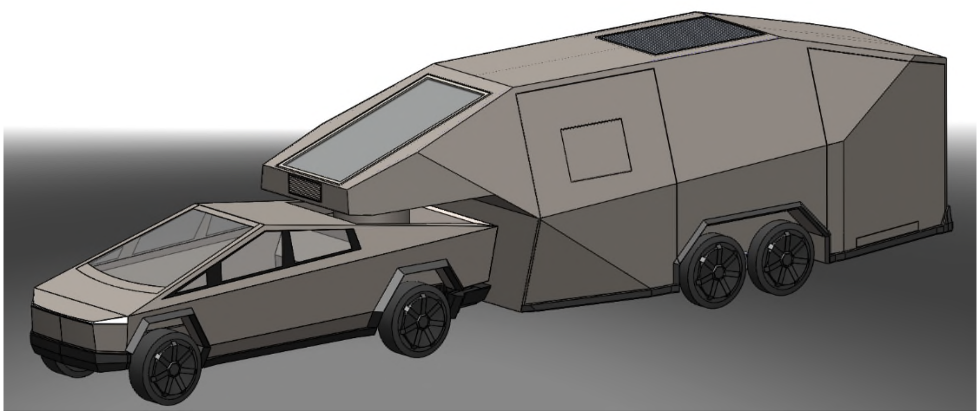
Armadillo Recreational Vehicle

As design studies for technology relating to sustainable and efficient housing concepts are being developed, a unified platform for integrating the concepts is needed. The use of a recreational vehicle (RV) was chosen as it represents the trend towards smaller housing as well as imposing space, technology, and integration limitations that highlight the flexibility of implementing the proposed concepts.

This design summary is a description of a technology demonstration platform, the Armadillo Recreational Vehicle. The summary describes critical features that relate to sustainable concepts, either already addressed in past studies, or features to be explored in future studies.

Basis of Design

The design is a 30ft total length fifth wheel RV based on the Cybertruck concept from Tesla Motors. Angular styling cues are taken from the Cybertruck design, married with the use of a mostly flat plate exoskeleton serving as the exterior boundary as well as the vehicle structure. The shape and size are optimized to mate to a Cybertruck, though it would be compatible with most other trucks with sufficient towing capacity.



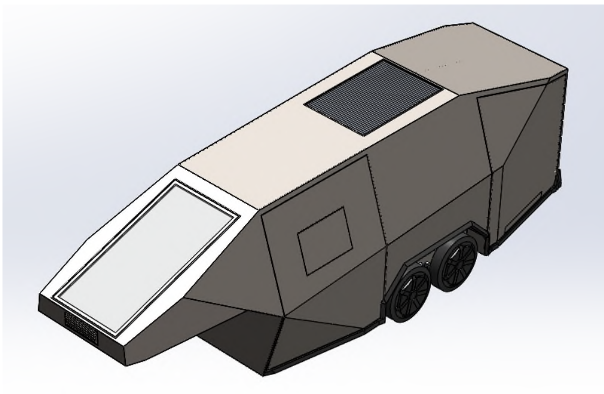
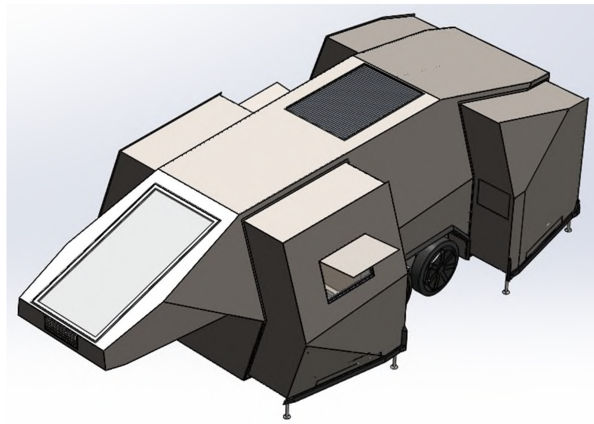
Description of RV

The Armadillo RV is a completely self-sustaining, off-grid housing alternative. It has all the requirements for full-time occupancy including:

- Kitchen with standard amenities including a range, oven, refrigeration, and sinks
- Bathroom including a shower, composting toilet, and vanity.
- Master bedroom capable of fitting a full-sized bed, clothing storage, and desk.
- A living room that can accommodate a sleeper sofa, entertainment devices, and dining arrangements.
- A small forward berthing area that can be used for additional sleeping arrangements or storage.
- Integrated plumbing, electrical and HVAC systems.
- Solar panels providing electricity and hot water.
- A water recycling system to minimize water usage.

- Integrated on-board battery system.

All amenities are available with the RV in its closed configuration (slideouts retracted) or with slideouts extended. The closed configuration results in approximately 150ft² of usable floor area, and the latter configuration has 210ft² of usable floor area.

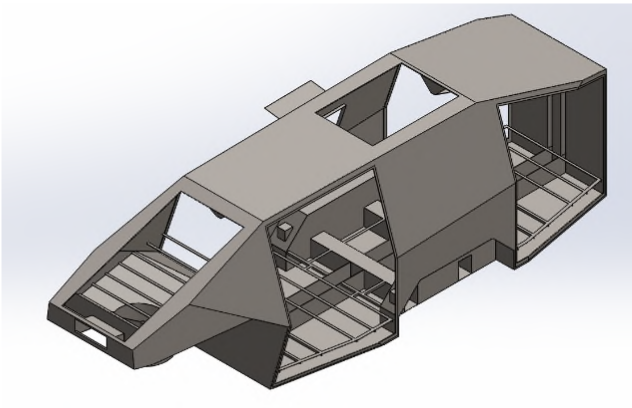



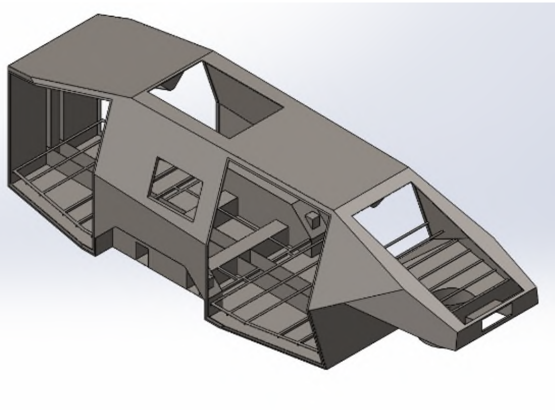
RV Specific Aspects of the Design

The purpose of the Armadillo RV is to highlight sustainable living concepts and not vehicle conceptual development. Therefore, RV specific aspects of the design are considered, by only to demonstrate high-level feasibility and define a space envelope for developed concepts. No additional design analyses or studies are planned for these aspects of the Armadillo. Specific items that fall under this category are the structural design, insulation, slideout design and operation, suspension and braking, towing attachment, and towing characteristics. Each of these aspects of the design are described below for meeting the requirement of defining the limitations for future design studies.

Structural Considerations

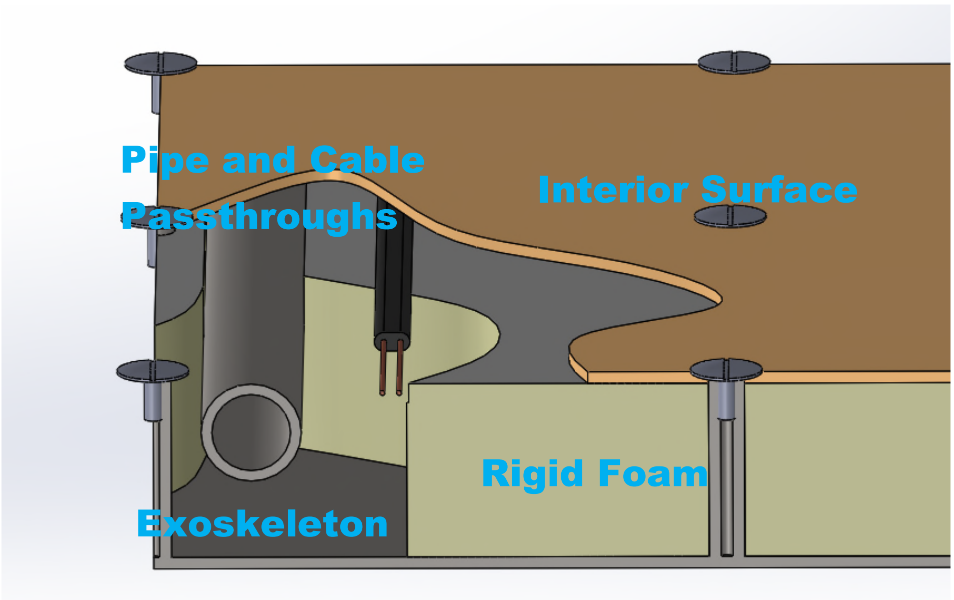
The structure is a 3mm thick stainless-steel exoskeleton with reinforcements around the openings and a "keel" and "spine" to counteract bending in the longitudinal direction. Nominally all portions are made of high strength stainless steel with continuous welds. Where pass-throughs are needed (as for plumbing or electrical cabling) re-enforcements will be made in a manner that would offset any weakening of the structure. This definition of the RV structure serves to determine the constraints for size and space available when performing future design studies. Pictures of the exoskeleton are shown below.





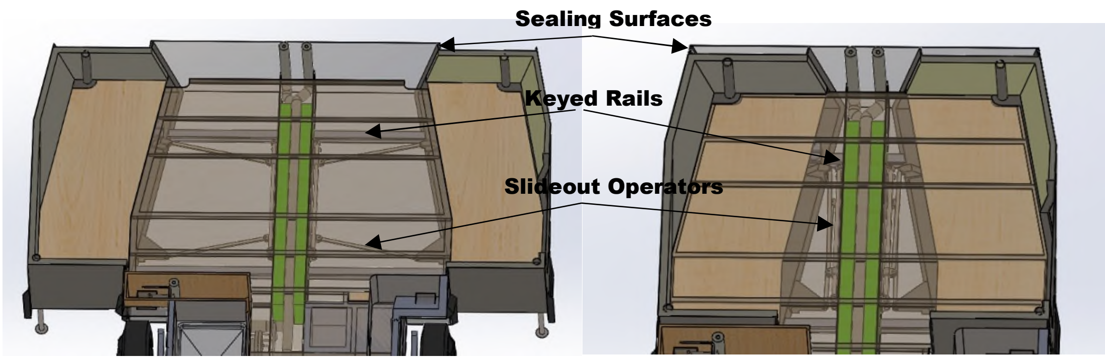
Insulation and Openings

The insulation system modeled closely represents a simplified approach to a developing home insulation concept. In this application the insulation system is a high thermal resistance rigid foam sandwiched between the exoskeleton and protective interior sheet. The assembly is held together by removable fasteners to allow access to embedded wiring and piping, as well as provide the ability to customize the appearance of the outer surface by replacement. The integration of the insulation system defines additional space considerations and can be used to determine heat losses that will have to be accounted for during future system design. Windows and doors have shutters that match the exoskeleton, so when closed they provide protection against the elements. Doors would have insulation on the interior surface similar to the wall insulation system. Windows would have double glazed glass with exterior tinting that could be electronically controlled. The figure below shows the construction of the insulation system.



Slideout Design

Slideouts are integrated to maximize internal volume and provide packaging challenges for mechanical and hydraulic systems. Four slideouts are included, each designed and operated in a similar manner. Slideouts are constructed in the same manner as the exoskeleton, using re-enforcing plates at the flanges that interface with the exoskeleton in the retracted and deployed configurations. The slideouts are supported and ride on keyed rails welded to the bottom of the exoskeleton structure. Screw-jack style operators provide the force to move the slideouts along the rails. In the deployed position deployable outriggers are integrated to provide tipping support for the entire RV. The floors for the slideouts are stowed under the main RV floor when the slideouts are retracted and are automatically raised to the same level as the main RV floor during slideout extension. Sealing between the slideouts and structural shell is done with the contact of gaskets on reinforced flanges in the retracted or deployed positions. This design minimizes the available under-floor space available for other systems (due to floor stowage and operator space requirements, and imposes additional seals that must be accounted for with the HVAC system. The figures below show the forward slideouts in the extended and retracted positions.



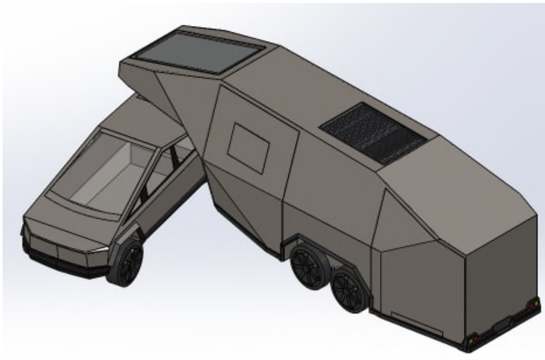
Suspension and Braking

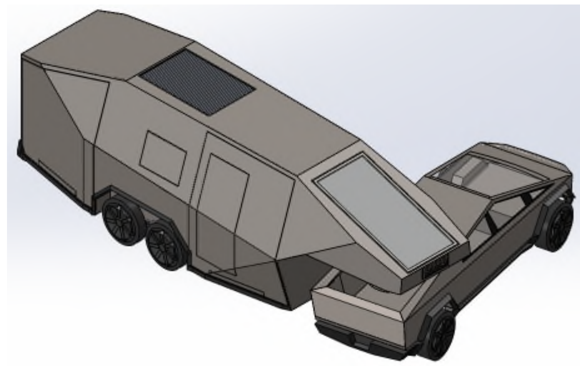
Suspension is currently modeled as a leaf-spring setup capable of supporting up to 20,000 lbs of weight. The ability to use air-spring suspension is also considered viable and would be implemented in the same space envelope. Braking is provided by disc brakes at each wheel as well as regenerative braking with an axle mounted generator. This could be used as a supplemental motor to assist with towing, but that has not been fully considered. Space allowance for the suspension and a thick axle mounted motor further challenges equipment packaging.

Towing Considerations

The towing attachment is a basic ball type gooseneck. The size of the gooseneck is based on preliminary dimensions of the Cybertruck to allow for "jack-knifing" during maneuvering without interference. Additional power and control hook-ups have not been developed, but some means of providing trailer power to the Cybertruck to supplement the battery capacity would be ideal. The design of the Cybertruck bed requires a high gooseneck, limiting the space available inside of the RV. The figures below show the cutouts of the gooseneck required to allow for maneuvering the fifth wheel RV with the Cybertruck.

Basic considerations on towability were considered, but not fully explored. These include placing the center of mass roughly between the two axles of the trailer, minimizing overall weight of components where feasible, fairing the trailer to improve aerodynamics, maintaining a low center of mass, and providing the same ground clearance and tire sizes as anticipated for the Cybertruck. Mostly these considerations led to a smaller available space envelope.





Sustainable Design Details

This section covers the areas where additional design work is anticipated or is in progress. It highlights the ability to create a sustainable off-grid housing solution without minimizing comfort or long-term livability. The concepts described are only the concepts considered so far, but additional designs and systems may be integrated in future studies.

Process Water Loops

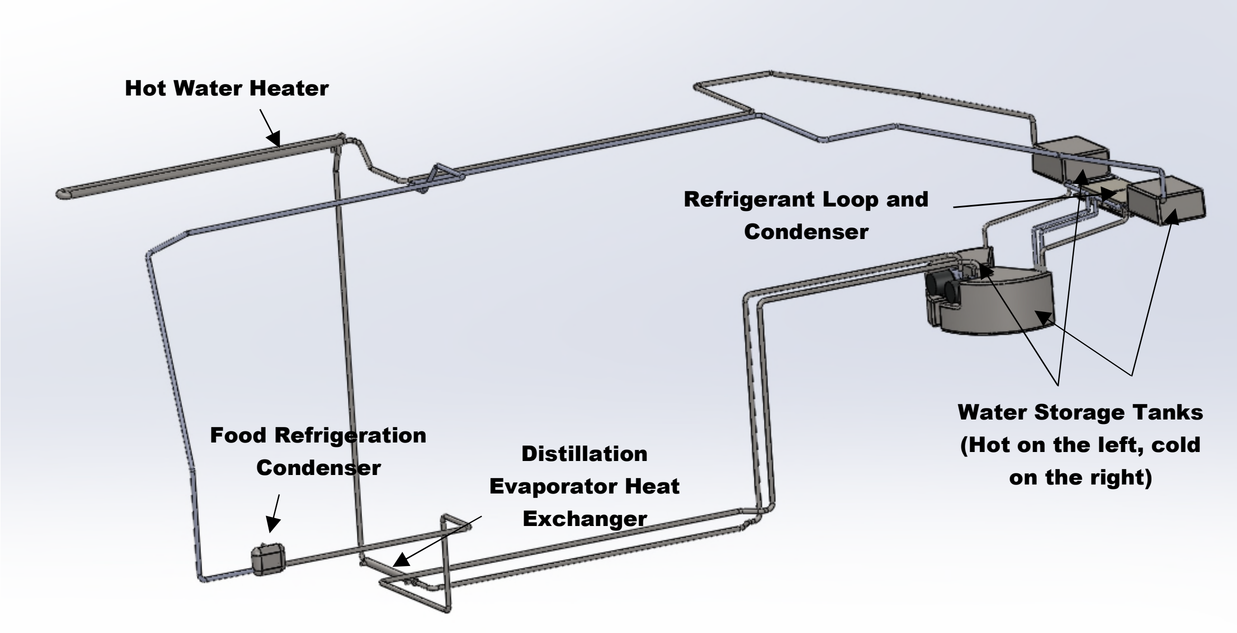
This concept was covered in part as the Residential Hot Water System White Paper (0001-005-WHT-01). A cold water loop similar in concept is also included in the RV.

The hot water loops services hot water heaters, the flash evaporator, and HVAC air handlers. Heat input comes from a solar hot water panel, waste heat from the cold water system, and electrical heating. The supply temperature is anticipated to be approximately 160°F with a maximum flow rate of 4gpm through heavily insulated standard ¾” piping.

The cold water loop services battery cooling, water cooled food refrigeration condensers, and HVAC air handlers. Cooling is provided by a large capacity high temperature refrigeration cycle driven by battery power. Cooling water supply temperature is anticipated to be approximately 40°F with a maximum flow of 4gpm through heavily insulated ¾” piping.

Both loops are supplied from the gooseneck area by tank mounted recirculation pumps. Return is back to head tanks to form a closed system. The figure below shows the loop layout and the integrated heat exchangers. The insulation has been removed, but a space allowance for 1 inch of insulation is provided for all surfaces. Note that smaller services (HVAC, battery cooling, etc.) are not detailed, and the method of tapping into the loops will be developed during detailed design studies.

Future studies will look at heat exchanger sizing, optimal refrigerants and refrigeration cycles, heat recovery from the cold water condenser, and realized efficiency through the use of solar water heaters and water cooled food refrigeration condensers.



Water Recycling System

The minimization of water usage and pollution minimization is considered a primary consideration for sustainable design. The starting concept is to design a system that can recycle grey water from onboard and external sources to provide potable water for cleaning and consumption. Note that the RV has no black water system as it uses a compostable toilet of standard design. Recycling of grey water from drains requires extensive water treatment at a much smaller scale than generally implemented. The size of the system would allow for treatment of the maximum anticipated water usage for a four-person family over a 24 hour period. This is estimated at no more than 150 gallons/day, so a small-scale recycling system operating at 0.5gpm would be running on average five hours a day, which could coincide with the timing of peak solar water heating availability and electrical production capability, both during the daytime.

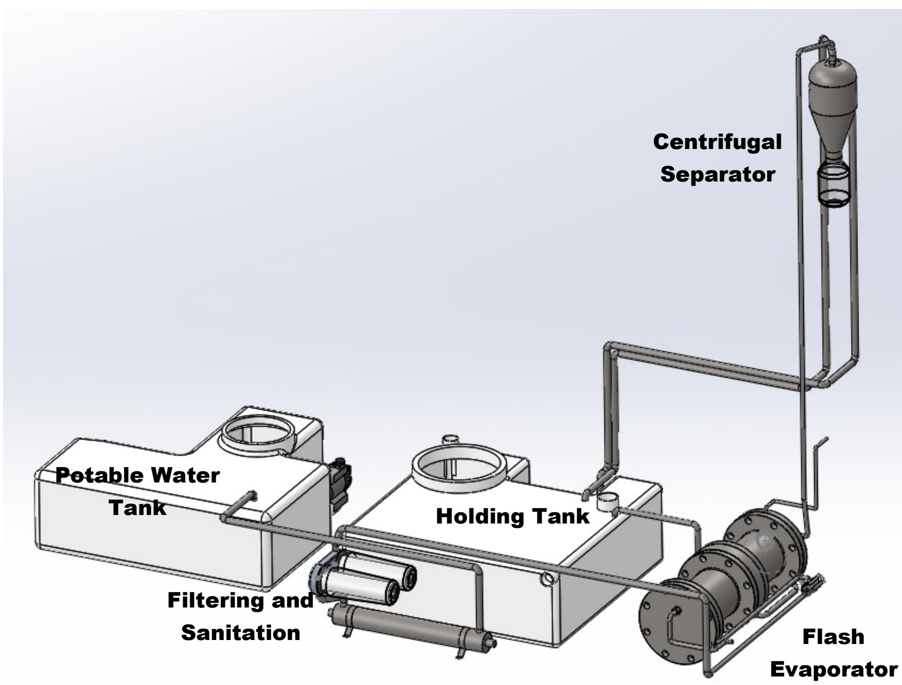
Disposable by-products of the water treatment system will be avoided where possible and the use of chemicals minimized to reduce environmental impact and allow for long-term un-supported operation. The initial concept is still in its infancy, but is envisioned to have the following steps:

1. Grey Water Collection - Grey water is collected from various sources including the shower, sinks, and condensation from air handlers. This grey water is stored in a holding tank where it is dosed with a minimal amount of coagulant to enable precipitation of impurities and surfactants. Dosing will be automated based on water treatment system dissolved solids readings to minimize chemical usage. The size of the holding tank (approximately 50 gallons) is such that continual demand on the treatment system is not required, allowing for its operation in off-peak times and when energy is more readily available.
2. Precipitate Separation - The dosed grey water is circulated through a centrifugal separator where precipitates are collected for solid waste disposal. A circulation pump connected to the holding tank operates on demand based on water level, power availability, schedule, etc.

The circulation also provides good mixing in the holding tank, minimizing settling of sludge in the holding tank and the requirement for regular cleanout and maintenance.

3. Water Distillation - Water with precipitates removed are sent through a multi-stage flash evaporative distilling unit to remove additional impurities. The heat source for the evaporator is the process hot water loop, with vacuum provided by an electric vacuum pump. Integrated automatic startup minimizes power consumption and allows for scheduling distillation to coincide with power availability, hot water usage, and daily schedule. The brine is redirected back to the grey water holding tank for re-processing and concentration of impurities, to be removed by the separator. Note that this is a low flow evaporator that produces approximately 0.5 gpm of fresh water.
4. Final Filtering and Sanitation - Distilled water is sent through a carbon filter to remove residual odors and then through a standard membrane filter to catch any carbon particles. The deodorized water is sent through a UV sanitation system to kill any residual biological contaminants that remain. As the water is very clean prior to entering the filters, filter changes should be very infrequent, minimizing the reliance on disposable products, and UV sterilization should be very effective given the clarity of the water.

The resulting water is held for use in a potable water tank. The supplied water is distilled and sanitized, so few if any chemicals should be required if water usage is consistent enough to minimize stagnant water conditions. Potable water is pressurized and distributed with an attached pump.



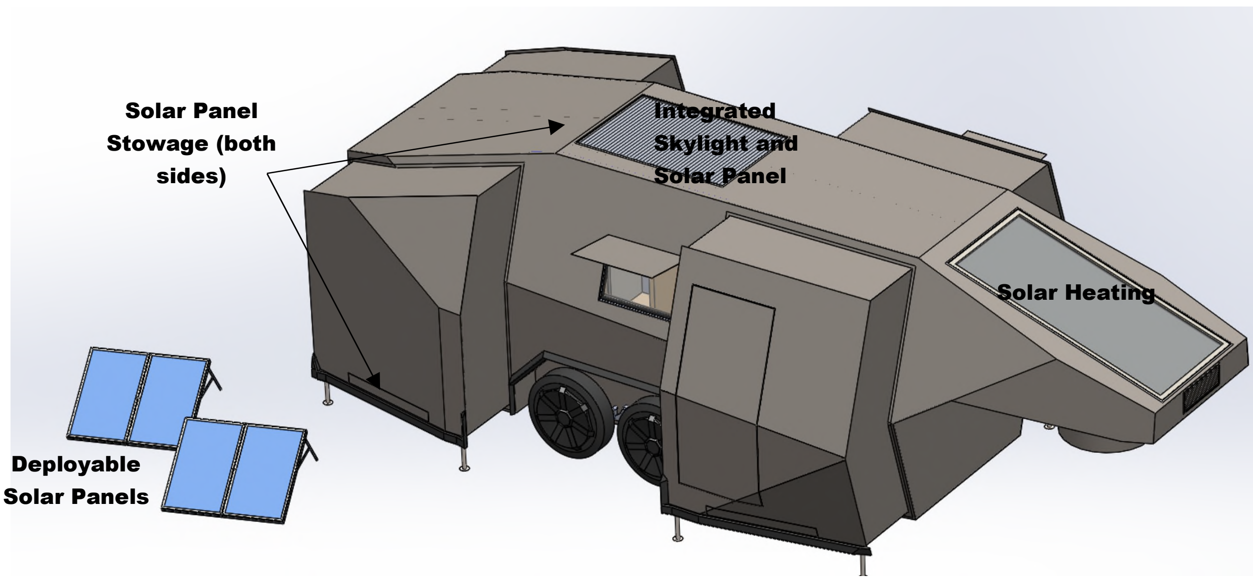
Usage of Solar Energy

Solar energy will be used as much as possible to generate power for the RV. Installed solar energy capture includes a solar water heater and skylight with integrated solar shades. Supplemental solar panels are deployable when stationary to enhance electrical generating capability.

Heating of water is very energy intensive and generating electricity to heat water is prohibitive given the low efficiency in converting solar energy to electricity. A large solar water heater is installed that directly heats the process hot water loop where solar energy is stored in the form of hot water in insulated storage and head tanks. Given the flexibility provided by having a process hot water system that provides most of the energy required for water purification, it allows for efficient use of solar energy when available.

For comfort and habitability purposes, a large skylight is incorporated in the RV design. To make the most of this surface area, internal louvers are integrated that provide shade and have embedded solar cells for additional power production. The louvers can be programmed to follow the sun to maximize collection of solar energy or manually operated to increase light in the RV.

Traditional deployable solar panels are stored in the RV for manual deployment when stationary. They provide the majority of the electrical energy required to power the electrical system when operating off-grid. They are sized to be stowed in provided compartments in the rear slideouts and have a surface area of approximately 2.5m², which on most days will be sufficient to provide the daily power for the RV as well as some charging of the onboard batteries. Additional solar panels could be integrated to the top surface of the RV, but they would impact aerodynamics, and working within the power limitations of the solar panels detailed enforces more focus on energy conservation.

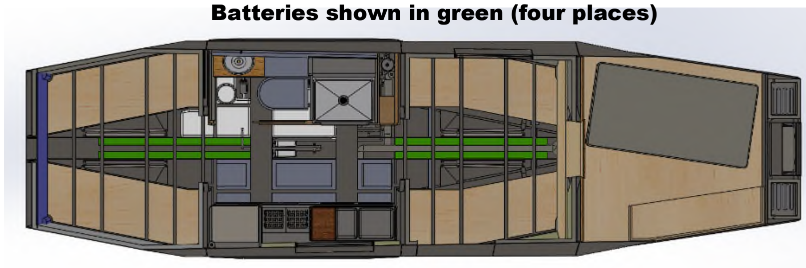


Electrical System

The electrical system is based on a high voltage battery system (compatible with a Cybertruck). Traditional battery management systems would be used to power a high power battery feed for appliances (electrical water heating, slideout operators, oven, refrigeration compressor) with the majority of the power being consumed as 24VDC for lighting, HVAC, process pumps, fans, etc. Some 120VAC outlets will be provided through an inverter to power traditional equipment.

The batteries are modeled after those found in the Model 3 and Model X. As currently arranged, 1,000W-hrs are shown in battery packs with the same dimensions and aspects of Model 3 battery packs. Additional power storage could be integrated with custom designed battery packs that maximize the available volume in the floor-pan area of the RV. Note the location of the battery allows for easy implementation of cooling through the cooling water supply header, and lowers the center of mass of the RV.

Batteries shown in green (four places)

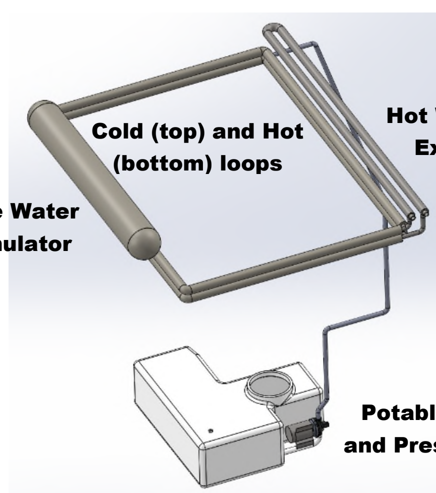


Main floor removed for clarity

Potable Water Plumbing

Plumbing consists of insulated conventional piping, with the majority being ½" nominal due to anticipated lower water usage and fewer connections than in a typical house. Water pressure will be slight lower than household plumbing at around 30psi, further conserving water usage. The potable water headers (both hot and cold) are fed from a single accumulator in the ceiling. The accumulator is connected to a cold loop ring header that is supplied water from the potable water tank. A high pressure pump provides potable water to the header. A pressurized air pocket at the top of the accumulator is used to maintain constant pressure for the potable water system.

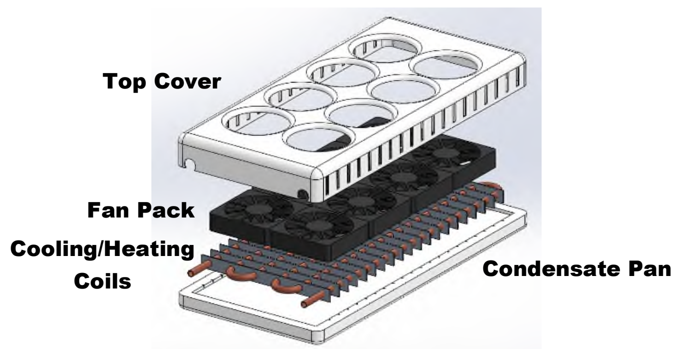
The hot water loop is supplied by flow from the cold water loop through the hot water heat exchanger. The hot water heat exchanger transfers heat from the hot process water to the hot potable water. Hot process water will be continuously circulating through the tube side of the heat exchanger, so potable hot water will be instantly available when demanded. For the small space envisioned, only one hot water heater is needed, and is sized to bring 2.5 gpm of water from 60°F to 110°F. This hot water heater serves the sinks and shower. The hot and cold loops, supply from the potable water tank, accumulator, and hot water heat exchanger are shown in the figure below.



Heating Ventilation and Cooling (HVAC)

HVAC is provided by three discrete air handling units that contain coils serviced by the hot or cold process loops dependent on the conditioning requirement (two in the general living area and one in the bedroom area). Independent fans take suction from the RV ceiling void and pass it over the coils for conditioning where it is distributed through the ceiling panels. The recycled air is filtered for particulates and odors in return vents located in the ceiling area over the kitchen.

The entire envelope of the RV is maintained at a slight positive pressure provided by a low volume pressure blower taking suction from the exterior of the RV through a HEPA filtration system. The positive pressure ensures that external air contaminants are prevented from entering the RV and provides a controllable amount of fresh air introduction.



Additional Considerations and Concepts

This section outlines concepts that have been considered, but little development has occurred to date, and may never be fully realized. These include:

- A stove system that duplicates the experience of a gas range, but is more energy efficient and requires no storage of combustible gases. The use of induction cooking is the most rational implementation for the RV, but the ability to cook in a manner similar to a gas stove without using combustion products may be investigated.
- Additional power generation beyond solar may require the use of wind energy. Integration of windmills, vertical turbines, tethered kites, or similar may be investigated as a means to enhance the energy generation capability of the RV.
- A hands-free faucet concept may be integrated with the kitchen. The concept would be a foot operated faucet with temperature control that does not require external electricity to operate.