and Firefly System are all Active Power Sources for Energy Use.			
2	**NO SUN** Operation when No Sun Power is available to the Solar System. The Grid and FireFly System can both provide power for Energy Use.			
3	**GRID DOWN** Operation when the Utility Grid is down. The Solar System and FireFly System can both provide power for Energy Use.			
4	**BACK-UP POWER** Operation when there is No Sun Power, and the Grid is down. The Firefly System can still provide power for Energy Use.			
5	**GRID POWER** Operation for the system when there is No Sun Power, and the FireFly System is depleted and cannot be an Active Power Source. The Grid is the only Active Power Source for Energy Use.			

Community Energy Solutions

With the proximity of the neighboring homes, and initial plans for the community to have a solar garden, a promising future development could be incorporating a community hydrogen system. This could be incorporated in various ways, most simply by providing backup power to neighboring homes in the case of a power outage. Since the Canopy will be the only home in the community that includes solar, the Canopy could act as the central powerhouse for hydrogen which could be dispatched to form a small microgrid. Not only would this help to reduce the cost for the system, it would help to provide affordable housing with backup power which typically is only done with an onsite generator.



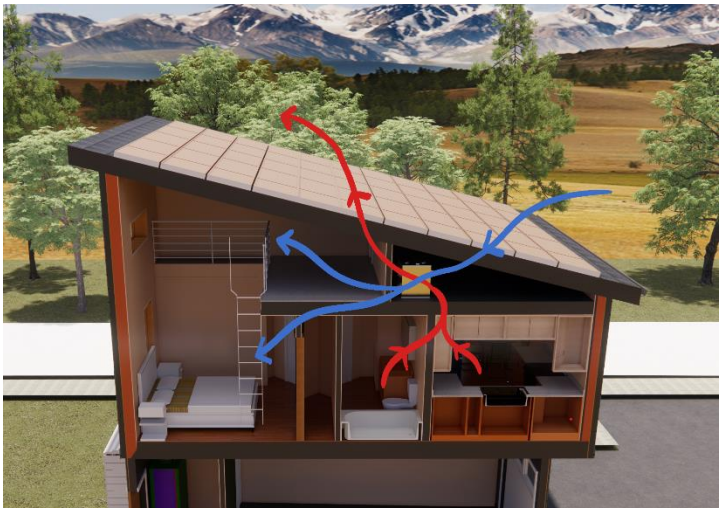
Wildfires

In December of 2021, The Marshall Fire broke out which became the most destructive fire in Colorado history. The uniqueness of the fire was that it occurred in December and was most ultimately a result of climate change. It rekindled the conversation of whether our aging electric infrastructure will be able to handle extreme weather events, and the role in wildfires.

With this recent wildfire, we wanted the home to be future proof to the ever-changing climate. The home features a full fire suppression system within the living space. Additionally, we will incorporate Fire and Ember Safe roof vents provided by Vulcan Vent. This helps to eliminate the spread and ignition of fires due to stray embers in the roofing material.

Demand Response Ventilation

Using our Renew Aire ERV, the home will be provided with continuous, balanced ventilation throughout the year. However, when outdoor air quality is drastically reduced, the ERV will stop providing outdoor ventilation air to help maintain indoor air quality.



Operational Carbon

The primary source of CO2 emissions within a home come from the operational energy. Although Net-Zero Energy offsets all the emissions that are used. A grid-connected energy independent home not only provides all the energy it needs without emitting CO2 as well as offsetting emissions. Through building modeling, it was determined that only 6% of the year required any grid power.

Energy Total		
Home Demand	4,336	kWh/Yr
Demand Met	94%	-
Demand From Solar	57%	-
Demand From H2	36%	-
Demand From Grid	6%	-

Ave Mtn. West Home Save Size	8,507	kWh/Yr

Yearly H2 Storage		
Tanks Empty =	404	Hours
Tanks Full =	1,621	Hours
From Grid =	313	Hours
To Grid =	2,822	Hours

The actual CO2 emissions that were emitted by using energy from the grid are shown below. The Hydrogen System drastically reduces the operation carbon by 97%. Using a fixed CO2 intensity for the 2022 Colorado State Electricity profile, a 20-year analysis was done. Over the course of 20 years if the grid remains the same, the home will only emit 3.02 Metric Tons of CO2. This is of course not counting all the energy that is offset from net-metering back to the grid.

2023 Estimated Emissions [EIA Colorado Electricity Profile]			
Home Size	**750**	***SF***	**% Reduction**
CO2 Emitted [Average Home]	5,027	*kgCO2*	0%
CO2 Emitted [Design, No Solar]	3,523	*kgCO2*	30%
CO2 Emitted [H2 System]	151	*kgCO2*	97%

20 Year CO2 Emissions [Fixed 2022 EIA Colorado Electricity Profile]		
Home Size	**750**	***SF***
CO2 Emitted [Average Home]	100.55	*Metric Tons*
CO2 Emitted [Design, No Solar]	70.47	*Metric Tons*
CO2 Emitted [H2 System]	3.02	*Metric Tons*

Use Water Twice

With the growing water scarcity issues following the Colorado River, we wanted to incorporate water reclamation or water reuse. Hydraloop's system is a low energy grey water recycling system that takes water from your shower and sink (except kitchen) to then be used for toilet flushing or for irrigation. Since the majority of the water we use in our homes is used in the shower or in the sink, by "Using Water Twice" we can capitalize on huge water savings without the cost of a whole home grey water filtration system.

Although the City of Boulder has not adopted Regulation 86, which outlines requirements for gray water, Hydraloop and our team have met with them to discuss the potential for future adoption to enable grey water recycling.