OFF GRID HOME BUILDING ESSENTIALS




A Comprehensive Planning Handbook for House Options, Solar, Wind, Water, Heating and Cooling

Self-Sufficiency Projects for Off Grid Living!

JOHN UTTERBACK

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Introduction

This is exciting! You have begun a journey that will allow you to escape the busyness, stress, and expense of city life and pursue your dreams of the peace, tranquility, and simplicity that off grid living offers. This pursuit promises to be a wonderful and fulfilling experience, but there are many things to consider. That's why I've written this book—to help you strategize and plan every step along the way. Your off grid adventure will be a lot of work, but in the end it will be worth it.

This book will help you carefully plan each step and avoid the most common mistakes. First, we will compare the different types of off grid homes, so that you can choose the one that best fits your budget and lifestyle. Next, we will look at the different types of electrical power, so you can select the best option or combination of options for your particular budget and situation. Third, we will consider the options for water sources. The one you choose will be determined largely by what your property has available. Finally, we will look at options in heating, cooling, and plumbing so you can consider which ones might best fit your budget, lifestyle, and house choice. This last group in particular may need to be part of your home planning, and be implemented during the construction phase. That is just one reason you will find this book to be very helpful—to assist you in the strategizing and planning phase so that nothing gets missed and everything comes together at the proper time.

Please keep in mind that this is not a "how to" book. Instead, it was designed to help you navigate all of the options for your home building essentials. The ultimate goal is to assist you in strategizing and planning your off grid journey to help you achieve your desired building success.

This book will be useful both for the beginner and for those who are already in process seeking more options. A good finish is always dependent upon a good plan—that is why this book is a great place to start!

PART 1

Home Building Examples

Part 1 describes the typical off grid home building types and general methods of construction. The home types are categorized into three different budget ranges according to total cost. This cost breakdown will be helpful in finding a home type that best fits your budget and lifestyle.

CHAPTER 1

Low-Budget Home Types

($2K to $50K)

Geodesic Dome House

(Inexpensive Kit Versions)

Geodesic dome kit houses are shell structures that come in kit form. This is a very affordable option for those wanting to get started quickly in off grid living. The spherical shape of the geodesic dome home is designed to create *structural integrity* with a simple frame and covering. The kit is relatively easy to assemble using basic tools.

Site Preparation

Once you have decided where the house will be located, the first thing that needs to be done is to clear and level the site. Clearing the site might require brush or tree removal with the use of chain saws. Leveling the site is typically done with machinery equipped with blades that are designed for earth moving and scraping (e.g., a bulldozer, bobcat loader, tractor with front-end loader, etc.).

Foundation and Materials

Once the site has been cleared and leveled, it is ready for the foundation. The foundation for this type of structure can be cement or wood. Because this structure is so lightweight, the most cost-effective foundation is a wooden deck.

The material for the deck will consist of 6"x 6" or 8"x 8" support post framing and joist boards, which are generally 2"x 10" or 2"x 12". The flooring material for the deck is most commonly ¾" 4'x 8' plywood.

The best way to build a deck is to begin by digging holes for the footings or support posts. To install the support posts, you can fill the holes with cement to serve as footings and insert brackets into the top of the cement for the posts. The posts can then be bolted to the brackets. Another option would be to simply cement the posts into the holes.

Once the support posts are installed, the support beams are laid across the top of the support posts. The floor joists are then attached to the top of the support beams. Finally, the plywood flooring is attached to the top of the floor joists.

Dome Frame Construction

The dome frame is made of painted, galvanized pipe and will arrive in pieces along with the hardware, accessories (if any were ordered), and fabric covering. Make sure the kit you order comes with specific instructions for assembly. All of the pieces should be numbered so you can follow the assembly sequence; otherwise, the assembly process and sequence can be difficult to figure out.

The assembly generally will require two people and can be a fun project. It fits together easily, and is kind of like building a giant erector set. The entire dome frame can be assembled in one day.

Dome Cover

The dome kit can be ordered with either an easy-to-apply vinyl fabric covering or a more permanent hard-shell covering.

Less Expensive Covers

The fabric cover for the frame will generally come in one piece. The material commonly used for the exterior cover of the dome is a PVC-coated polyester mesh tarp, also known as vinyl. This cover typically comes with windows consisting of clear plastic. For cold weather areas, it is also possible to obtain a thermal insulated liner that can be installed to the interior frame.

More Expensive Covers

Geodesic domes can also be ordered with a hard-shell cover, which is composed of fiberglass sections that attach to the frame.

Door and Window Installation

The kit will come with a pre-hung door, windows, and door frame, which will attach to the door opening in the dome frame.

R-Values

The R-value (insulation performance rating) on the dome fabric is very low. For cold temperatures, you can install a thermal liner of insulation on the interior. Depending on the type of liner, the R-value can vary from R-2.8 to R-8.5.

Considerations

Pros	Cons
Easy to assemble	Challenging to create space for cabinets
Quick to build	
Inexpensive foundation	
Inexpensive structure	

Cost Analysis

Criteria	Result
Price range	$4.5k–$50k depending on sq. ft.
Price per sq. ft.	$13–$33
Size range	150 sq. ft. (14 ft. dia.)–1,200 sq. ft. (40 ft. dia.)
Typical size and cost	452 sq. ft. (24 ft. dia.) for $10k
Time to build	6–8 weeks

Cob House

The cob house is a fun and unique structure that is often a favorite among singles and couples who want to save money as they begin their off grid journey. A cob house is similar to an adobe house (discussed later in this chapter), as both are made of a mixture of clay, sand, and straw. However, in the adobe house the mixture is made into sundried bricks and stacked, while the cob mixture is molded and formed freeform into place while still wet as the walls are built.

Site Preparation

All sites will require some sort of clearing and leveling. Since this structure is relatively small compared to other home types, the leveling can often be done with basic tools like shovels and rakes.

The Foundation

Begin the foundation by digging a trench around the perimeter of the outer structure circumference. The trench dimensions should be roughly 15–18 inches wide and 18–20 inches deep.

In areas where there is a lot of rainfall, you will need to add a French drain to the bottom of the trench and then cover it with gravel. In more arid areas, the French drain can be excluded and you can simply fill the bottom of the trench with about 6–8 inches of gravel.

Next is to build a stem wall on top of the gravel to a height of about 15 inches above ground level. This support wall is generally made with rock and mortar. The mortar is a mixture of lime, sand and water.

Wall posts for the wall frame should be inserted into the rock support wall as the support wall is being constructed. This will allow the wall posts to be held in place by the support wall. The wall posts should be about 8 inches in diameter and 8–10 feet tall. For a 15-foot diameter house (175 sq. ft.), there should be about eight wall posts, about 6 feet apart.

Make the top of the stem wall rough and unfinished, so that the cob has an uneven surface to adhere to. Once the support wall is complete, and the mortar is dry, you are ready to begin the wall construction.

Wall Construction and Materials

The wall of the house is constructed with cob, which is a mixture of clay, sand, and straw (2 parts clay to 1 part sand). The cob mixture can be mixed in a wheelbarrow with a shovel or on a tarp by pulling the tarp back and forth to mix the clay, sand, and straw. Add water, then knead the mixture using your feet. (Yes, your feet.)

Once you have made the mixture, separate it into large "loaves" and carry them to the wall for pushing/kneading into place to form a solid wall. The wall is usually completed one layer at a time. As each layer is kneaded into place, make finger holes into the sides, to later accommodate a sand and clay plaster that will be added to the outside and inside as a final step.

As the wall layers are added, drive nails halfway into the wall posts so that the cob can adhere to the posts. When the wall is about 3 feet tall, you can install electrical wiring, exiting the wall into electrical gang boxes for outlet use later.

When the cob wall is about 4 feet tall, add 2-feet-long 2"x 6" planks vertically to the top of the wall, every 3–4 feet around the wall's circumference. To give the cob something to adhere to as the wall continues upward, add nails to the vertical planks that stick out about 2 inches. The vertical planks will provide the top plates something to be nailed to once the wall is finished.

Door and Window Installation

Install window and door frames in place as the wall is being built, so that the cob can be built to and around the frames. Add nails to the window and door frames so that the cob can adhere to the frames.

Roof Construction and Materials

Once the walls are complete, they should be about 6 feet tall. A top plate made of 2"x 6" boards can be fastened around the top of the wall, to the vertical planks built into the wall. The top plate will provide support for the roof beams.

The roof frame can be either an octagon shape like that used in a yurt, a typical post-and-beam frame, or a reciprocal type of design. For a circular structure, the reciprocal frame option is a favorite, as it can support a lot of weight. After the roof framing is complete, the roof can be enclosed by attaching 1"x 10" boards, or sheets of plywood cut to fit, to the top of the roof frame. To create a finished look, nail 2"x 6" fascia boards to the end of the roof beams or rafters around the outside perimeter.

The Floor

The floor can be made of anything you want. Some cob houses have been made using a combination of layered material designed to absorb and drain moisture. For instance, a 3-inch layer of gravel overlaid with a 2-inch layer of decomposed granite topped with a 4-inch layer of cob is a common floor option. Another option is the more customary use of cement.

Whatever material you choose, the floor is generally done after the walls and roof have been completed.

R-Values

The R-value of a cob wall construction is roughly .25 to .3 per inch. A 15-inch construction would yield an R-value of R-3.75 to R-4.5.

Considerations

Pros	Cons
Materials are common and can be found on site	Labor-intensive
Relatively quick to build	R-values are somewhat limited
Inexpensive to build	Durability is challenged in wet climates

Cost Analysis

Criteria	Results
Price range	$6k–$10k, depending on sq. ft.
Price per sq. ft.	$20–$30
Size range	150–300 sq. ft.
Typical size and cost	200 sq. ft. (16 ft. dia.) for $5k
Time to build	1–2 months

Earth Bag House

This type of house is really interesting. It uses natural materials like the cob house, but is a step up in structural integrity, durability, and R-value. Earth bag homes can be constructed in the typical square room layout or in a dome shape. Rectangle bags work better for the square room format, and tube bags work better for the dome shape. I'll use the dome structure for this example and cost analysis.

Site Preparation

Once the site has been selected, cleared, and leveled, the layout for the structure will need to be marked. Since the layout for the footing is circular, the footing location can be marked with spray paint.

The Foundation

The foundation follows the generic method used for most houses, with cement for the footing and foundation. A trench is dug for the footing. The trench should be roughly 12–15 inches wide and 15–18 inches deep. Rebar is then installed in the trench to give the cement structural integrity and strength. After all of the trenches have been dug and rebar installed, the next step is to order a cement truck for pouring cement into the trenches. Because cement will be poured at a distance, a pumper truck generally is used to reach all of the trenches. Once the trench has been filled with cement and leveled, eyebolts can be inserted along the outer edge of the footing, every 4 feet or so.

Wall Construction and Materials

Building the wall is where the majority of work will be required. The bags are generally one of two types: rectangular bags or tube bags.

The rectangular bags are relatively easy to fill and carry. The tube bags come in a roll and can be cut to length. The tube bag option creates a wall with more stability, but because the tube bags are long, they have to be filled in position on the wall.

The bags are filled with a mixture of clay, sand, and cement. It is best to add a bit of water; this will make the mixture cohesive and solid once it is in place on the wall. After filling the bags with the moist mixture and placing them on the wall, tamp them with a heavy metal pipe with a flat base.

Water lines and drain lines can be laid in place across the top of the cement footing, and doors can be framed before the wall construction begins. The first layer of bags will then go on top of the cement footing. After each layer of bags has been placed and tamped, two strands of barbed wire are laid on top of the bags for tensile strength and to facilitate an adhesiveness.

Each progressive layer needs to be placed a few inches further toward the center of the room, so that the walls have a dome shape when completed. When the wall is about four bags high, the electrical conduit can be laid in place on top of the wall.

When the walls are 10–12 ft. high, poles 8 inches in diameter can be placed across the top of the wall, about 3 ft. apart. These poles will give the house structural integrity, as well as serve as a scaffolding platform for finishing the walls.

To finish the interior and exterior walls, cover them with stucco. You do this by covering the walls with chicken wire, then plastering the stucco onto the chicken wire.

Roof Construction and Materials

Once the walls are complete, there should be a 3–5-ft. opening at the top of the dome. A circular skylight can be framed and inserted at the top, with eyebolts on the exterior of the frame to connect to the cables. The cables will run from the top to the eyebolts in the footing, and can be tightened with a turnbuckle.

Door and Window Installation

Windows and doors can be framed in the appropriate places during the wall construction and will be framed in an arched top shape in order to accommodate the weight of the bags.

The Floor

Once the walls have been built, the floor can be prepared for cement. Rebar will be installed on the floor surface, and then the cement can be poured and leveled.

R-Values

The R-value for the earth bag construction is R-26 to R-30, which will help keep the house cool in the summer and warm in the winter.

Considerations

Pros	Cons
Materials are common and can be found on site	Needs 2-3 people minimum for construction
Relatively quick to build	Very labor intensive
Inexpensive	
High R-values	

Cost Analysis

Criteria	Results
Price range	\$7k–\$28k depending on sq. ft.
Price per sq. ft.	\$15–\$40
Size range	500–700 sq. ft.
Typical size and cost	500 sq. ft. (25 ft. dia.) for \$20k
Time to build	1–3 months depending on number of people

Adobe House

The adobe house is one of the oldest forms of house building. It consists of dried bricks made of a sandy clay loam. The bricks, being sun-dried, are quite durable and have been known to last for decades in arid climates. This type of structure is a popular option because of the natural ingredients used to make the bricks and because of the good R-value (the adobe house is quite cool in the summer and can retain heat well in the winter).

Site Preparation

Once the site has been selected, it will need to be cleared and leveled. After the leveling, the layout for the structure will need to be marked. This is commonly done with batter boards and string.

The Foundation

The foundation consists of a trench filled with rebar and cement for the footing to support the walls. The floor will also be constructed with rebar and cement. The cement footing normally will extend above ground by 12 inches. This prevents storm water from undermining the wall.

Another method for the footing entails digging a trench with a backhoe and then filling the trench with gravel so that moisture can drain. With this method, the floor surface will be completed after construction of the walls and roof is complete.

Wall Construction and Materials

The walls will be made of adobe bricks. These bricks commonly consist of a mixture of clay, sand, and a little bit of straw. Because the walls require a large number of bricks, a brickmaking machine is normally used.

An adobe structure requires roughly 8,000 bricks per 1,000 sq. ft. The machine can produce about 300 bricks per hour. It takes 2–3 weeks for the bricks to dry. Once dried, three people can lay roughly 250 bricks per day.

Once the bricks are dry, the building process can commence. The first layer will begin with about an inch of mortar on the surface, with the bricks laid on top. Once that stem layer is dried in, the wall can start going up. The wall is laid one layer at a time, by applying mortar on the surface and between the bricks. As the wall progresses, measures should be taken to assure that the bricks are level and the wall is plumb.

Door and Window Installation

As the wall goes up, frames for the windows and doors should be installed at the proper heights and desired locations. After the walls and roof are complete, then the windows and doors can be fitted into their frames.

Roof Construction and Materials

The roof can be constructed as either a gable roof with trusses or a sloping shed-type roof. The latter is typically arranged with the front wall higher than the back wall, laying the rafters from front to back with overhangs on both ends.

After the roof frame is built, the top is normally completed by attaching plywood sheets to the top of the rafters, then finished with either shingles or corrugated metal sheeting.

The Floor

If cement was not used for the foundation, the floor can be done after the walls and roof are completed. One traditional way of creating a floor for an adobe house is to use a mixture of clay, sand, and cement similar to that used for the mortar on the walls. The floor mixture might need a bit less water, however, in order to have a more solid consistency. The floor will need to be laid in layers in order to prevent cracking—maybe 2–3 inches each layer, with maybe 2–3 layers. Each layer can be troweled to have a smooth, finished surface. Once the final layer is dry, the surface can be treated with a sealer to make it waterproof.

R-Values

Adobe house bricks have an R-value of .25 to .3 per inch. A typical wall using bricks 14 inches wide would yield an R-value of R-3.5 to R-4.

Considerations

Pros	Cons
Materials are common and may be found locally	Very labor intensive unless a brickmaking machine is used
Relatively quick to build	2–3 weeks are needed to dry bricks
Inexpensive	
Good R-values	

Cost Analysis

Criteria	Results
Price range	\$50k–\$60k depending on sq. ft.
Price per sq. ft.	\$50
Size range	1,000–1,200 sq. ft.
Typical size and cost	1,000 sq. ft. for \$50k
Time to build	4 months

Straw Bale House

The straw bale house is an interesting structure because the walls are constructed by using a type of material that is easy to find, easy to use, and has a high R-value. Straw bales are like giant bricks of insulation. The house will have a similar foundation, frame, and roof as that of a barn. The exciting part is that once the framing is complete, the walls can be constructed very quickly. After the total construction is complete, one would never know by the house's appearance that straw bales were used for wall insulation.

Site Preparation

The site preparation will need to be done with excavating equipment such as a bulldozer, bobcat loader, or tractor with a front-end loader to make the site level. Once leveled, the process of laying out the foundation site can begin.

The Foundation

Because framing will be necessary, it is best to have a traditional footing and foundation made of concrete. This entails framing a trench, installing rebar, and then filling with concrete. For the foundation, a concrete slab is best.

Wall Construction and Materials

The wall construction generally begins by securing two 4"x 4"s to the floor, 18 inches apart, around the perimeter of the foundation. A foam vapor barrier is then placed between the 4"x 4"s, with gravel poured on top of the foam up to the top of the 4"x 4"s. To secure the straw bales rebar can be used, sticking up vertically between the 4"x 4"s about 12–15" high and 3 ft. apart. The rebar would need to be inserted into the concrete when the slab is poured. Another method is to simply insert nails in the top of the 4"x 4"s to serve as cleats to hold the bales in place.

The framing will consist of studs and top plates, similar to the way a barn is built. The vertical studs should be 4–6 feet apart, around the perimeter of the walls. Double wall plates will be placed on top of the studs to support the roof frame.

The first layer of straw bales will be placed on top of the vertical rebar (or nails in the 4"x 4"s) and then secured to the vertical posts. This can be done with rabbit screen, stapled to the post with fencing staples and secured to the bales with artificial turf staples. If the spacing of the vertical posts allows for more than two bales between them, then each layer should also be interlocked together with a running bond.

Roof Construction and Materials

The roof can be framed with either a typical gable-type design with trusses or as a sloping shed-type roof with rafters placed on top of the wall top plates.

Door and Window Installation

The windows and doors should be framed with headers into the wall frame before the straw bale stacking begins. The straw bales can be cut and re-tied to fit around the window and door frames.

Wall Finishing

The walls are finished by attaching chicken wire to both the interior and exterior sides of the walls. Stucco is then applied to the chicken wire, to seal the straw from the elements and to make that nice finished adobe look and feel. This is one of the advantages of a straw bale house: There is no need for sheetrock on the inside or siding on the outside. Once the stucco is applied, your walls are complete.

The Floor

Because the building is constructed on a concrete slab, any type of flooring desired can be used to accommodate one's preference and style.

R-Values

One advantage of the straw bale house is the insulated R-value. The R-value can be between R-40 and R-60, depending on how tight the bales are packed in the baling process.

Considerations

Pros	Cons
Materials are common and may be found locally	Extra measures needed to prevent moisture absorption (e.g., adding stucco)
Quick to build	Building codes may be an issue
Inexpensive	Low number of studs for hanging things
Good R-values	

Cost Analysis

Criteria	Results
Price range	$15k–$30k depending on sq. ft.
Price per sq. ft.	$15–$40
Size range	1,000–1,200 sq. ft.
Typical size and cost	1,000 sq. ft. for $25k
Time to build	4 months

Yurt

Yurts are European nomadic structures that have been around since the beginning of time. With the recent movement toward affordable housing, yurts have become popular using modern materials and can be ordered in kit form.

In essence, a yurt is a round structure with a roof that is typically made of poles extending to a circular top center compression ring. Coverings for the walls and roof can vary, depending on kit choices.

The yurt is a popular choice because of its simplicity and relatively low cost, and because it can be constructed almost anywhere.

Site Preparation

The site will need to be cleared but not necessarily leveled, because a deck will suffice for the foundation.

The Foundation

Because of the relatively light weight of the structure, the foundation is most often a wooden deck. The deck will consist of piers made of concrete, posts, beams, floor joists, and decking material. In the center of the deck, a circular platform about 4–6 inches tall, is constructed in the same dimensions as the yurt's circumference. This will be the floor of the yurt, and will also serve as the foundation to which the door and window frames will be attached, as well as the bottom of the walls. Siding is normally installed around the perimeter of the circular platform with a 2-inch lip sticking up. This helps hold the lattice wall on the edge of the platform as the wall is extended.

Door and Window Installation

Once the circular platform for the yurt has been constructed, the pre-hung door and window frames can be installed along the outer edge of the circular platform.

Another type of kit calls for the window frames to be installed after the construction is finished.

Wall Construction and Materials

The lattice wall is then extended and attached to the outer edge of the circular platform. The base of the lattice wall is secured to the platform siding with the connectors that come with the kit.

Roof Construction and Materials

The tension cable is extended around the top of the lattice wall, and the two ends are secured together. Scaffolding is erected in the center of the platform, in order to support several people. The platform needs to be about 8–10 feet tall.

To begin, 2–3 people can be on top of the scaffolding. Two people can hold the top center compression ring while the third person installs one rafter at a time. After several rafters are installed, only one person is needed to finish the rafter installation on the scaffolding. One end of the rafter is inserted into the compression ring, with the other end connecting to the tension cable on top of the lattice wall.

Roof Liner, Insulation, and Top Cover

The roof liner is extended as a cover on top of the rafters. The roof insulation cover is then extended on top of the liner. Finally, the roof cover is extended over the insulation cover. Once the roof covering is installed, the top cover is attached to the top of the wall.

Wall Insulation and Covering

The wall's side insulation is extended around the wall and attached to the top of the wall. The wall's side cover is then extended around the wall on top of the insulation and tied to the top of the wall, and is also screwed to the siding that extends around the perimeter of the floor platform's circumference.

Flooring

The yurt is built on a wooden platform, which serves as an underlayment and can be covered with any type of flooring material desired.

Insulation

The yurt normally has an insulation layer, under the top cover and sidewall covering. With this layer installed, the R-value is typically R-9 to R-10.

Considerations

Pros	Cons
Can be purchased in a kit form	Top covers are heavy and difficult to install
Quick to build	Interior layout inside a round structure can be challenging
Relatively inexpensive	No studs for hanging things
Good R-values	

Cost Analysis

Criteria	Results
Price range	\$14k–\$36k depending on sq. ft. (kit only)
Price per sq. ft.	\$25–\$33
Size range	500–900 sq. ft.
Typical size and cost	900 sq. ft. for \$33k
Time to build	1–2 weeks

Arch House

This house type option is cost-effective, is easy to build, and can be constructed very quickly. The building can be purchased in a kit form, and the steel version is the most viable option due to its durability and high fire-resistance rating.

Site Preparation

The site will need to be cleared and made relatively level, depending on the type of foundation selected.

The Foundation

The building can be built either on a deck, which would allow the terrain to be somewhat sloping if necessary, or on a concrete slab, which would require a level site.

A deck built on concrete piers, with beams, floor joists, and floor boards or plywood is most common. This option allows for more freedom in remote site selections where roads for cement trucks aren't available.

Wall and Roof Frame Construction and Materials

Once the deck is ready, the walls can go up very quickly. Metal ribs form both the walls and the roof. A platform rib bracket is attached to the outer edge of each side of the deck floor to accommodate the ribs. A top rail can be positioned with either a crane, scaffolding, or a ladder on each end. While the top rail is being held in place, ribs can be attached to the bottom deck edge bracket and the top rail.

A rib should be installed on each side of each end to start. Once those first four ribs are in place, the top rail no longer needs to be supported by hand and the remainder of the ribs can simply be installed one at a time. The house can go up quite quickly and easily.

Wall and Roof Siding Construction and Materials

Once the ribs are in place, horizontal purlins can be installed midway up the ribs, if desired. The end frame can be installed next, to offer more stability while the siding is being installed.

An insulation material is first applied to the outside surface of the rib structure. After the insulation layer is installed, the metal siding is installed. The siding is installed from front to back beginning at the deck level. Each sheet of siding is applied above the previous sheet, until arriving at the top rail.

Door and Window Installation

If not already done, after the insulation layer and siding are installed, the ends of the building can be framed to accommodate the doors and windows.

Flooring and Interior Wall Covering

Since the deck serves as a floor underlayment, the flooring can be any kind of material desired. Interior walls can be covered with tongue-and-groove boards or plywood.

Insulation

The insulation layer that comes with the kit will yield an average R-value of about R-7 to R-13. For additional warmth, an insulated covering can be applied to the inside walls, much like in a geodesic dome structure.

Considerations

Pros	Cons
Can be purchased in a kit form with multiple sizes available	Insulation upgrades will most likely be needed in most areas
Quick to build	Windows are limited to the ends only
Relatively inexpensive	Perhaps noisier during rainstorms
Good strength-to-weight ratio	Framing walls inside is more challenging with a curved wall

Cost Analysis

Criteria	Results
Price range	\$19k–\$24k depending on sq. ft. (kit only)
Price per sq. ft.	\$20–\$24
Size range	800–1,200 sq. ft.
Typical size and cost	1,000 sq. ft. for \$23k
Time to build	2–4 weeks

Grain Silo House

Having grown up on a farm, I find this house type very interesting. It literally takes a structure designed as a grain silo and converts it into a house. If the idea of a round house is acceptable to you, and you want something durable and virtually weather-proof, this option might be a good fit.

Site Preparation

This type of structure is quite heavy, so a concrete foundation will be needed. With that said, the site will need to be cleared and leveled—probably with excavating equipment such as a bulldozer, bobcat loader, or tractor with a front-end loader.

The Foundation

Once properly marked, the concrete foundation can be started by framing and bracing the concrete containment wall. Rebar will then need to be installed in the interior of the foundation site to finalize the preparation for the concrete. Several people will be needed to level the concrete while it is being poured. Eye bolts can be inserted into the outer perimeter of the concrete foundation after it has been poured and leveled.

Roof and Wall Construction and Materials

The walls for the grain silo come in corrugated metal sections, which are bolted together one ring at a time. A popular way of constructing the wall is to start with the top. Once the top is bolted together, a crane will be needed to lift the structure just enough to add the next subsequent ring of sections. Each new ring of sections will be bolted together "under" the previous ring.

After each ring is complete, the crane lifts the entire structure, so that the next ring can be bolted on. Once the entire structure is complete, the crane can gently lower the structure into place on the concrete foundation. The bottom of the structure is generally secured to the eye bolts that were inserted in the concrete during the foundation pour.

Door and Window Installation

Once the structure has been completed and bolted to the concrete pad, windows and doors can be cut using a cutting torch. Once the holes have been cut, pre-hung doors and windows can be inserted into the holes, secured with metal screws, and calked.

Insulation

The interior of the silo structure is generally insulated by spraying insulation foam on the walls. Spray foam insulation is often made from polyurethane and is very energy efficient. There are many advantages to using this type of insulation: It stops condensation, prevents heat and air transfer, deadens the sound of rain and hail, is easy to install, and helps to prevent mold and mildew. The R-value of spray foam insulation is about R-6.5 per inch. With a 2-inch layer, the R-value would be R-13.

Interior Walls and Framing

The inside of the silo walls can be covered with plywood. Interior rooms can be framed to organize the space, and a second story can be framed in, doubling the square footage.

Considerations

Pros	Cons
Can be purchased new or used as a grain silo	Laborious with all of the bolts
Relatively quick to build	Will need a crane for lifting the structure as it is being built
Relatively inexpensive	Framing walls inside is more challenging with a curved wall
Very durable	

Cost Analysis

Criteria	Results
Price range	$8k–$16k (silo only, 19–24 ft. high)
Price per sq. ft.	$16–$23
Size range	572–706 sq. ft.
Typical size and cost	706 sq. ft. x 2 (if 2-story) for $16k
Time to build	2 months

Shipping Container House

The shipping container home type has become very popular in the last few years. This option allows for a lot of versatility: Shipping containers can be set up almost anywhere and can be stacked in various ways and set side by side or end to end. One can achieve comfortable living space relatively cheaply.

The containers come in various sizes. The most common are 8 feet wide and either 20 or 40 feet long. They can be purchased new, used, or refurbished.

Site Preparation

The site will need to be cleared and leveled—probably with excavating equipment such as a bulldozer, bobcat loader, or tractor with a front-end loader.

The Foundation

Because shipping containers are relatively heavy (especially if they are stacked), the foundation will need to be concrete. This can be accomplished with a concrete footing and slab or with concrete piers.

Installation

Shipping containers will arrive on a flatbed truck. A crane will be needed to pick up each container and place it on the concrete foundation.

The containers can be arranged however you want. One option is to put two 40-ft. containers together side by side and then cut out the adjoining center walls to form a 16'x 40' space.

Another popular arrangement is to have two containers placed parallel to each other, with enough space in between them to create a "great room" by adding concrete slab for a floor and a framed roof overhead.

Heavy Equipment Required

A crane will be needed for the container placement. A backhoe may be needed to dig the trench for the footing of the concrete slab.

Door and Window Installation

After the containers are in place, doors and windows can be cut in the metal with a cutting torch. A metal frame can then be welded into place to accommodate the pre-hung doors and windows.

Flooring

The container will arrive with a plywood floor. Most people will simply apply the desired flooring material on top of the plywood.

Interior

The interior can be as nice or as basic as you want. Since the width of the container is only 8 feet, you will need a bit of creativity for the interior framing and layout in order to make the most of the limited space.

Insulation

Insulation can be applied a number of different ways. Two common and effective choices are to use spray foam insulation or a unique product called InSoFast Insulation Panels. These are insulation panels that fit the corrugations of the wall and are applied with adhesive. The R-values of these two methods will vary from R-11 to R-20, depending on thickness.

Considerations

Pros	Cons
Plentiful supply	Interior work is laborious
Low cost	Requires heavy equipment for placement
Quick installation	Inside insulation is more work
Easily customized	Inside space is limited
Low maintenance	
Fire resistant	

Cost Analysis

Criteria	Results
Price range	\$2k–\$3k (8'x20') or \$3k–7k (8'x40')
Price per sq. ft.	\$12–\$22 depending on condition
Size range	2-8'x40' containers = 640 sq. ft.
Typical size and cost	640 sq. ft. for \$14k
Time to build	1 month

Tiny Homes (Kits)

There is a type of structure being advertised online as a "Tiny Home," which has traditionally been sold as a garden shed! Since the off grid movement is beginning to consider all kinds of possibilities, I have included this type of structure as an option.

The exterior can be quite charming. After construction, all one would need to do is add electrical, water, and plumbing, and then finish the walls, ceiling, and floors—and voila—you now have a small, inexpensive, cozy housing alternative.

Site Preparation

Site preparation will consist of clearing and leveling. Since this is such a small area, it could even be done by hand.

The Foundation

Since these structures are relatively light, cement blocks are the only foundation supports needed. With that in mind, the structure should be ordered with runners underneath to lie on top of the cement blocks.

The Kit

Kits for these structures come in a number of sizes. The ones that best serve as a modest, single dwelling are those with dimensions of 12'x 16' or 12'x 20'.

The structure will consist mostly of OSB sheathing panels and 2"x 4"s. These kits typically come with windows and doors. The structure will need to be assembled. Some pieces may need to be cut.

To make the structure livable, you can add tile to the floors, along with insulation and drywall to the walls and ceiling. Lighting, plumbing, and electrical will need to be purchased and installed as well.

Considerations

Pros	Cons
Low cost	Material will need to be weather-proofed
Materials delivered	Limited in size
Quick assembly	
Easily customizable interior	
Low maintenance	

Cost Analysis

Criteria	Results
Price range	\$4k–\$9k depending on sq. ft.
Price per sq. ft.	\$37–\$43
Size range	192–242 sq. ft.
Typical size and cost	242 sq. ft. for \$9k
Time to build	2 weeks

Low-Budget Home Types Comparison (\$2k to \$50k)

Home Type (Sorted by price)	Price Range (k)	$/sq. ft.	Size Range (sq. ft.)	Time to Build
1. Shipping Container	2–3	12–22	160–640	1 month
2. Tiny Home (Kit)	4–9	37–43	192–242	2 weeks
3. Cob	6–10	20–30	150–300	1–2 months
4. Earth Bag	7–28	15–40	500–700	1–3 months
5. Geodesic Dome	4.5–50	13–30	150–1,400	6–8 weeks
6. Grain Silo	8–16	16–23	572–706	2 months
7. Yurt	14–36	25–33	500–900	1–2 weeks
8. Straw Bale	15–30	15–40	1,000–1,200	4 months
9. Arch	19–24	20–42	800–1,200	2–4 weeks
10. Adobe	50–60	50	1,000–1,200	4 months

CHAPTER 2

Medium-Budget Home Types
($30K to $100K)

Log Cabin

As you can imagine, the concept of building a house out of logs is "as old as the hills." The appeal of the log cabin option is very understandable—the rustic, wilderness look and feel is highly attractive to those who want to live off the grid.

Log cabins come in kit form with many different designs for size and layout. The kit option is super convenient and can be assembled relatively quickly, but the kit and assembly process can be expensive.

Another option for those fortunate enough to have extra timber on their property is to cut the trees themselves and cut the logs using a portable sawmill. This is a fun and memory-making process, but it can be quite laborious—requiring several people and the right equipment.

Site Preparation

This type of structure is quite heavy, so a concrete foundation is needed. The site, therefore, will need to be cleared and leveled—probably with excavating equipment such as a bulldozer, bobcat loader, or tractor with a front-end loader.

The Foundation

The foundation for this type of structure can consist of either a concrete slab or a concrete footing around the perimeter of the structure's layout, with concrete piers in the center to support floor joists. Because it is sometimes required to build a stem wall to elevate the house to be above snow, I will use the footing and pier option in this explanation.

A small trench should be dug for the footing, with rebar installed. The forms should be set at about 18 inches wide and extend about 15 inches above ground.

Wall Construction and Materials

In areas that get a lot of snow, a stem wall can be built on top of the footing to raise the house above snow levels. The stem wall can be used to raise the level of the floor. First, 2"x 8" boards are laid flat on top of the footing and 8"x 8" vertical posts are positioned four feet apart, on top of the 2"x 8" boards. Next, stem logs are laid on top of the posts. Pylon posts would then be placed on top of the concrete piers, and support beams laid on top of the pylons to support the floor joists. Once the stem logs and support beams are in place, then the floor joists are laid on top. Plywood would then be nailed to the joists to provide the floor underlayment, and also applied to the outside of the stem wall, in order to close in the area under the house.

If the log cabin is not going to be built in an area where snow is common, then the stem logs can be laid on top of the footing and support beams on top of the piers, to provide the support for the floor joists without using a stem wall.

Once the floor platform is complete, 2"x 8"s are nailed around the perimeter of the floor platform, with a foam vapor barrier laid on top of the 2"x 8"s. Start the log walls by laying logs on top of the 2"x 8"s. Spear joints can be used at the corners for self-milled logs or laid overlapping with pre-cut kit logs. Once the first layer of logs is laid, the logs are screwed to the 2"x 8" underneath. After that, each layer of logs will be laid with the foam vapor barrier between the logs and then screwed to the log layer underneath. When logs are butted together on the wall, a hole is drilled and a dowel driven between the butted ends to prevent air penetration. The doors and windows are normally framed in as the walls go up.

Interior Walls and Loft Construction and Materials

Once the walls are complete, the interior room walls can be framed by using 2"x 4"s. After the interior faming is complete, the floor joists can be placed on top of the interior framing, for a loft. Smaller log beams can be used for the floor joists, with plywood or tongue–and–groove boards on top as the upper floor.

Roof Construction and Materials

Framing can be done on the top of the walls on each end of the cabin, to accommodate a center gable beam. An upright vertical post (with a saddle notch at the top) can be placed in the center of the cabin, to accommodate the center gable. The center gable can then be placed on top of the front and back frame and center upright post. This center gable will be the top rail on which the rafters will rest. The rafters are laid on top of the side walls, joining on top of the center gable. Plywood is applied to the top of the rafters, and tar paper on top of the plywood. Then either shingles or metal sheets are nailed on top of the tar-papered plywood.

To finish the exterior, siding can be applied to the outside of the frame that was built on top of the wall on each end of the cabin to accommodate the gable beam. The tops and bottom of the logs that were milled to provide flat surfaces can be used as siding, or small log poles can be milled in half and used.

Heavy Equipment Required

A lot of heavy equipment will be needed to move, cut, and stack the logs. A backhoe will be needed to dig the footing trench. A tractor with a front-end loader will be required for carrying the logs. A portable sawmill may be required for milling non-kit logs. A crane will be required to set the logs and beams in place.

R-Values

R-values of the logs are about R-1.4 per inch, yielding roughly an R-value of R-15 to R-17 for the cabin.

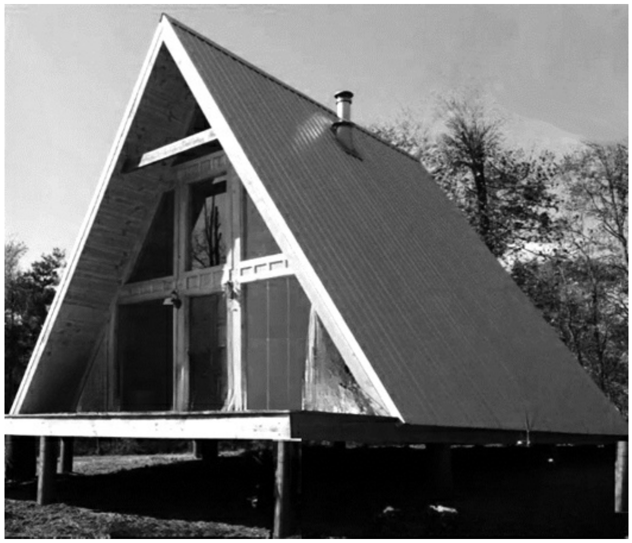
Considerations

Pros	Cons
Can be purchased as a kit with shell logs pre-cut and ready to fit together	Laborious
Long-lasting and aesthetically pleasing	Requires a lot of heavy equipment
Moderately inexpensive	Material is very heavy
Can hold up well in snow areas	
High R-values	

Cost Analysis

Criteria	Results
Price range	$48k–$72k
Price per sq. ft.	$40–$60 (pre-cut, prepared logs only)
Size range	1,000–1,200 sq. ft.
Typical size and cost	1,200 sq. ft. for $50k
Time to build	2–3 months

A-Frame House



The A-frame house is one of those types of homes that are fun to consider because they are so unique. The basic difference between this type of structure and other more typical wood-framed construction is that the roof serves as both the roof and the sidewalls. For that reason, there can be somewhat of a savings in construction costs.

Site Preparation

The site will need to be cleared and leveled with appropriate equipment, such as a bulldozer, bobcat loader, or tractor with a front-end loader and scraper.

The Foundation

The foundation can consist of either piers and a wood deck, or for a more permanent build, a perimeter footing and cement slab may be poured for the interior foundation.

If the foundation is a wood deck, 2"x 4"s are nailed around the perimeter of the deck to serve as support backstops for the rafters. If the foundation is concrete, then metal brackets can be inserted into the concrete as supports for the rafters.

Roof and Wall Construction and Materials

The A-frame roof can be done different ways. The A-frame trusses can be prefabricated and set in place with a crane or be constructed in place.

One way of constructing the A-frame in place is to begin by erecting two 23-foot posts, built by nailing 2"x 6"s together. The posts should be positioned on each end of the structure. The purpose of the posts is to serve as supports for the top ridge beam. Once the posts are positioned and braced, the gable beam can be laid on top with the assistance of a crane. You can arrange for the gable ridge beam to extend out beyond the structure's front wall, to create an overhang for a covered porch.

The 2"x 6" rafters are attached to the deck or concrete brackets and then nailed to the ridge beam at the top. Normally, a rafter is erected on each side of each end of the gable ridge beam, then the remaining rafters are placed roughly 3 feet apart. The pitch of the roof is roughly 15”x 12”—that is, for every 12 inches across, it goes up 15 inches.

Once all of the rafters are attached, then plywood sheets can be nailed to the top of the rafters to complete the solid roof surface. Tar paper can then be applied to the plywood. The most common material for the final roof surface is metal sheets.

After the A-frame is complete, you can remove the upright support posts initially used to support the ridge beam.

Door and Window Installation

Once the roof is complete, the front and back walls can be framed. The doors and windows can also be framed in at this time, to accommodate the pre-hung windows and doors.

Insulation

Before the interior walls are covered, it is good to apply the interior insulation. Insulation can be applied a number of ways: spray foam insulation, loose filling insulation, or the typical fiberglass batting. R-values will vary from R-10 to R-14 for spray foam or R-19 to R-21 for fiberglass batting, which is roughly R-3.2 per inch thickness.

Interior

After the insulation is complete, the interior surface of the roof can be covered with tongue-and-groove boards for that rustic look. Once the inner surface of the A-frame is complete, then interior framing can be done to construct rooms, a loft, etc.

Heavy Equipment Needed

If a concrete footing is used, a backhoe will be needed for the trench. If piers and decking are used, then a post hole digger is often used for the pier pylons. A crane is commonly needed to set either the ridge beam or the prefabricated A-frame trusses in place.

Considerations

Pros	Cons
Relatively low cost due to less timber involved for build	Upper space limited with roof pitch
Pitched roof good in snow areas	Steep pitch makes applying roof covering challenging.
Attractive, with wilderness feel	

Cost Analysis

Criteria	Results
Price range	$30k–$100k depending on build
Price per sq. ft.	$35–$75
Size range	850–1,200 sq. ft.
Typical size and cost	1,200 sq. ft. for $50k
Time to build	2–3 months

Steel Frame Home Conversions (Agriculture Building)

Because of my farm upbringing, I find this home type quite exciting. It is a steel structure typically designed to store farm equipment.

Being made of steel, the structure is very durable—yet it can be assembled relatively quickly, easily, and inexpensively. The structure also has great potential, as framing can be done on the inside to arrange the rooms any way you want. Because of the metal siding, insulation is required on the inside for warmth and noise reduction.

Site Preparation

Because this is a steel structure, the frame will be heavy, warranting the need for a cement foundation. The site will, therefore, need to be cleared and leveled—probably with excavating equipment such as a bulldozer, bobcat loader, or tractor with a front-end loader.

The Foundation

The best type of foundation for this type of structure is a concrete slab. This will allow adequate support for the steel frames and serve as an excellent flooring platform.

Bolts will be inserted into the concrete at strategic locations in the interior and around the perimeter of the concrete slab. The bolts in the center are used for the upright posts that support the upper center of the roof truss. The bolts around the perimeter will be for the upright support posts that support the ends of the roof trusses.

Building Frame Construction and Materials

The structure will begin by attaching the upright support posts to the bolts in the concrete. The roof trusses will then be carried into position by a crane, and then lowered onto the upright support posts. There will be three support posts for each roof truss—one in the upper center and one on each end.

Once the trusses are bolted to the top of the support posts, then the crossbeams can be added to the top of the trusses. The crossbeams are bolted to the top of each truss, lying horizontal. There is generally a crossbeam every 5 feet or so from the top center down to the walls.

Additional metal framing will be applied on each end of the structure to accommodate doors and windows. Any windows on the sides of the building will be done after the siding is applied.

Wall and Roof Construction and Materials

Once the main building frame is up, then purlins will be added midway up and horizontally to each wall upright support post. Additional metal strips will be added to the top of the walls, horizontally, and along the outer edge of the concrete slab. These purlins and metal strips will provide the surface to which the siding will be screwed.

The siding metal sheets are screwed to the support surfaces all around the sides of the building and then to the roof. The tops of the siding will be cut to fit after having been screwed to the side of the structure. Lastly, trimming is applied along the top, where the roof and walls meet, and along all of the outside corners.

Door and Window Installation

Once the building has been erected, the doors and windows can be inserted into their frames on the main entrance. For windows on the sides, holes can be cut in the siding and then framed with metal frames. A pre-hung window can then be inserted and screwed in place.

Heavy Equipment Required

Heavy equipment will be needed to set the upright support posts, roof trusses, and roof crossbeams in place. A scissor lift or boom lift will be needed for applying metal sheets to the exterior walls and to the roof. A pumper truck may be needed for pouring the concrete slab.

Insulation and Interior Wall Covering

Insulation can be applied in one of a number of ways: blanket insulation, spray foam insulation, loose filling insulation, or ridged board insulation. R-values will vary from R-10 to R-14. Interior walls can be finished with plywood and sheetrock or just sheetrock.

Considerations

Pros	Cons
Can be purchased as a kit	Laborious
Low cost	Requires heavy equipment
Quick build	More work and cost to insulate
Easily customized	
Low maintenance	
Fire resistant	

Cost Analysis

Criteria	Results
Price range	\$30k–\$60k depending on sq. ft.
Price per sq. ft.	\$25–\$50 (kit) or \$75–\$150 (package)
Size range	1,200–1,500 sq. ft.
Typical size and cost	1,200 sq. ft. for \$50k
Time to build	2–3 months

Tiny Home (Prefabricated)

Tiny homes or houses can come in every shape and size imaginable. They are becoming quite popular for off grid living and as an option for affordable housing. They generally come on a chassis with wheels, like the old mobile homes did. Because they are mobile, and small, they fit just about anywhere. Most are 8 feet wide and come in a variety of lengths.

Site Preparation

Site preparation will consist of clearing and leveling. Leveling will more than likely need to be done with some sort of heavy equipment like a bulldozer, bobcat loader, or tractor with a front-end loader or scraper.

Foundation Type 1

If the house does not come on wheels, a footing will more than likely be needed, requiring a trench, rebar, and concrete. A concrete slab can be used inside the footing.

Plumbing

After the house is well supported, the plumbing for water and sewer are connected to those pipes that should have been ready on site.

Foundation Type 2

If the house comes on wheels, then a foundation will not be needed. The frame underneath can be placed on screw jacks, and the axels and tongue can be removed, if desired. If they are removed, then a more permanent skirting can be added. A trench would need to be dug around the perimeter. Fiberglass panels can be attached to the bottom outer edge of the house, extending down into the trench, then the trench is filled with concrete to create a permanent seal from moisture.

Prefabricated

Since these types of homes are prefabricated, there is no need to discuss wall, roof, door, and window installation.

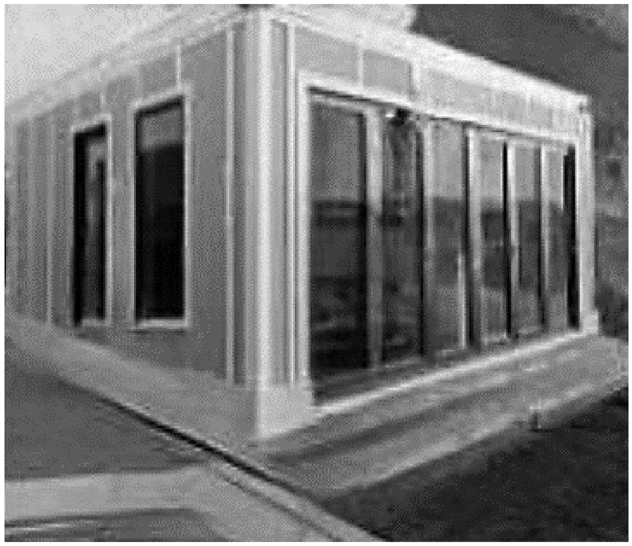
Considerations

Pros	Cons
Relatively low cost	Laborious
Easy to transport	Requires heavy equipment
Quick installation	More work and cost to insulate
Easily customized	Limited space
Low maintenance	
Fire resistant	

Cost Analysis

Criteria	Results
Price range	\$30k–\$60k depending on sq. ft.
Price per sq. ft.	\$75–\$300
Size range	160–400 sq. ft.
Typical size and cost	225 sq. ft. for \$50k
Time to build	1–4 weeks

Foldable House



Wow! This is an exciting new option that, as of this writing, hasn't started to be delivered yet. The "Casita" by Boxabl is a foldable house that comes with everything you might need in a home. There are things, of course, that need to be done ahead of time to be prepared for the house delivery (e.g., foundation, water, sewer, permits, etc.).

The Casita is a self-contained, totally self-sufficient unit. It is 100% electric—heating, cooling, cooking, washing, drying—everything, with its own solar system already installed. It comes totally equipped with a functional kitchen, bathroom, and HVAC. The only things you would need to add are a couch and a bed.

There are a lot of these types of homes beginning to surface on the market as "droppable," "foldable," and the like, but the Boxabl home is a truly foldable structure that is far more inexpensive than any of the competitors. In some cases, it is half the cost of similar concepts.

Once the house has been set on its foundation, it literally unfolds into a fully functional house in a matter of minutes—an amazing accomplishment designed to meet the needs and demands for affordable housing.

As of this writing, the only size offered is 19.5'x 19.5'. In the future, the company says it may offer other sizes such as 20'x 20', 20'x 30', 20'x 40', and 20'x 60'.

Site Preparation

The site will need to be cleared and leveled. Leveling may need to be done with some sort of heavy equipment like a bulldozer, bobcat loader, or tractor with a front-end loader or scraper.

The Foundation

The Boxabl house will need a concrete foundation. This can be a concrete slab or concrete piers. If concrete piers are used, spacing requirements should be sought from the manufacturer.

Prefabricated

Since the Boxabl house is prefabricated, there is no need to discuss wall, roof, door, and window installation.

Considerations

Pros	Cons
Low, reasonable cost	There may be long waiting list for delivery in its start-up.
Easy to transport	It has a flat roof, so a gabled roof may be required in some locations.
Prefabricated	It comes in one style and cannot be customized.
100% self-sufficient with solar system	Initial size is limited to 19.5'x19.5'.
Totally self-contained	
Made of steel, concrete, and EPS foam	

Cost Analysis

Criteria	Results
Price range	About $50k (at the time of this writing)
Price per sq. ft.	$133 (at the time of this writing)
Size range	375 sq. ft.
Typical size and cost	375 sq. ft. for about $50k
Time to build	2–3 months to prepare, 1 hour to install

Medium-Budget Home Types Comparison ($30k to $100k)

Home Type (sorted by price)	Price Range (k)	$/sq. ft.	Size Range (sq. ft.)	Time to Build
1. Steel-Frame	30–60	25–50	1,200–1,500	2–3 months
2. Tiny House	30–60	75–300	160–400	1–6 weeks
3. A-Frame	30–100	33–75	850–1200	2–3 months
4. Boxabl	50	133	375	1–4 weeks
5. Log Cabin	60–100	40–60	1,000–1,200	2–3 months

CHAPTER 3

High-Budget Home Types
($100k to $368k)

ICF Wall Construction House

This type of off grid home employs typical house construction with the exception that the walls are made with insulated concrete forms (ICF) and filled with concrete, instead of being framed with wood and sheet rocked. The insulated concrete forms provide the vapor barrier, insulation, and framing members, all in one.

A house constructed with ICF is 3–5% more expensive than wood-frame construction, but the savings in energy costs plus other advantages warrant its consideration.

Construction with exterior and interior walls made with ICF allows the house to be quieter, more durable, and very energy-efficient. The energy cost for a typical stick-built house is roughly $0.10 per square foot, while a house built with ICF walls is about $0.03 per square foot. ICF walls not only reduce the energy bill, but also allow for more stable interior temperatures.

Site Preparation

Because this is a more typical house with heavy concrete walls, a concrete foundation is imperative. The site will therefore need to be cleared and leveled with excavating equipment like a bulldozer, bobcat loader, or tractor with a front-end loader.

The Foundation

Before the foundation is poured with concrete, the plumbing for water and sewer will need to be installed. These pipes are normally installed in trenches.

The foundation will begin with a typical trench around the layout perimeter for the footing, dug with a backhoe. The trench will need to be framed, have rebar installed, and then filled with concrete. Vertical rebar will be inserted in the concrete before it dries, to accommodate attachment of the walls.

Rebar will then be installed within the area inside the footing perimeter. This inside area will then be filled with concrete to serve as a floor for the home and the foundation for the walls. Because this may be a large area, a pumper truck is a common necessity in order to get the concrete poured in the needed areas.

Wall Construction and Materials

The ICF blocks are roughly 16 inches high and 48 inches long. These blocks are fully reversible and interlock with each other to build the wall form. The ICF walls are typically used around the perimeter of the house as well as for the interior walls.

Once the ICF walls are built and properly braced, concrete is poured into the interior of the walls with the assistance of a pumper truck. Because the entire wall is being poured, and because concrete is so heavy, several passes of pouring only a few vertical feet at a time will be required.

Advantages of this type of construction are the ease and time savings in construction.

Roof Construction and Materials

After the walls are constructed and poured, the roof is constructed with wood-frame construction. The roof is commonly built with gabled trusses with rafters. These can be prefabricated or built on site.

Once the roof framing is complete, plywood is nailed on top of the rafters; then tar paper is applied, then the shingles.

Door and Window Installation

Doors and windows are framed into the ICF walls as the walls are being built. The openings are generally framed in with 2”x 6” boards and headers, to which the pre-hung doors and windows will be attached.

R-Values

The R-value of ICF walls is R-22 and higher. The EPS foam with concrete in between creates a highly energy-efficient thermal barrier that has 58% better overall R-value than insulated wood-frame walls with batting.

Heavy Equipment Needed

A lot of heavy equipment is needed for this type of construction: a backhoe for the footing trench, a pumper truck for pouring concrete, and if the roof trusses are prefabricated, a crane may be needed to lift the trusses into place on top of the walls.

Considerations

Pros	Cons
Energy-efficient	More expensive
Quiet	
Stable temperatures	
More durable	
Stronger	

Cost Analysis

Criteria	Results
Price range	\$192k–\$368k
Price per sq. ft.	\$120–\$230
Size range	1,400–1,600 sq. ft.
Time to build	3–4 months

Earth-Sheltered House

The earth-sheltered house can be constructed in several ways in order to benefit from the earth's insulating properties. There are three common types of earth-sheltered construction: One type is to have the house constructed next to a hillside where at least the back wall is up against rock or soil. A second type is called "berm-built" construction, whereby earth is pushed up against each side wall, and perhaps the back wall as well. Third is the underground type, which is totally covered with soil, allowing only the front wall to be exposed.

The main purpose for using one of these types of construction is to be energy-efficient. The earth can provide a layer of insulation, allowing the inside temperatures to be somewhat constant. Having the walls exposed to the earth, however, can come with a unique set of challenges.

For bermed and underground house types, the soil is going to be heavy—especially when wet—dictating the need for a very strong structure. This means that, in most cases, the structure will need to be constructed with concrete.

Site Preparation

Because the house will most likely need to be built of concrete, the site will need to be cleared and leveled with appropriate equipment such as a bulldozer, bobcat loader, or tractor with a front-end loader and scraper.

If an underground house is planned, extra removal of dirt may be required to prepare for the below-surface construction.

The Foundation

The typical footing trench with rebar, and interior floor with rebar, will require the typical preparation before being poured with concrete.

Wall Construction and Materials

Because earth-sheltered homes are exposed to the earth, with all three types the site needs to be carefully planned so that water will naturally drain away from the structure. This is really important.

The hillside construction will have at least the back wall against earth or rock, dictating a need for at least the back wall to be made of concrete. For the bermed version, all the walls should be made of concrete to hold up under the weight and moisture of the soil.

The underground version will require the entire structure, including the roof, to be made of concrete in order to withstand the heavy weight of earth on top, as well as to hold up under potentially long periods of moisture exposure.

Because the walls will be made of concrete but will need some type of interior insulation, the ICF wall construction model would work well for this type of building.

Roof Construction and Materials

The roof of the hillside and bermed versions can be either wood or concrete. The underground version's roof must be concrete.

For the underground house, several layers of vapor barriers will need to be laid on the roof before soil is pushed onto the top.

Door and Window Installation

The hillside version may have windows on the side(s) of the house, but the bermed and underground versions can only have windows on the front of the structure. Doors on all three versions will be on the front wall and will normally be framed in for a pre-hung door, as with most houses.

R-Values

Again, the main purpose of having an earth-sheltered home is to benefit from the insulating properties of the earth. Even so, the inside walls will need some type of insulation, in order to assist in retaining heat in cold months. ICF walls could assist with this need. If ICF walls are used, the R-value for the bermed and underground versions would be roughly R-22 to R-30.

Heavy Equipment Needed

Because of the nature of this type of construction, a bulldozer, bobcat loader, or tractor with a front-end loader and scraper may be needed for clearing and leveling the sites.

A backhoe will be needed for digging footing trenches. Pumper trucks will be needed to assist in the pouring of concrete. A bulldozer, bobcat loader, or tractor with a front-end loader and scraper may be needed for pushing soil up against the walls for the bermed type house. For the underground house, the same type of equipment will be needed for digging the hole for the below-surface structure and for pushing soil onto the roof.

Considerations

Pros	Cons
Energy savings	Poor ventilation
More constant temperatures	Limited access for natural lighting
Soundproof	Potential for high humidity
Low maintenance	Leaks are difficult to repair.
	Resale is difficult.
	High initial cost
	Difficult to expand

Cost Analysis

Criteria	Results
Price range	$168k–$350k
Price per sq. ft.	$120–$250
Size range	1,200–1,400 sq. ft.
Typical size and cost	1,400 sq. ft. for $280k
Time to build	3 months

Barndominium (kit)

The barndominium frame can be all steel or a hybrid of steel and wood. The hybrid consists of main roof support beams and roof trusses made of steel, with wall frames and roof rafters made of wood. These kits use the steel frame house construction model and a modified frame design to accommodate different home design plans and easier insulation.

Site Preparation

Because the roof supports and roof trusses are made of steel, a concrete foundation will be needed. The site will, therefore, need to be cleared and leveled—probably with excavating equipment such as a bulldozer, bobcat loader, or tractor with a front-end loader.

The Foundation

The foundation, being made of concrete, will need a framed trench with rebar and an interior slab that will need to be prepared with rebar before pouring.

Wall Construction and Materials

Construction of the structure begins with erecting the 6-inch tube roof support posts around the perimeter of the concrete foundation, which are attached to the concrete. The web truss roof girders are then placed on top of the support posts.

Horizontal studs (called purlins), are fitted into place between the perimeter roof support posts. These horizontal purlins can be made of steel or wood and provide the frame for hanging windows and siding.

Once the windows are hung, sheets of foam insulation can be attached to the horizontal wall purlins, then covered with metal siding.

Roof Construction and Materials

Horizontal roof rafters made of steel or wood are attached to the top of the web truss roof girders. Roof insulation is applied to the top of the rafters, then metal sheets are attached to the rafters on top of the insulation. Putting on the final trim on the gable, eaves, and exterior corners completes the roof.

Door and Window Installation

The window frames are installed before the siding is applied. The doors can be hung at that time or after the roof is complete.

R-values

To complete the insulation, batting and drywall can be added to the interior walls and ceiling, if desired. The R-value of fiberglass batting is generally around R-19 to R-21.

Interior

The kit does not come with interior walls, thereby allowing you to design the interior as you wish. You can have plans drawn up to give to a contractor, if desired.

The ceiling can be vaulted or flat, and the house can have a second story or loft. The beauty of this kind of structure is that once the frame is built, the interior is a blank canvas.

Heavy Equipment Needed

A backhoe will be needed for digging the footing and plumbing trenches. Other heavy equipment will be needed to set the upright support posts, roof trusses, and roof crossbeams in place. A scissor lift or boom lift will be needed for applying foam and siding sheets. A pumper truck may be needed for pouring the concrete slab.

Considerations

Pros	Cons
Can be purchased as a kit	Requires heavy equipment
Low cost	May be costly to heat
Quick build	
Easily customized	
Low maintenance	
Fire resistant	
Spacious interior with lots of options	

Cost Analysis

Criteria	Results
Price range	$75k–$150k depending on sq. ft.
Price per sq. ft.	$70–$100
Size range	1,080–2,400 sq. ft.
Typical size and cost	1,800 sq. ft. for $126k
Time to build	1–2 months

Manufactured Home

Manufactured homes are the current version of what used to be called mobile homes. They are constructed like wood-framed homes in every way. The only difference is that the manufactured homes are built in a factory and then transported to the home site, instead of being built on site.

The manufactured home can come in a host of floor plans. These are quite nice inside, having all the latest appliances, quartz countertops, a fireplace, and so on. The advantages are a lower cost and the ability to be transported to a different location.

Site Preparation

The site will need to be cleared and leveled. That should probably be done with excavating equipment such as a bulldozer, bobcat loader, or tractor with a front-end loader.

Foundation Step 1

This step is usually done differently from the typical house that requires a foundation. The home is normally transported in two or three sections, depending on the layout ordered. After arrival at the site, the sections are backed into position, winched together, and bolted together at strategic points.

Once in position and connected, the home is then supported by placing jack stands underneath the bottom frame. Once supported, the axels and tongue are removed and the remainder of the support jacks are placed underneath the bottom frame.

Plumbing

After the house is well supported and leveled, the plumbing for water and sewer is connected to pipes that should have already been installed on site.

Foundation Step 2

Once all of the plumbing is laid and connected, a trench is dug around the perimeter of the house. Fiberglass panels are connected to the bottom outer edge of the home and extend down into the trench. Concrete is then poured into the trench up to ground level, encompassing the fiberglass panels. This creates a strong waterproof skirting around the perimeter of the house.

Garage and Driveway

After the edging panels are installed, a garage can be built, if desired. Once finished, the final touches would be to pour a concrete driveway, house steps, and sidewalks, if needed.

R-Values

The insulation in the house will consist of batting and drywall. The R-value would therefore be roughly R-19 to R-21.

Considerations

Pros	Cons
Can order with desired floor plan	Requires transport cost
Relatively low cost for a good-size home	Sometimes difficult to find insurance
Quick setup	Sometimes difficult to find financing
Can transport almost anywhere	Sometimes long waiting list
Like normal wood-framed house	
Nice interior	

Cost Analysis

Criteria	Results
Price range	$156k–$162k, depending on sq. ft.
Price per sq. ft.	$90–$160
Size range	1,600–1,800 sq. ft.
Typical size and cost	1,600 sq. ft. for $160k
Time to build	1–4 weeks (depending on garage)

High-Budget Home Types Comparison ($100k to $368k)

Home Type (sorted by price)	Price Range (k)	$/sq. ft.	Size Range (sq. ft.)	Time to Build
1. Barndominium	75–150	70–150	1,080–2,400	1–2 months
2. Manufactured	156–162	90–160	1,600–1,800	1–2 months
3. Earth-Sheltered	168–350	120–250	1,200–1,400	3 months
4. ICF Walls	192–368	120–230	1,400–1,600	3–4 months

PART 2

Home Electrical Systems

Electricity is considered one of the most common essentials in off grid living, especially now that solar is so available. Here in Part 2, we will discuss the four most common sources for electrical power: solar, wind, hydroelectric, and generators. Most people choose at least a solar option. It is not uncommon, however, to use a combination of two or more sources in order to try to capture all that is possible in electricity generation. By covering these typical sources, the intent of this part of the book is help you determine which option or combination of options will best serve your needs.

Please note: I am not an electrician. The descriptions of systems within this part of the book are intended to assist you in strategizing and planning different options and in becoming aware of potential costs. For purchasing of parts and implementing designs, a professional electrician should be consulted.

CHAPTER 1

Solar

Because sunlight is generally available to any property owner, solar power has become the main source of electricity in off grid living. A solar panel is a collection of photovoltaic cells, which generate electricity (DC) through photovoltaic activity. A collection of solar panels is referred to as a photovoltaic (PV) array, or solar array.

The purpose of this chapter is not to be an exhaustive tutorial on how to install a solar system. Rather, this chapter is designed to provide an introduction to the solar option for strategizing and planning purposes. The goal is to describe, in general terms, how to go about planning and designing a system, how it all fits together, and what the general costs will be for major components and the system as a whole.

Design and Planning

In order to design the system, we generally begin at the bottom and work upward. It is in this manner that the size and number of solar panels are ultimately derived. The installation process, discussed later, will begin at the top and work downward.

Determining Power Usage

First, we want to list all the desired appliances and items that use electricity and determine how many watts each item or appliance uses and how many hours per day they will potentially be used. You can find this information on the device, online, or by using a special meter. To illustrate, I have provided a sample chart that shows this type of information:

Appliance / Item	Watts	Hours of use	Watt hours
Light bulbs x 3	15 x 3 = 45	5	225
Laptop computer	50	5	250
TV	110	2	220
Microwave	600	.5	300
Refrigerator	350	24 x 30% = 7	2,450
Fans x 2	70 x 2 = 140	5	700
Clothes washer	500	1	500
Battery charger	240	2	480
Total	**2,035 watts**		**5,125 watt hrs.**

Determine System Voltage Needed

The first step in the design is to determine the size of the voltage system to be used—either 12v, 24v, or 48v. The system voltage will determine the components to be used: panels, charge controller, batteries, inverter, etc.

Small systems (less than 1,000 watts) usually use a 12v system, medium systems (1,000–3,000 watts) usually use a 24v system, and large systems (more than 3,000 watts) normally use a 48v system.

The reason we need to raise the voltage for larger wattages is because, by raising the voltage, the current is reduced proportionately. This is important because low-voltage/high amperages need heavier-duty parts and wiring, which increases the costs.

Peak Load Watts

The total number of watts for all of the appliances and items listed in our example is 2,035. This is called the "peak load," which would be the total amount if all of the appliances and items were turned on simultaneously.

We will therefore use this "peak load" figure of 2,035 watts to determine which voltage system to use. Since 2,035 falls within the 1,000–3,000 watt parameter, we will use 24v as our system voltage.

Determine Best Type of Battery

There are three types of batteries that are typically used for solar systems—lead-acid, nickel-cadmium, and lithium-ion batteries. They each have their pros and cons.

The lead-acid battery is a common choice for small solar systems. The advantage is that these batteries are relatively inexpensive. The disadvantage is that you can only discharge the battery 50% (called the "depth of discharge"). They are also quite heavy.

The nickel-cadmium batteries are better applied for small applications, like AAA–D type batteries. One disadvantage is that they tend to form a memory barrier when partially discharged on a regular basis. The memory barrier would be the new capacity limit.

Lithium-ion is by far the best choice for solar systems. They are smaller, lighter, and provide more energy than the other choices. The disadvantage is that they are more expensive.

Sizing the Battery Bank

Considering the pros and cons of each battery type, I'm going to use a lithium-ion battery for this example. To determine the size and number of batteries needed for our example solar system, several formulas will be used to take various types of inefficiencies into account.

Initial System Size

To begin, an understanding of the basic relationship between volts, amps, and watts is needed. Using water as an analogy, voltage is the water pressure in the pipe, amps or current is the gallon/minute of water being pushed through the pipe, and watts would be the total volume of water in the bucket over a certain amount of time.

Volts x Amps = Watts * Watts ÷ Volts = Amps
* Watts ÷ Amps = Volts

Our initial system size begins with our "total watt hours" figure of 5,125 watts. Using a 24v system, we have the following: 24 volts, 5,125 watts, 213 amps.

Determine Depth of Discharge (DOD)

Batteries have a depth of discharge (DOD) amount limiting how much of the stored energy can be used. Lithium-ion batteries have a DOD of 80%. Considering this, we need to increase the battery wattage accordingly: 5,125 watts +20%= 6,150 watts. This yields a new system of 24 volts, 6,150 watts, 256 amps.

Determine Days of Autonomy

Because the sun doesn't shine every day, we need to plan for cloudy days when the solar system isn't producing. The way to plan for non-productive days is to have several days' worth of stored energy. These extra days of storage are called "days of autonomy." Generally, 3–5 days are used in planning. However, adding batteries, solar panels, a larger charge controller, an inverter, etc., can be expensive. With that in mind, it is common to begin with 1.5 days of autonomy and then add to that as the budget allows. We will use 1.5 days of autonomy for this example. To make this adjustment, multiply the total wattage by 1.5 days: 6,150 watts x 1.5 = 9,225 watts with 384 amps.

Consider Inverter Inefficiency Loss

We are considering the inverter at this point because there will be a small amount of inefficiency loss in the inversion process. The inefficiency loss is generally 4–10%. We will use 4% for this example: 9,225 +4% = 9,594 watts with 399 amps.

Determine Battery Bank Layout

For the battery bank, we will be using 24v lithium-ion batteries with a built-in battery management system (BMS). The BMS protects from over/under charging, monitors battery temperatures, and manages cell balancing.

We will need a bank of batteries that yields 24 volts (v), 399 amp-hours (ah), and 9,594 watts (w). To accomplish this, we can have the following: four 24v 100ah batteries wired together in parallel to yield a bank total of 24v, 400ah and 9,600w (9.6kW).

Please note: when either batteries or panels are wired together, they have to be joined either "in series" or "in parallel." When joined in series, the volts are added and the amps remain the same. When joined in parallel, the volts remain the same and the amps are added.

Sizing the Solar Panel Array

Now that we know the desired size of our battery bank, which is 24v, 400ah and 9,600w, we can design the solar panel array to accomplish this requirement. To complete the design of any solar system, we need to determine the peak sun hours per day. We can find this by looking at a special map detailing this information. In the United States, for instance, New Mexico and Arizona have 4–5 peak sun hours. All other Southwestern states have 3–4 hours. The remainder of the United States has 2–3 hours, except for the upper Northwestern and Northeastern states, which have 0–2 hours.

For our example, we will use 4 peak sun hours. We will then divide the battery bank size by 4 hours to get the total solar panel wattage needed: 9,600 watts ÷ 4 = 2,400 watts. This would then give us the PV array size of 24 volts, 2,400 watts, and 100 amps.

Pairing and Sizing the Charge Controller

In our example, we will be looking to create a system that is 24 volts, 2,400 watts, and 100 amps. We can use 250-watt panels to accomplish our wattage needs. However, when considering how to plan and design the solar panel configuration, the charge controller must be properly paired with the PV array and sized with the battery bank.

There are two common ways to accomplish this pairing and sizing of the charge controller with the system. First, the PV array must be paired with the charge controller by using the VOC (open-circuit voltage). The total VOC of the PV array input to the charge controller must not exceed the charge controller VOC limit.

Second, the amperage output of the controller must be enough to charge the battery bank. A rule of thumb is the "10–20%" rule: Take 20% of the total battery bank amperage to find the minimum amperage needed (400 amps x 20% = 80 amps).

Next, divide the PV array total wattage by the battery bank voltage (2,500 ÷ 24 = 104 amps). This is the minimum amperage output for the charger. A charge controller with an output of 100 amps will suffice to exceed the 80 amps needed for charging the battery bank.

When selecting PV panels and a charge controller, the overall goal will be to select a set of panels that will achieve the total system wattage needed and a charge controller that will allow that input, plus deliver the amp output needed for the battery bank.

For this example, we can consider 250-watt panels and match this with a charge controller that has the following parameters:

MPPT 150/100 Charge Controller

Battery bank nominal voltage	24 volts
Max PV input voltage	150 volts (max VOC)
Current rating (output amps)	100 amps

Solar Panels specifications

Watts	250 watts
VOC	26.4 VOC
VMP	22.6 volts
IMP	11 amps

When wiring the panels together, we need to construct the array in such a way that does not exceed the controller parameters. For instance, we purchase 10 250-watt panels to achieve a total of 2,500 watts. If we connect all of them in series, that would be a total of 264 VOC, which exceeds our 150 VOC limit on the controller. However, we can use a combination of series and parallel connections to achieve our goal and thus remain within the controller's parameters. For example:

- Connect 2 strings of 5 panels in series = 132 VOC (11 amps each string).
- Then, wire the two strings in parallel = total 132 VOC (22 amps).

Matching Solar Array to Charge Controller Comparison

	Solar Array	Charge Controller
Battery Voltage		24v
Total VMP	113	
Total VOC	132	150
Total Watts	2,500	2,900*
Total Amps	22	100

Pairing Results:

1. *PV/Controller Pairing*: 132VOC is < Controller 150 VOC
2. *Battery/Controller Sizing*: charger output 100 amps > 80 amps needed for charge
3. *Actual* Charge Controller *Input*: 113 volts x 22 amps = 2,486 watts
4. *Actual* Charge Controller *Output*: 24 volts x 100 amps = 2,400 watts

Additional Considerations

- For areas that have a lot of cloudy days, you might need to design a system with more days of autonomy.
- Higher quality panels are more expensive, but will yield more wattage and are more efficient.
- Panel voltages will vary with temperature (less in summer, and more in winter). The panel data sheet should provide the correction factors for determining the variables.

Installation

With the planning, we started at the bottom and worked our way up. For describing the installation, we will start at the top and work our way down.

Solar Panels

Solar panels come in three types: monocrystalline, polycrystalline, and thin-film. The primary differences between them are in the way the panels are manufactured.

Monocrystalline solar panels consist of cells that are made from one single silicon crystal. This allows the cells to be more efficient, but they are more expensive as well. Polycrystalline solar panels consist of cells that are produced from silicon fragments rather than a single, pure silicon crystal. This allows for the panels to be less expensive, but they are also less efficient.

The thin-film solar panels are made from a variety of materials. The most common types are those made from either cadmium telluride or amorphous silicon. They have an advantage of being lighter and quite flexible, allowing for easier installation. However, they have lower efficiency and power capacities than both the monocrystalline and polycrystalline varieties.

When shopping for panels, it is best to buy ones designed for use in an off grid system. For instance, in a "grid-tied" system, some manufacturers are selling panels with micro-inverters installed on each panel. The power coming from the panel array is therefore AC, and thus avoids the need for an inverter before attaching the system to the grid.

In an "off grid" system, however, the power coming from the solar panel array should be DC, in order to charge the batteries. In an off grid system, your batteries are your power source—the solar panels are only "battery chargers."

Panel Installation

For solar power, you need to find the best location for the panels, so that they have the most sun exposure for the longest amount of time. This might be on the roof of the house, but it is not uncommon to resort to solar panel mounts on the ground, located somewhere near the house.

A rooftop mount will generally consist of a series of rails, to which the panels will be attached. The tilt and orientation will be fixed according to what is available on the roof.

For a ground mount, the installation will consist of a series of posts, to which the series of rails will be attached. Then panels are attached to the rails. The tilt and orientation can be planned so that the panels receive the most sun for the longest period of time.

The orientation (north south, east, west, etc.) desired should be taken into account when the posts are installed. The best tilt can be determined beforehand, and the rails can be attached to the posts to accommodate the tilt desired. A general rule of thumb is to use the latitude degree as the tilt angle. For a more detailed figure, you can find a chart for your area online.

Wiring

The solar panels can be wired together in series, in parallel, or in a combination. The total amperage of the system, and the distance from the PV array to the house, will dictate the size of wiring you will need. You can find charts for this or you can consult an electrician.

Once the PV array has been installed and wired together to yield the voltage, amperage, and wattage combination you want, the wiring to the house can be installed. This is usually pulled through an underground conduit that is designed for underground installations.

Control and Energy Storage Location

The underground conduit should eventually arrive at the location that will house the various power control and storage components. This is generally near the house. It can be in the garage or in a shed designed for such. This location will shelter the charge controller, battery bank, inverter, and various other incidental components.

Charge Controller

The purpose of the charge controller is to regulate the voltage and current from the PV array in order to prevent over or under charging of the battery bank.

Charge controllers come in two types: PWM (pulse-width modulation) and MPPT (maximum power point tracker). PWM controllers are less expensive and can be used for smaller systems. MPPT controllers are more suitable for larger systems. The technology is newer, and they are more efficient in regulating voltage.

The charge controller size should be selected to be rated to the capacity of the PV array system. For our example, we chose an MPPT controller, rated with an output of 24 volts, 2,400 watts, 100 amps.

The power wires from the PV panel array should be connected to the charge controller on the terminals that are marked for input from the solar panels. The cables to the battery bank should be connected to the terminals marked for output to the batteries.

If desired, a shunt can be inserted in the negative cable between the charge controller and the battery bank, which measures the real-time charging voltage of your battery system. The battery monitor can calculate the state of charge, power consumption, estimated remaining runtime, and other helpful information about your battery system.

A fuse can also be inserted between the charge controller and the battery bank on the positive side, to provide extra protection.

Battery Bank

As determined earlier, the batteries selected for this example were lithium-ion batteries with a built-in BMS system in each. It was also determined in the planning phase of this example that a battery bank of 24 volts, 400 amp hours was needed. We further determined that four 24v 100–amp hour batteries wired together in parallel would yield the desired total.

Inverter

The purpose of the inverter is to change the battery DC voltage to AC. There are three types of inverters:

1. Square wave inverter: This is an inexpensive type that can work with some power tools and universal motors, but is not designed to be used with everyday electronics.
2. Modified sine wave inverter: This type is an improvement over the square wave type, but is still not designed for complex electronics and, like the square wave, can cause sensitive electronics to overheat and malfunction.
3. Pure sine wave inverter: This type is the most expensive and is designed to emulate the power from a generator or power company. As such, it works well with all kinds of electronics.

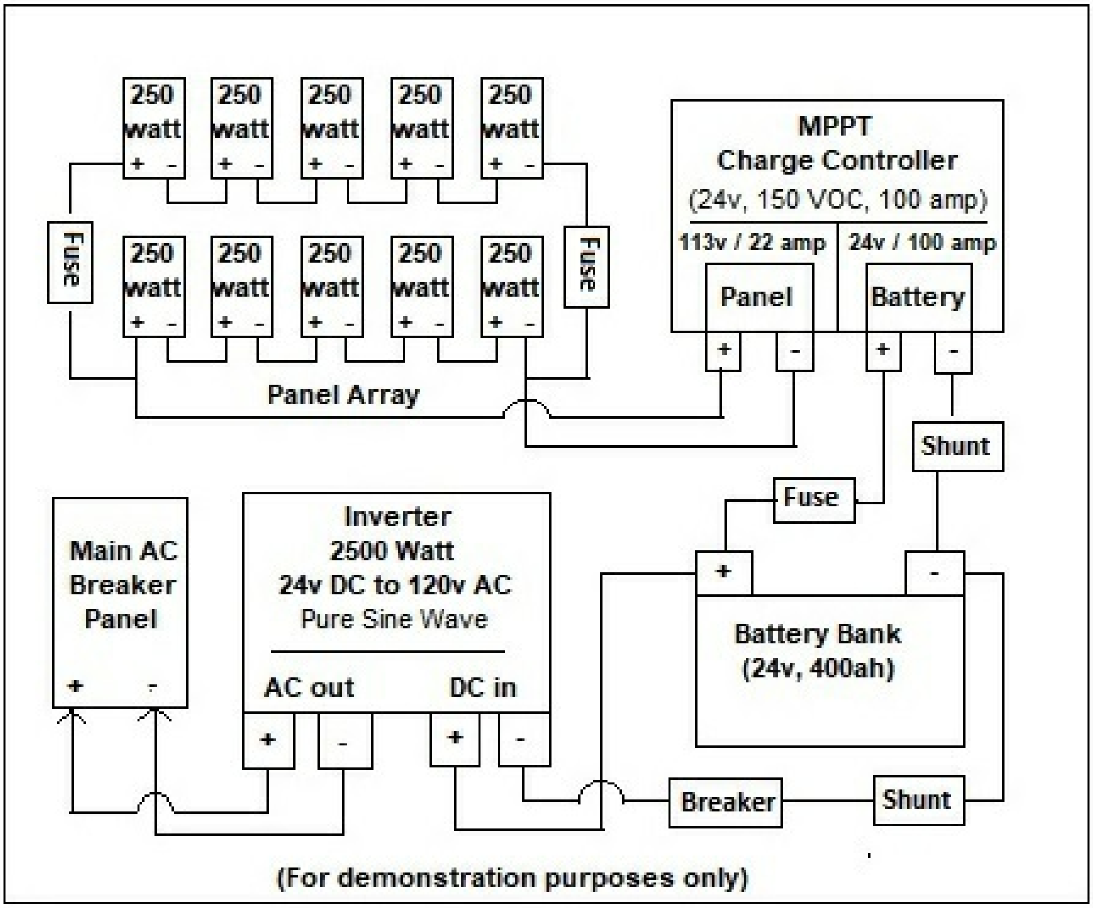
For our example, we selected a pure sine wave inverter that is rated for the solar system's voltage, wattage, and amperage. Additionally, the size of the inverter should be large enough to cover the household "peak load." With this in mind, the inverter selected for our example is a 2500w, 24v DC to 120v AC pure sine wave inverter.

For wiring, cables from the battery bank are connected to the terminals on the inverter marked "input from batteries." If desired, it is possible to insert a shunt between the battery bank and the inverter on the negative lead. The shunt could provide a digital readout of the amount of current being used from the batteries. You could also install a disconnect switch between the shunt and the inverter, for safety.

The wiring from the inverter is a cable from the terminals marked "output to AC." The 120v AC output is then wired to the main breaker bus of the house.

Please note that some household appliances, such as clothes dryers and water heaters, use 240 volts. Because most people living off grid are able to use gas for these higher usage appliances, I have not included that option in our example. However, it is possible to design a system to accommodate 240 volts; it would just require more solar panels and more batteries, larger-gauged wiring, larger and more expensive charge controllers, inverters, and so on.

Please also note that it is possible to use a hybrid inverter that combines the inverter and charge controller in one unit. There are several advantages to using this type of hybrid inverter: By combining two units into one, the overall cost is greatly reduced. The hybrid inverters are generally newer technology and thus offer a variety of ways to digitally monitor your power system. We will not use a hybrid inverter for this example.



Cost Analysis

Item	Cost
Solar Panels (monocrystalline)	\$250–\$350 each
Charge Controller (MPPT)	\$450–\$850
Batteries (24v lithium-ion)	\$600–900 each
Inverter (pure sine wave)	\$250–\$400
Total for average 2.4kW system	\$7k–\$10k
Cost per kW	\$4k

- Major components only. Does not include fuses, shunts, disconnect switches, solar mounts, conduit, installation equipment, or labor.

CHAPTER 2

Wind Turbines

Extracting energy from the wind is not a new concept. Due to increased interest in recent years, wind turbines have become more efficient and less expensive for off grid home applications. It is interesting to see the different types of wind turbines and how effective they can be.

It is possible to use wind turbines as the sole source of electrical energy, but that would require a constant flow of wind, which is quite rare. In most cases, wind turbines are used to supplement another source of energy, such as solar.

Just like solar is dependent upon sunshine to generate electricity, the wind turbine will only generate when the wind blows. The solar/wind turbine hybrid system can allow these two energy sources to complement each other. For instance, many of us can expect sunshine in the summer months, but may experience weeks or even months of overcast skies or rain during the winter months. It is generally during those stormy weeks or months that the wind most often blows—potentially creating an energy-generating opportunity both day and night.

In this chapter, we will look at how technology has improved, and how to discern by way of careful evaluation if this is a good option for you. This chapter will cover such things as the types of turbines, wattage output, the most suitable locations for wind turbines, major installation components, and a cost analysis.

Types of Turbines

Wind turbines generate electricity by allowing the wind to turn a rotor shaft. There are a number of different types of rotor systems available on the market. Some are quite creative and light, which allows them to be operational at lower wind speeds.

Generation Type

There are basically two types of wind turbine design—horizontal and vertical. The horizontal type is the most common, which turns by way of propellers. The propellers can be long and few or short and many. The vertical type turns by way of fins that can be straight and in the shape of a paddle wheel, or they can be curved in the shape of an egg beater.

Generation Output (AC vs. DC)

The small, home-type wind turbine will generate electricity in one of two ways—

either in AC or in DC. The PMA turbine is an “alternator” type and will generate electricity in AC using three wires. The PMG turbine is a “generator” type and generates electricity in DC using two wires.

As in the solar system, the electrical generation source is used to charge a bank of batteries, which must be charged with DC. Therefore, the PMA (AC) type will require a “rectifier” to convert the AC to DC, between the wind turbine and the charge controller. Some hybrid controllers have the rectifier built in to accommodate the three-wire AC turbine type.

Turbine Operation

The wind turbine consists of a rotor, a generator/alternator, a tail fin, and a tower support. When the wind blows, the tail fin will serve as a weathervane and cause the turbine to turn into the wind.

As the wind speed increases, the turbine rotor blades will begin to turn at the “start-up” or “cut-in” speed, and begin to generate electricity at around 10 mph. The faster the rotor turns, the more electricity that is generated. The optimum speed for electricity generation is at the “rated wind speed.” If the wind speed increases to the “cut-out” speed, the automatic braking system is initiated to protect the turbine from turning too fast and getting damaged.

There is also a manual braking system, which is an on-off toggle switch that can be operated from the ground. Both braking systems operate an electromagnetic brake, which is applied to the rotor shaft.

How to Choose a Turbine

As in the solar system, in order to know which type and size of wind turbine to select, we need to know the daily home usage of electricity. Since in most cases the wind turbine will be used in concert with a solar system, the wind turbine should be sized to meet the needed demand when the solar system is not producing. The wattage size, therefore, should be similar to the solar wattage output.

Turbine Examples

The wind turbine will be rated for wattage and voltage output. The specifications for the turbine will also include start-up wind speed, rated (best operating) wind speed, cut-out speed, and survival (maximum) wind speed.

In our chapter on solar, we used a battery bank of 9,600 watts. If the wind turbine is to supplement the solar system, the turbine should be capable of achieving the total solar system’s wattage/voltage within a 24-hour period.

When choosing a wind turbine, the selected option should be capable of generating useful wattages at historical wind speed ranges in your area. With all this in mind, we will use turbines with a 2,000-watt capability for our comparison.

Example 1

- Watts: 2,000
- Volts: 24
- Start-up wind speed: 7 mph
- Max speed: 111 mph
- Number of blades: 3
- Cost: $700

Figure 2,2,1

Example 2

- Watts: 2,000
- Volts: 24
- Start-up wind speed: 6 mph
- Max speed: 125 mph
- Number of blades: 11
- Cost: $1,230

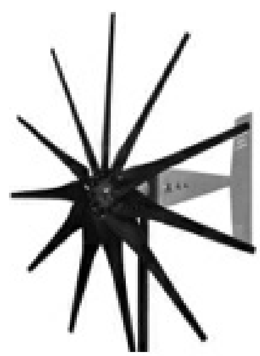


Figure 2,2,2

Example 3

- Watts: 2,000
- Volts: 24
- Start-up wind speed: 6 mph
- Max speed: 89 mph
- Number of blades: 3
- Cost: $578

Figure 2,2,3

Example 4

- Watts: 2,000
- Volts: 24
- Start-up wind speed: 8 mph
- Max speed: 103 mph
- Number of blades: 5
- Cost: $635

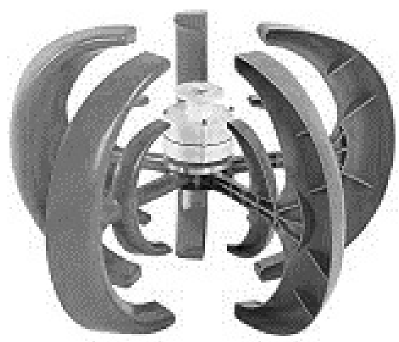


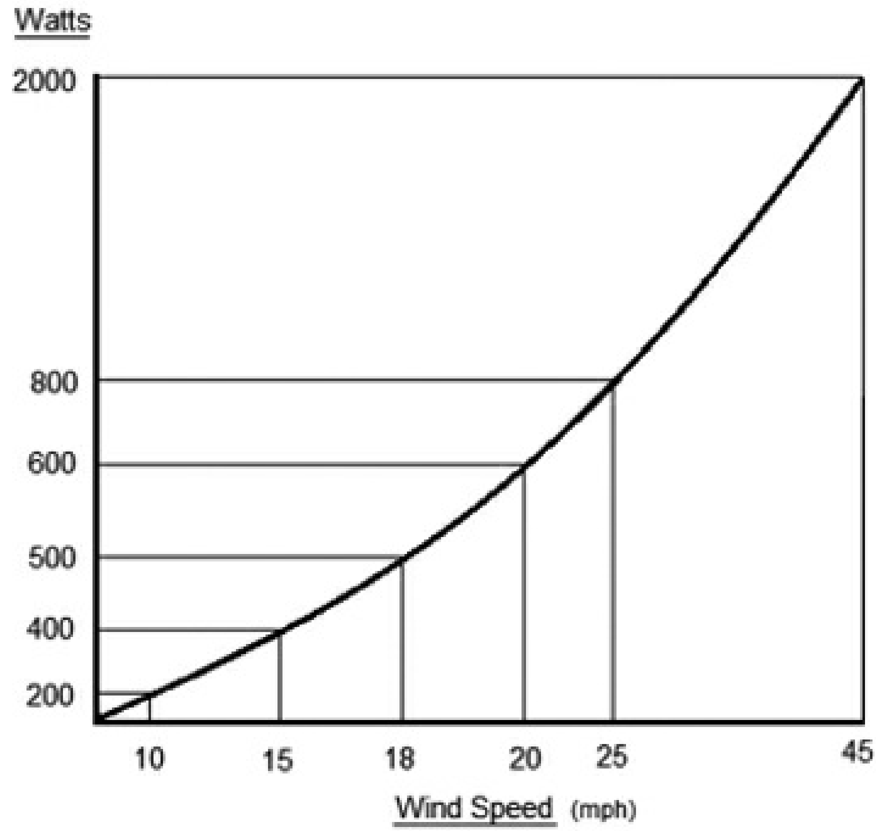
Figure 2,2,4

Both the start-up wind speed and the rated wind speed are important. One should choose a start-up speed that is below the local wind speed average. Unfortunately, rated wind speeds can be misrepresented. This should be the speed at which the turbine produces the rated wattage. Try to find a turbine that has published wind speed testing results like those demonstrated in the graph below.

Small wind turbines will begin to produce electricity at around 10 mph. The higher the wind speed, the more power they produce. As you may know, wind generally starts low, builds up to a peak strength, and then eventually begins to slow down again. That is the nature of a typical weather pressure system.

The graph below shows a power curve for a small 2,000-watt wind turbine. This turbine has a start-up or "cut-in" speed of 6 mph, but doesn't produce 2,000 watts until the wind reaches the rated wind speed of 45 mph. Most of its power generation is going to be in the 15–25 mph range.

This is the nature of wind turbines—the power generation is a function of the wind speed and, therefore, in a 24-hour period that power generation can start low, build to a peak, then decrease as the wind dies down.



Graph resembles data for Raptor G4 - 11, by Missouri Wind & Solar

By using this type of graph, the total watts generated for a 24-hour period can be charted. For instance, imagine a wind slowly increases over an 8-hour period, peaks at 20 mph and remains at peak for about 4–6 hours, and then slowly decreases for the next 8 hours. Conceivably, the total wattage generated over a 24-hour period could be the 9,600 watts needed to charge our example battery bank.

This, of course, is ideal; in reality, wind speeds and durations are going to vary throughout each day. This is why you should try to determine what the average wind speed is for your area.

How Much Wind Do You Have?

Wind Data

Part of the process of determining if a wind turbine would be a viable option is to find out how much wind your location receives. It would be important to know the typical wind speed and prevailing wind direction for each month throughout the year—especially the fall, winter, and spring months.

If you have the time to evaluate your site before the implementation of a plan, the ideal way to accumulate wind information is to install an anemometer on your property. The anemometer is a device that measures wind speed and wind direction. This information could provide the necessary information for accurately determining what the wind potential is for your location and which weeks and months would provide the best wind generation potential.

Of course, using an anemometer for planning purposes would require a year of data collection. If timing for your preferred installation does not allow that much planning, there are other sources you can use to obtain wind information, though it could be less accurate and less relevant to your particular location. These other wind sources can include your local airport, weather stations, and historical wind data maps found online.

Local airports and weather stations record daily wind data, which is typically archived. The wind data collected at local airports is generally recorded at a height of 30 feet above ground level. Wind data collected at weather stations is generally recorded at a height of 5–20 feet above ground level.

This information from airports and weather stations is more accurate and relevant than state and national historical wind maps, but can still be somewhat different from your particular location because of obstacles and terrain.

Useful wind information can be extracted from state and national historical wind maps found online—for example, from websites such as that of the National Oceanic and Atmospheric Administration (*https://www.noaa.gov/*). This data is generally recorded as averages for a certain time frame and location. Though wind speed and direction can vary depending on the source, this data does provide a general idea of how much wind your area will receive during certain months of the year.

Wind Speed Chart

The following chart will give you an idea of how to estimate wind speed. This can be estimated using a wind sock, or an accurate reading can be achieved with an anemometer.

Wind Category	Wind Speed (mph)
Gentle breeze	5–9
Moderate wind	10–20
Strong wind	21+

Best Location

Choosing the best location for the wind turbine installation is just as important as choosing the correct size of the turbine. Wind flow can be impeded, disrupted, and changed by many factors such as trees, buildings, terrain, etc.

Wind Flow and Distance

There are two important things to consider when choosing an installation site: wind flow and distance. The best site location is where the most wind flow occurs. In a general sense, the higher the wind turbine can be installed, the more wind can be experienced. This can be achieved by constructing as high a turbine support pole or tower as possible or by installing the turbine pole or structure on higher terrain such as a hilltop.

The other consideration is distance. The closer the turbine is to the battery bank, the more efficient the system will be. Longer distances result in increased electrical resistance in the wiring and thus a larger voltage drop. This makes the system less efficient, requiring larger wire and an increase in cost.

Obstacles

A number of things can affect wind flow. Terrain (e.g. hills), trees, rocks, buildings, and so on are all considered obstacles to wind. Any or all of these types of obstacles can affect wind velocity and direction.

In order for the turbine to be exposed to the highest possible wind speed, it needs to be placed where there is the least amount of interference from obstacles. A good rule of thumb for placement is to pick a spot upwind from any potential obstacles and 30 feet above any obstacle within 300 feet of the installation.

Another adverse effect of obstacles on wind is turbulence. The more wind flow is disrupted, the higher the likelihood of turbulence on the leeward side of the obstacle. Turbulence can make wind speed erratic and less efficient. Gusts can also cause voltage surges.

Towers

When choosing a tower, one should consider location, height, and maintenance needs. All of these criteria are important, and the specific requirements will dictate which type will work best for your particular site.

Tower Types

There are two general types of towers: the stand-alone type and the pole type. The stand-alone tower is sturdier and more reliable in high-wind areas, but is also more expensive, more difficult to construct, and less easy to accommodate maintenance needs.

The pole type construction, typically called a “tilt-pole” type, consists of a metal pole and supporting guy wires. The size of the pole will depend on the size and weight of the wind turbine and the desired height of the pole. The manufacturer should be able to provide these dimensions.

Pole Heights

The hub height of a pole, which is the distance from the ground to the center of the rotor hub, is generally determined by the height needed to get the best and most wind flow. Obviously, the higher the pole, the more area is needed for lowering the pole for maintenance purposes.

Pole Support Cables

Poles that are relatively short (20 feet or less) generally require only one set of guy wires, with the guy wire height at 50% of the pole height. Poles taller than 40 feet may require two sets of guy wires, with guy wire heights at 50% and 75% of the pole height. For instance, if a pole height is 50 feet, then the height of the first set of guy wires would be 25 feet, and the height of the second set of guy wires would be 37 feet.

To determine the guy wire length, we use the Pythagorean theorem ($a^2+b^2=c^2$) for a right triangle. We will assume for this example that side "a" and side "b" are equal. For the first set of guy wires, the theorem application would be $25^2+25^2=c^2$**.** To find c^2 (the length of the guy wires), we would use the following formula: $c=\sqrt{(a^2+b^2)}$, whereby $c=\sqrt{(1{,}250)}=35$ feet.

In most cases, the guy wires (cables) would connect to a ground anchor that is either augured or cemented into the ground and would be tightened via a turnbuckle.

(*Note: You should always consult the manufacturer for the size of the pole required for various heights and for corresponding guy wires.*)

Pole Base

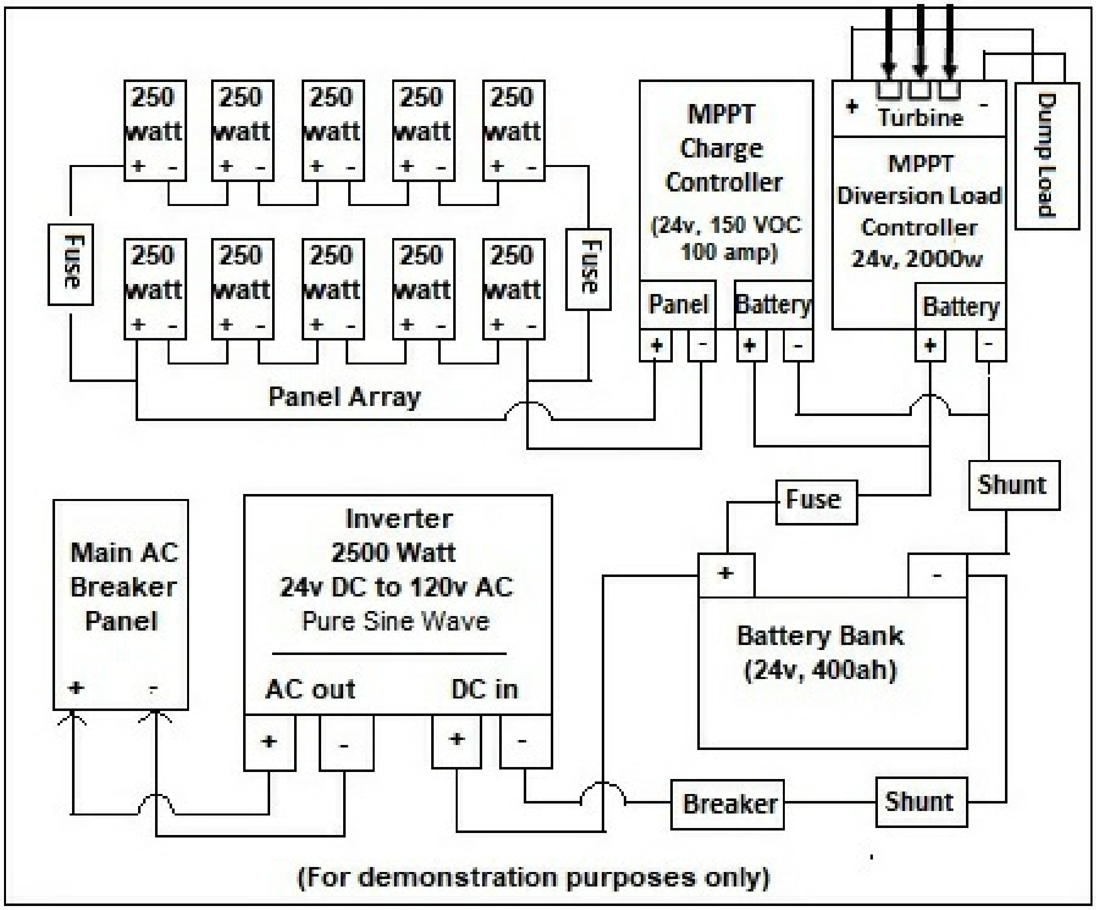
The pole base should be constructed out of concrete in order to provide a strong base that will not weaken when conditions are wet and windy. If a tilt-pole is constructed, a swivel bracket should be incorporated into the concrete to provide a strong, fixed support yet allow the pole to be laid down flat on the ground for maintenance purposes.

Installation

As part of the wind turbine system, a rectifier will be needed (for a PMA turbine) to change the current from AC to DC. A diversion load controller with a dump load resistor will also be needed to divert excess power when the battery is fully charged.

While it is possible to have an MPPT solar-and-wind turbine combined in the same charge controller, it would be more difficult and more expensive to find one that meets the specific pairing needs for the solar system. Therefore, it might be best for the wind turbine system to have its own charge controller, separate from the solar charge controller.

Some hybrid charge controllers for the wind turbine include the rectifier as part of the controller (e.g., 3-wire AC in from the turbine and 2-wire DC out to the battery). This type should also include the dump load resistor as part of the package.



Maintenance

The wind turbine consists of a rotor, generator, tail fin, and tower support. All of these parts should be inspected from time to time. The turbine (generator/alternator) will more than likely require some form of periodic maintenance protocol. The manufacturer's instruction manual should provide a maintenance schedule for your particular model.

Cost Analysis

Item	Cost
Wind Turbine	$250–$3,250 (1kW–3kW)
Diversion Load Controller (MPPT with dump load resistor)	$100–$300
Total cost	$350–$3,250 (for 1kW–3kW)

- *Note: Some wind turbines come with a charge controller but may not include a dump load resistor (to be purchased separately)*
- *This price range does not include the tower, guy wire cables, bottom post brackets, turnbuckles, wiring, labor, etc.*

Cost Comparison

	1kW	1.5kW	2kW	3kW
Turbine	$250–$1,000	$700–$1,900	$700–$2,100	$900–$3,000
Controller	$100+	$150+	$180+	$250+
Total	$350–$1,400	$850–$2,050	$880–$2,280	$1,150–$3,250

Please note: There are numerous small wind turbines on the market, with a wide price difference for the same size turbine. Therefore, it would be prudent to do due diligence in researching the reliability of the manufacturer and product. Check the warranty, product reviews, and rotor material (e.g., carbon fiber vs. plastic), and verify whether the turbine has been tested and certified. There are two sources you can use for checking certification:

1. *The Small Wind Certification Council (ICC-SWCC) provides independent, accredited certification for wind turbines that meet or exceed the requirements of specified standards.*
2. *The National Renewable Energy Laboratory's (NREL's) National Wind Technology Center also provides information about small wind turbine testing and development.*

CHAPTER 3

Hydroelectric Turbines

This is an exciting option for generating your own electrical power. If you have a creek or stream on your property, consider yourself fortunate, for you have a source of drinking and household water at the very least. If you have enough flowing water to generate electricity, you are very fortunate indeed. The beauty of a hydroelectric system is its potential for generating electricity 24/7 regardless of what the weather is doing.

Hydroelectric generation comes in a variety of sizes and output potentials. Since this book is focused on off grid systems appropriate for small to medium homesteads, this chapter will concentrate on the smaller hydroelectric systems known as micro and pico hydropower systems.

Micro hydropower systems are categorized as those that produce 5–100kW, while pico systems produce less than 5kW. We will be describing a pico system in this chapter.

Pico hydropower systems consist of four main parts: the water source, penstock (piping), the turbine, and the power storage and control room. The first important step in evaluating this particular option for electrical power is to determine the hydropower potential.

Hydropower Potential

In order to determine the hydropower potential of your water source, you must know the “flow rate” and the “head.” The flow rate is the amount of water provided in gallons per minute. The head is the amount of vertical drop from the water source to the turbine site in feet.

Once you know both the flow rate and the head, you can determine the amount of power to expect by using the following formula:

Flow (gpm) x Head (feet) ÷ 10 (correction factor) = Power (watts)

Seasonal vs. Continuous

Some creeks and streams flow year-round, and some flow mostly due to runoff from snow and rain. If the water source has an adequate flow year-round, you can design the hydropower system accordingly. If there is enough flow and head, the system could feasibly produce the needed electrical power year-round.

However, if the creek or stream flows fluctuate due to seasonal changes, then you would need to design the system based on the annual average or the lowest rate expected during the year.

Flow Rate Determination

There are several ways the flow rate can be measured. The method of choice depends on the amount of water available in the creek or stream.

Bucket Method

The bucket method works well for small creeks or streams with limited amounts of water flow. All you need to do is divert the amount of water that would be used for the hydropower system into a gallon jug or five-gallon bucket. Once the water begins to fill the container, note the number of minutes it takes to fill the container. This will give you the gallons-per-minute figure for your calculations.

Float Method

If the creek or stream has enough water flow for a waterproof object to float a distance of 30 feet, you can use the float method. To use this method, you will need to know the width and average depth of the creek or stream.

After the width and depth have been measured, the area of the creek or stream can be determined using the following formula:

- A (area) = W (width) x D (average depth)
- Example: A = 3 ft. wide x .75 ft. average depth
    - A = 2.25 sq. ft.

Next, mark off the distance for the floating measurement. Begin by marking a starting point and an ending point, 30 feet apart. Place a floating object (such as an empty plastic water bottle) at the starting point and then time the number of seconds the object takes to float down to the ending point. For this example, let's say it takes 120 seconds to float 30 feet.

This measurement will be used to determine the velocity of water in the creek or stream. Due to uneven side and bottom surfaces in the creek or stream, a correction factor of 65% will be used. The following formula can be used to determine the flow rate of the water:

- Velocity (V) = feet per second x .65 (correction factor) = corrected feet per second
    - 30 feet ÷ 120 seconds = .25 feet per second (fps) x .65 = .1625 fps
    - .1625 fps x 60 seconds = 9.75 feet per minute (fpm)
- Flow = A (sq. ft.) x V (fpm) = cubic feet per minute (cfm)
    - 2.25 sq. ft. x 9.75 fpm = 21.9 cfm
- Percent of flow = percentage of creek flow rate to be used for hydropower
- Useable flow (cfm) = 21.9 cfm x .25 (percent of flow) = 5.48 cfm
- Useable flow (gpm) = 5.48 cfm x 7.48 (conversion factor) = 41 gallons per minute (gpm)

The more gpm that can feasibly be extracted from the creek or stream, the more power can be produced. But again, the amount of watts produced depends on both flow and head. If there is not enough head, more gpm will be needed to arrive at the desired hydropower potential. Conversely, a high head will require less gpm to arrive at the same desired power.

(*Note: Water diverted from a creek or stream for hydropower purposes should be returned back to the water source downhill from the turbine in order to avoid any possible environmental impact to fish and wildlife.*)

Head Determination

There are a number of ways the head measurement can be derived. Both the amount of vertical drop and the friction head loss should be taken into consideration.

Methods

The following methods are most commonly used for determining the amount of head. They are listed from least to most accurate.

Topographical Maps

Topographical maps can be used to get a general idea of the elevation differences in your area. The contour lines on the maps can be in intervals of 10, 20, 40, 60, and 80 feet. If you can spot on the map the locations of the water source and where you plan on having the turbine, you should be able to get a rough idea of the head measurement by counting the contour lines.

Altimeter/GPS

The use of an altimeter or GPS with an altimeter function is another means to determine the total vertical drop. This would be a bit more accurate than using a topographical map, but still not as exact as other means such as the hose method or surveyor’s transit method.

Hose Method/PSI Gauge

The hose method consists of a water hose that runs from the water source to the turbine site, filled with water. A pressure gauge reading pounds per square inch (psi) would be fitted to the end of the hose at the turbine site. Once the hose is filled with water and all air is purged from the end of the hose, the result should yield a psi reading. The psi reading would then be multiplied by 2.31 (conversion factor), to equal the feet of head.

Surveyor’s Transit/Hand Level

The surveyor’s transit level, or surveyor’s hand level, is the most accurate way to measure the elevation drop in feet. The use of either a transit level or hand level will require two people. For this explanation, we will use a surveyor’s hand level and rod.

To begin, the person holding the hand level (the surveyor) should stand at the water source and look downhill toward the person holding the surveyor’s rod (the rod holder). The rod holder will be standing downhill (maybe 30–40 feet) and hold the surveyor's rod upright so that the surveyor can get a reading.

The surveyor will read the feet and tenths on the rod and mark that as reading A. Next, the rod holder will remain in place while the surveyor walks about 30–40 feet downhill from the rod holder. The surveyor will then look uphill at the rod and get a second reading from the rod in feet and tenths and mark that in the book as reading B. Then reading B will be subtracted from reading A to get "elevation drop #1" in feet and tenths.

The surveyor will then remain in place while the rod holder walks downhill about 30–40 feet below the surveyor. The surveyor will then look downhill and get a reading on the rod in feet and tenths and mark that in the book as reading C. Then the surveyor will walk downhill 30–40 feet below the rod holder, look uphill, and get a reading on the rod in feet and tenths and mark that in the book as reading D. Subtracting reading D from reading C will provide "elevation drop #2" in feet and tenths.

The surveyor and rod holder will continue this process until arriving at the turbine location. By adding all of the elevation drop amounts, the total will yield the total head measurement in feet.

Friction Head Loss

Fluid flowing through any type of pipe will suffer a certain amount of friction head loss (FHL). The longer the run (length of penstock), the more FHL will be encountered, which will result in loss of head. For a 1.5-inch pipe, the head loss will be .07 feet per feet of run.

Gross and Net Head

The total head reading is considered to be the "gross head" amount in feet. Gross head minus the friction head loss equals net head.

- Useable flow rate (in gpm) x net head (in feet) = power (in watts)

Low vs. High Heads

Head is generally categorized as either high, low, or ultra-low. A head of more than 66 feet is considered high, and one between 10 and 66 feet is considered low. A head lower than 10 feet is considered ultra-low and is generally not feasible unless it has a very high flow rate.

A high head can provide valuable leverage when needed. A high head can make up for low flow rates that otherwise would be too few gallons per minute to produce power.

Penstock

The piping used for transporting the water from the water source to the turbine is referred to as "penstock." The most common types of penstock for micro and pico hydropower systems are white polyvinyl chloride (PVC) pipe, black polyethylene (PE) pipe, and black high density polyethylene (HDPE) pipe.

Penstock Descriptions

PVC pipe can be used when the distances are relatively short and the terrain is not rocky. Because PVC pipe is rigid and relatively inflexible, it can be a poor choice when the slope is relatively steep and/or there are a lot of terrain challenges.

PE is relatively inexpensive and very flexible, but the wall thickness is thin compared to HDPE. PE pipe can be an acceptable choice if the piping does not need to have a lot of turns (where kinks can occur) and does not need a high-pressure rating.

HDPE is usually the most popular choice, even though it is more expensive than the others. Like PE, HDPE is flexible and can be used in steep, rough terrain, but without the risk of kinks. The wall thickness is greater than PE and, therefore, can be purchased with a high-pressure rating.

Penstock Size Considerations

The size of penstock should be large enough to accommodate all of the flow that you are wanting to use. Most penstock sizes for pico hydropower systems are in the 2–3 inch range. Since the pressure rating should be at least 40–50% greater than the psi at the turbine, a pressure rating of 100 or 125 is normally adequate.

Penstock Layout Considerations

The piping layout should avoid steep turns and angles; otherwise, this would create a large head loss, adversely affecting the flow rate. The piping should be laid with a continuous downhill slope to avoid any air lock problems.

The flow rate should be at or above 5 fps to avoid ice forming in extreme cold temperatures. If the flow rate is less than 5 fps, then the pipe may need to be buried to avoid freezing in winter months.

The pipe layout plan should provide for the turbine to be as close to the point of use as possible to avoid long wiring runs, which can cause voltage drops.

Water Valves

There are two typical types of water valves that can be used in a water line: the gate valve and the ball valve. Ball valves are easier to use because the water can be turned off quickly, but therein lies a potential problem: Turning off the water quickly can cause "water hammer"—a surge in pressure, which can result in a water line leak. Therefore, a gate valve is the better choice for micro and pico hydropower systems

Turbines

Micro and pico hydropower systems normally use impulse type turbines that generally use water velocity to turn the turbine wheel. There are three types of impulse turbines: the Crossflow turbine, Pelton wheel, and Turgo wheel. The most common turbines for micro and pico hydropower systems are the Pelton wheel and Turgo wheel.

The Pelton wheel is a metal plate with cups on the outer edge. Water enters the turbine housing at a high velocity through one or more nozzles, causing a water jet. The water jets are directed toward the cups on the turbine wheel, causing the wheel to turn. Because the power generated by the turbine wheel is dependent upon the velocity of the water, this type of turbine works best with high-head and low–flow rate systems.

The Turgo wheel type of turbine is similar to the Pelton wheel, but the Turgo wheel is generally lighter in design and weight. The water enters the same way through nozzles, and the water jets are directed at the cups on the water wheel. Because the wheel is smaller and lighter, high speeds can be achieved with a medium head and medium-to-low flow rate.

Installation

Micro and pico installations are composed of a forebay, penstock, a turbine, and a power control room. The hydropower system can be designed to provide all of the electrical needs of the homeowner, or just to supplement other electrical sources. The installation always begins at the water source and is developed downhill from there.

Forebay

In order for the appropriate amount of water to be diverted into a penstock, the water supply must be collected in a water intake box, called a “forebay.” The intake box should be designed to prevent debris and air from entering the piping.

The intake box typically consists of a cement or metal box that is arranged in the creek bed to collect a reasonable depth of water, so that the water entering the piping at the bottom of the box will not suck in air. A type of screen system will also be needed to prevent trash, debris, and rocks from entering the box.

Such types of prefabricated boxes exist on the market, but they can be expensive. Many believe the expense is worth the investment, in order to save a lot of trial and error in developing your own design. Such a prefabricated box is listed in the Cost Analysis.

Penstock

Once the water intake box has been installed, the penstock can be attached and laid. PE and HDPE pipe can be purchased in rolls of 100 feet or more. When unrolling the pipe, do your best to prevent kinking. Once a kink is formed, it is difficult to “unkink” the pipe at that location. The larger the pipe, the easier it will be to lay it in its desired location without kinks. If you live in an area that reaches temperatures below 32 degrees F (0 degrees C) and the terrain allows, bury the pipe to prevent freezing.

Turbine

The hydropower turbine should be installed close to the power control room, if possible, to reduce the amount of voltage drop experienced from long wiring distances.

The turbine is generally installed on a stand that has been constructed for this purpose. The stand can be constructed out of wood, metal, plastic, or a combination of materials. The idea is to have the turbine at a reasonable level for operation and maintenance and, at the same time, avoid the penstock having to increase in elevation to reach the turbine.

The penstock typically ends at the turbine site and is attached to a 3-inch PVC pipe, about 4 feet long. This 3-inch pipe is used to accommodate valves, a pressure gauge, and a water hammer arrestor. The end of the 3-inch PVC pipe can then be arranged to either accommodate a Turgo turbine or a Pelton turbine.

Turgo Turbine

For a Turgo turbine, the 3-inch PVC pipe can be split into a PVC "Y" manifold. There would be a pipe coupling on each end of the Y. Flexible connection hoses are attached to each of the two couplings of the manifold and then connected to two nozzles on the Turgo turbine.

Pelton Turbine

For a Pelton turbine, the 3-inch PVC pipe can be reduced to a 1.5-inch pipe in order to connect to a square PVC manifold that fits around the square housing of the turbine. The square manifold has four ball valves (one on each side of the turbine housing), which direct the water into four nozzles that are inside the turbine housing. The turbine and the square PVC manifold all fit inside a turbine support box roughly 18 inches square and 7–8 inches tall.

Small adjustments can be made to increase the power output—such as changing the size of the nozzles, increasing the number of nozzles used (1–4), shortening the length of the flexible connection hoses (for a Turgo), and lowering the height of the turbine support box.

Power Control Room

Normally, the power control room is located at or attached to the home. It is in this room that all of the power control components are installed. Like the wind turbine, the water turbine produces AC power. As the AC power line (three wires) enters the power control room from the turbine, it will first need to be rectified, changing AC to DC. From the rectifier, DC power goes to the MPPT (+ auxiliary) controller. Small wires from the auxiliary output terminals run to a relay that connects to a "diversion load," such as a water heater, to use up the excess power when the batteries are fully charged.

After leaving the MPPT (+aux) controller, the DC power will be connected to the battery bank. From the battery bank, the power will be connected to the inverter (which was sized to cover "peak load"), and from the inverter it will be connected to the main house breaker panel.

Following are the criteria we will use for our example, to demonstrate how the hydropower system works and how it is all connected.

Example parameters:

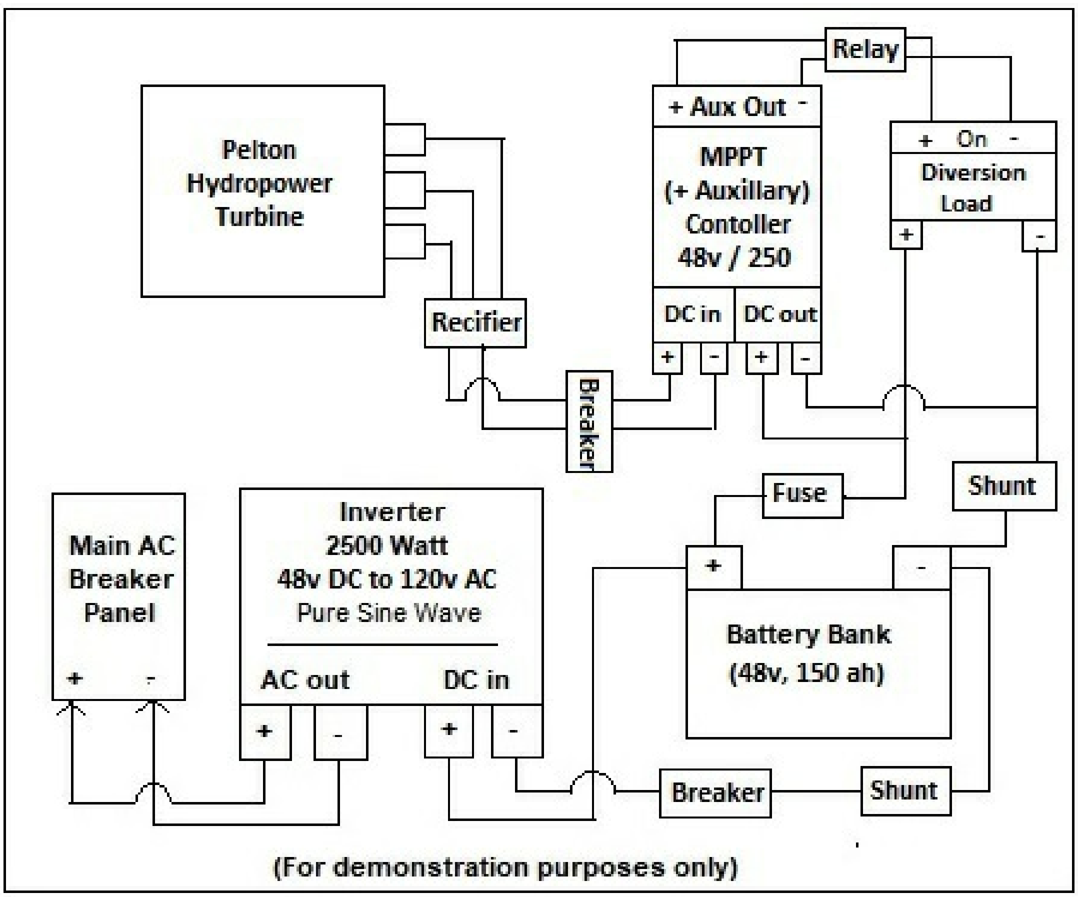
- Flow rate = 21 gpm
- Gross head = 150 feet
- Psi at head = 65 psi

- 500 ft. pipe run with 1.5-inch pipe
- 500 x .07 (friction head loss per ft.) = 35 ft. loss
- 150 ft. head – 35 ft. loss = 115 ft. net head
- 21 gpm x 115 ft. ÷ 10 = 240 watts
- 240 watts x 24 hours = 5,760 watts/day

While 240 watts may not seem like much, the beauty of a hydropower system is that it produces power nonstop, 24/7. With that in mind, a 240-watt hydropower system can yield 5,760 watts per day, which can be stored in a battery bank. That size battery bank can actually provide enough power for a modest homestead—assuming the flow rate is relatively consistent year-round.

By using the above parameters, we have a relatively low rate and a relatively high head. These parameters best fit a Pelton turbine, which comes only in a 48v version. For our example, we will use a charge controller, battery bank, and inverter suited for 48 volts. The battery bank will consist of three 48v, 50ah lithium-ion batteries, which are connected in parallel to provide a 48v, 150ah battery bank (7.2kW of storage).

The following diagram demonstrates how such a system fits together.



Cost Analysis

Item	Cost
Pelton hydropower turbine 48v*	$1,650
Elgin Coanda intake box*	$1,200
MPPT controller (+ auxiliary)**	$785
Batteries (48v lithium-ion)	$770–$1,400 each
Inverter (pure sine wave)	$330–$400
Total estimated cost	$6.5k–$8.5k

- Cost analysis includes major components only
- *Langston's Alternative Power Supply
- **Midnight Classic MPPT 48v/250 charge controller, for solar, wind, and hydro

Recommendation

To create a professionally designed system with specialized parts such as turbines, an intake box, and electrical components, you can contact a specialist such as Langston Alternative Power at https://www.langstonsalternativepower.com/.

CHAPTER 4

Generators

For off grid living, most people consider generators as a supplemental source of power. When the sun isn't shining, and the wind isn't blowing, generators can provide power for household needs. When supplemental power is needed for only a few days or weeks at a time, a mid-size generator can generally provide enough sustainable power. However, when supplemental power is needed for longer periods of time, a whole-house, backup generator would probably be a better fit.

This chapter will deal with how to determine the size of generator you might need; compare various types of generators, hookup methods, and fuel type options; and look at the pros, cons, and cost analysis for the various generator systems.

Generator Size

Because a generator is used, in most cases, to provide household electrical needs when other off grid sources are not producing, we would use the same criteria and data to determine the size of generator needed.

House Load Demands

Household electrical demands are determined by adding up all of the wattages of the house appliances and other devices that use electricity. For the appliances that have electric motors (e.g., refrigerator, window air conditioners, etc.), note what the start-up surge wattage demand is for each. Finally, add the total running wattage to the highest of the start-up surge wattages and use this figure to determine the total wattage needed for the generator.

Needs

Because of the expense involved in purchasing and running a generator, the typical use is primarily for supplementing the off grid electrical system when that system isn't generating (e.g., when there is no sun or wind). Estimating the length of time when a supplemental generator is needed will help determine the type of generator to invest in.

Types of Generators

There are generally four types of generators used for off grid applications: a small, portable type, a mid-size portable inverter type, a large portable inverter type, and a large standby type. Comparison criteria include price, fuel consumption, capacity, outlets, start-up method, and other features.

Conventional vs. Inverter Generators

Conventional generators generally run at a consistent high speed, and the voltage level can be irregular at times. The exhaust system may be a lower quality, allowing a higher noise decibel level and more exhaust fumes.

Inverter generators are referred to as “inverter type” because they generate power in AC, then rectify that to DC, then invert that back to AC. This process creates a pure sine wave, allowing the voltage level and the hertz frequency to be more stable. This “cleaner voltage level” is necessary for electronics such as computers, phones, printers, TVs, and power tools. These generators are also more fuel efficient, because the generator powers up or down to meet the load demand.

Small Generators

Small generators can be either conventional or the inverter type. These generators can be a useful tool for off-grid living, but rarely are used as a supplemental source for the entire household. If a small generator is used, it is generally only for a few appliances in an emergency situation.

Considerations

Pros	Cons
Low cost	Capacity limited
Relatively lightweight	Can be noisy
Portable	
Low maintenance	

Comparison

Criteria	Results
Price	$150–$700
Capacity	Up to 2kW
Fuel type	Generally, gasoline
Fuel consumption	.2 gph
Outlets	Generally, 120v only
Start-up method	Generally, pull-cord start
Features	Fuel level

Mid-Size Portable Inverter Generators

Most mid-size generators are the inverter type. While these generators do not have quite enough capacity for an entire household, they can service more appliances than a small generator can. Mid-size generators are heavier than small generators, but often come with wheels, allowing them to be moved easily. The wattage capacity is larger than small generators, yet the mid-size generator can still be somewhat fuel-efficient for its class. Because of the size increase, it can also have a quieter exhaust system.

Considerations

Pros	Cons
Relatively low cost	Capacity limited
Portable	
Low maintenance	
Relatively quiet	

Comparison

Criteria	Results
Price	\$350–\$1,000
Capacity	2kW–3.5kW
Fuel type	Generally, gasoline
Fuel consumption	.4 gph
Outlets	Generally, 120v and 240v
Start-up method	Pull-cord or electric start
Features	Fuel level, low-oil shutoff

Large Portable Inverter Generators

Large portable inverter generators have enough capacity for an entire household. These generators are heavier than small or mid-size generators, but can come with wheels, allowing them to be moved relatively easily. The fuel consumption in gallons per hour is still somewhat efficient considering the capacity and size. They are generally quiet and have an electric start.

Considerations

Pros	Cons
Reasonable cost	Portability limited by weight
Portable	
Low maintenance	
Relatively quiet	
Capacity large enough for house	
Electric start	
More fuel type options	

Comparison

Criteria	Results
Price	$500–$2,000
Capacity	5kW–7.5kW
Fuel type	Gasoline, diesel, or propane
Fuel consumption	.75 gph
Outlets	Generally, 120v and 240v
Start-up method	Electric start
Features	Fuel level, low-oil shutoff

House Standby Generators

House standby generators are permanently installed and connected directly to the main breaker panel of the home. They are connected through an automatic changeover switch, designed to power up immediately when the main power source loses power, providing uninterrupted power. These generators can be ordered to use any of the three main fuel types. They also have an assortment of features for monitoring performance.

Considerations

Pros	Cons
Can power entire home	Expensive
Automatic transfer switch	Installation permanent
Low maintenance	
Relatively quiet	
Electric start	
More fuel type options	
More features	

Comparison

Criteria	Results
Price	\$3,800–\$7,000
Capacity	12.5kW–26kW
Fuel type	Gasoline, diesel, or propane
Fuel consumption	2–3 gph
Outlets	Generally, 120v and 240v
Start-up method	Electric start
Features	Fuel level, low-oil shutoff, watts, voltage, etc.

Storage and Maintenance

Since most generators in an off grid situation are not typically used with any regularity, there are a few storage considerations to keep in mind.

Electric Start Batteries

Most small generators use a pull-cord for starting. Medium and large portable generators may come with either a pull-cord or an electric start option. All home standby generators have an electric start.

Because these electric start options use small 12v batteries, they will need to be maintained. The last thing you want to happen when you need supplemental power is for the electric start battery to be dead.

Fuel Shelf Life

We will go more in-depth into fuel comparisons later in the chapter, but it merits mentioning here that gasoline and diesel have a shelf life. For instance, if gasoline sits in a tank for a long period of time without being used, it can begin to break down in its composition. Some of the compounds in the fuel will evaporate, and the remainder separates into mostly water and varnish. The shelf life of your fuel can be extended by adding a fuel stabilizer to the tank.

Scheduled Maintenance

There are a few things in a generator that need to be cleaned or replaced periodically. For instance, spark plugs may need to be checked yearly for fouling and proper gap. The air filter should be cleaned or replaced every 150–200 hours of operation. The oil should be changed every 100 hours or so of use.

Connection Methods

Most generator applications require some sort of fixed method of connecting the generator to the needed loads. While it is possible to run an extension cord to an appliance such as a refrigerator, if there is a need for a generator on a fairly regular basis then a more permanent connection method should be installed at the breaker panel.

There are four main ways to connect the generator to the breaker panel: via a manual transfer switch, an automatic transfer switch, an independent charge controller, or an inverter/charge controller.

Manual Transfer Switch

This type of transfer switch can be used for the entire house or for just a few items. It is generally used with medium and large inverter generators.

The manual transfer switch is a box with a predetermined number of breakers that are designed to power selected electrical lines in the main breaker panel. For instance, the transfer switch box may have four breakers that can be used to power four identified breakers in the main breaker panel. The transfer switch box also includes the receptacle for the generator input.

After the transfer switch panel box is installed, select four items in the main breaker panel that require power during an emergency (e.g., refrigerator, battery chargers, computer, and a set of lights, etc.). Those four main breakers are then connected to the transfer switch breakers, so that those four items are powered either by the main power bus or by the generator. If the transfer switch breakers are pulled down, those four lines are powered by the generator. If the transfer switch breakers are pushed up, those four lines are powered by the main power bus. Those four lines are powered by one power source or the other, but cannot receive power from both at the same time.

The manual transfer switch can come with as many breakers as one desires—even for items that require 240v. The limiting factor would only be the amount of wattage the generator can safely provide.

Automatic Changeover Switch

The automatic changeover switch is generally used with permanent home stand-by generators. It is connected to the house's main breaker bus.

The automatic changeover switch is a power switching device that constantly monitors the power voltage at the main breaker bus of the house. When power is lost from the primary power source, the changeover switch automatically sends a signal to start the generator.

Once the generator has sufficient power to support the home, the automatic changeover switch shifts the load to the generator, while monitoring voltage and frequency tolerances. Conversely, when the primary power source is restored, the load is moved from the generator back to the primary power source and the generator is shut down.

Because the procedure is somewhat complicated, an electrician should be called upon to do the connection work.

Independent Charge Controller

For small, medium, and large portable generators, it is possible to connect the generator to the battery bank through its own independent charge controller. A MPPT controller would work best, and the size of the controller can be selected to exceed the maximum output of the generator.

Even though this option is possible, it warrants mentioning that some people do not believe this is the wisest choice for connecting the generator to the battery bank due to balancing issues. With that in mind, you might want to consult a qualified electrician about this particular option.

Inverter/Charge Controller

The inverter/charge controller may be the safest and most efficient option for connecting small, medium, and large portable generators to the house. The inverter/charger is designed to receive power from the generator in order to either charge the battery, service a load in the house, or both.

Charging the Battery Bank

When the batteries are not being charged by the solar system, wind turbine, or hydropower system, the generator can charge the battery bank. The inverter/charger will have a specific terminal for the generator input. After starting the generator, the inverter/charger will rectify the AC input from the generator to DC and direct that to the battery bank.

Charging Batteries and Power to Load

If there is a load demand in the house while the battery bank is being charged, the inverter/charger can also send AC from the generator to the load. In essence, the inverter/charger would be sending rectified DC to the battery bank and AC to the load in the house at the same time.

Power to Load Only

If the load in the house becomes too large to both charge the batteries and service the load at the same time, the inverter/charger will disconnect the battery bank and only send AC from the generator to the load.

Generator Assist

If the load becomes too large for the generator to supply, the inverter/charger will send both AC from the generator and inverted DC to AC from the batteries to assist with the load demand.

Types of Fuels

Small, medium, and large portable generators can be purchased to use either gasoline, diesel, or propane. The most common and least expensive ones generally use gasoline. Most house standby generators use either diesel or propane.

Gasoline

Gasoline is the most commonly used fuel for generators and is the most accessible. It is also, in most places, the least expensive per gallon.

Pros	Cons
Very accessible	Lowest shelf life (~12 months)
Least expensive per gallon	Most dangerous to store
	Highly flammable

Diesel

Diesel is less common for small and medium generators, but can be found in large portable generators and house stand-by generators. It is the least expensive fuel per kilowatt, and the accessibility is generally acceptable in most areas. One downside is that low loads for long periods of time can cause carbonizing of the injectors, called "wet stacking."

Pros	Cons
Good accessibility	Shelf life (~18–24 months)
Reasonable price per gallon	Very smelly when spilled
Highest kW per gal	Carbonizing of injectors
Highest fuel efficiency	
Lowest cost per kW	
Least flammable	

Propane

Propane is generally available with large portable generators and home stand-by generators. Trucks can deliver to home-installed propane tanks, but may have difficulty delivering during seasons with high rain and snow.

Pros	Cons
Good accessibility in good weather	Highest price per gallon
Best storage options	Lowest kW per gallon
Highest shelf life	Lowest fuel efficiency
Cleanest burning	Highest price per kW
Quietest type of generator	

Fuel Comparison

Criteria	Gasoline	Diesel	Propane
Accessibility	1st	2nd	3rd
Price per gallon	1st	2nd	3rd
Energy density (kW/gal)	2nd	1st	3rd
Energy price ($/kW)	2nd	1st	3rd
Energy efficiency	2nd	1st	3rd
Storage safety	3rd	2nd	1st
Shelf Life	3rd	2nd	1st
Noise level	3rd	2nd	1st
Total score	2nd	1st	3rd

Generator Cost Analysis

Criteria	Small	Medium	Large	Standby
Price	$150–$700	$350–$1,000	$500–$2,000	$3,800–$7,000
kW	.5–.7kW	2–3kW	5–7kW	12.5–26kW
$/kW	$100–$1,000	$175–$333	$100–$286	$304–$269
Fuel consumption	.2 gph	.4 gph	.75 gph	2–3 gph

PART 3

Water Source Ideas

You can go without many things while living off the grid, but you can't survive without this one essential—water. Some pieces of property present more than one option, while others might be limited in available water sources. Part 3 will help you determine what is available, how to access those options, and which option will best meet your needs.

CHAPTER 1

Water Wells

Of all water source options for off grid living, this is the most preferred. While drilling a water well is the costliest option, if there is water available underground, this can be your steadiest and longest-lasting source of water. The biggest challenge is to know whether there is an accessible source underground and, if so, how much will be available. With that said, a thorough water survey will be needed. This chapter will list all of the main methods for conducting your survey, which types of drilling will be the best option for your location, and how to finish the well to yield the best water pressure.

Planning

Once you have decided upon the option of well drilling, a survey is needed to ensure the best chance of success. The survey consists of several parts. After completing all of the steps, you should have a good idea of the probability of finding an underground source of water.

Cost

The first step in any plan is to carefully weigh all of the options and the cost of each. If more than one option exists for your location, then you can select the one that best fits your budget. Depending on the soil type, however, you might have only one or two options to choose from.

Feasibility Study

A feasibility study will need to be conducted to determine the likelihood of water availability. This study has several parts, and the information gleaned from these parts should give you a fairly good idea if there is water available underground or not.

U.S. Geological Survey Records

There are good sources online for water table depth and ground water level information. This information can be found for each U.S. state, and extracted in the form of maps or tables.

State Water Resources

Each U.S. state generally has created interactive maps with a variety of datasets showing geospatially referenced groundwater levels, groundwater table elevation, and changes in ground water levels over time.

Neighbors

Neighboring wells can be an excellent source for local water information. Local wells can give you information as to the depth of the wells, gallons per minute, what type of wells were drilled, and the type of equipment that was used to drill them. Water level trends can also be very useful. Please note that depths can vary even in areas that are close in proximity.

Consultants

Two sources are typically used for well water consultation: water well drilling companies and dowsers (aka “water witchers”).

Water well drilling companies can be a very good source for information—especially if they have drilled wells in your location. They should be able to tell you what kind of well equipment was used, the common depth of the wells, the percentage of dry wells drilled, the general water level of the wet wells, and the quality of the water found. They may also be able to do a water survey for you.

Dowsing or “water witching” is an unscientific means for determining the best location for drilling a water well. The dowser or water witcher uses a Y-shaped wooden branch, metal tuning rods, or similar devices to sense where underground water exists. Due of the level of success in using this method, some people consider it worth trying to see how it compares with the results from the other survey sources.

Location

The location for the well can be tricky. Obviously, the best location is where the best chance of success will be, given all of the information from maps, neighbors, and consultants. However, additional considerations can also come into play.

For instance, there may be some places on your property that you would want to avoid being near the well. Such places would include corrals for livestock, septic tanks, and leach fields. Other situations to avoid include locations that are too far away or too far downhill to pipe water to your home.

You will also want to find a location that will be accessible to the drilling rig both for drilling and for future maintenance needs.

Permits

Consult with local and state agencies to find out what permits may be required.

Drilling

There are a number of methods used for drilling wells. Most use some form of a drilling rig, but the methods for drilling and extracting the dirt and rock fragments vary. The best option is generally contingent upon the type of soil you have, the depth of the water table or aquifer, and whether rocks or bedrock are going to be encountered.

Shallow Wells <100 Feet, with No Rocks

There are three methods for drilling water wells that can be used when the soil is not rocky and the water table is shallow (less than 100 feet): auguring, jetting, and driving. The soil type will generally dictate which of these three would be the best choice.

Auguring

For a clay soil type, the auguring method can be used. This method is generally limited in depth capability and is therefore used when the water table is expected to be in the neighborhood of 50–75 feet or less.

Jetting

The jetting method is best used in a clay or clay loam soil type. This method basically consists of a drill rod that is lowered into the well hole, with the depth of the hole being increased by the use of a high-pressure water jet. The force of the water breaks up the soil at the bottom of the well and forces it up and out of the well. The well depth of this kind of option is limited to approximately 50 feet or less.

Driving

Driving is a method best suited for sandy soils and when the water table is relatively shallow. The method consists of a pipe with a driving point. The driving point generally has a pointed end and is constructed to allow water to enter the pipe through the bottom. The pipe is either pressed or pounded into the earth and driven to a depth of 30–50 feet. Areas using this method generally have a water table in the 25–30 feet range.

Shallow Wells >100 Feet with Rocks or Bedrock

The following three methods are the more commonly used for drilling water wells: cable tool rigs, rotary, and percussion rotary. Even though these methods can be used for drilling wells to depths well over 150 feet, the example described in this chapter will assume an average well depth of about 150 feet.

Cable Tool Drilling Rig

The cable tool drilling rig provides a percussion type of drilling, which is achieved by dropping or pounding a percussion "hammer" into the bore hole. The process pulverizes the soil and rock at the bottom. Water is added to the hole manually from the top. Once the bottom is well pulverized, the percussion tool is raised by cables. A "bailer" is lowered into the hole to remove the muddy mixture of soil and rock. The bailer is a bucket with a trap bottom and is used to scoop out the overburden. It is then raised and emptied, and then the hammer is re-inserted into the hole to repeat the process.

Rotary Drilling

The rotary system is composed of a drill rig with a drill head that turns the drill rods, and a carousel of drill rods that are generally 20-25 feet long. The drill head screws onto a drill rod, and an oversized 9-inch dual or tri-cone roller bit screws onto the bottom of the rod.

When the drilling begins, high-pressure air and water are blown through the rod and out the bottom of the drill bit at roughly 380 psi. This high-pressure air and water blows the drill fragments out of the well hole. Once the drill rod is down about 20 feet or so, a collar is applied to the rod, the head is disconnected, and the head is raised up to attach to another rod from the carousel. The new rod is lowered and screwed into the previous rod, and the drilling commences anew.

As the hole is extended downward, the high-pressure water and air continues to blow the mud mixture to the top and out of the well. If the overburden is too sandy or silty, bentonite clay can be added to the hole to make a type of slurry, which is used to stabilize the sides of the hole and keep the hole open.

Once the hole hits bedrock, the drilling continues for another 10–20 feet. At that point, the drilling rods are brought out one at a time and returned to the carousel, and the 9-inch oversized drill bit is removed from the last drill rod.

Casing, consisting of 6-inch steel pipe, is then lowered into the hole, one piece at a time. The first piece has a reinforced steel bottom. Like the drill rods, one casing is lowered until a new piece needs to be added. Each new casing is screwed into the previous piece and then arc welded together. This process continues until it reaches the bottom, and then the casing is pressed into place to seal the hole. This is necessary to prevent contaminants from entering the water from around the outside of the casing.

After the casing has been installed into the hole, the drilling process is continued with a smaller drill bit that fits inside the casing. The drilling will continue into the bedrock until water-bearing fractures are found. At that point, drilling will continue for another 10–12 feet.

The drilling rods will then be removed, and the casing will be sealed by pouring grout or bentonite clay between the casing and the hole. The next step would be to install the submersible water pump into the well.

Percussion Rotary Drilling

Percussion rotary drilling is the same as rotary drilling, except that the bit has a hydraulic piston that hammers the bit up and down at a rapid rate as it is turning. This allows for a greater penetration rate through bedrock.

Percussion rotary drilling can be more expensive, but is commonly used where more drilling into bedrock is expected.

Water Delivery System Planning

Once the well drilling has been completed and the casing has been sealed, the next step is to plan the water delivery system. This will include a submersible pump and a pressure tank.

For this example, we will say that water was found at 135 feet and drilling continued another 15 feet, making the bottom of the well at 150 feet. The flow rate of the well is 10 gallons per minute, and the water fills the casing up to a level of 50 feet. (Note: The recommended minimum well flow rate is 6 gpm for a family of four.) The following list summarizes well water levels in the example:

- Water source found: 135 feet
- Bottom of drilled well: 150 feet
- Flow rate of well: 10 gpm
- Static water depth: 50 feet

Water Demand

Before we can determine the size of water pump and pressure tank needed, we need to consider what the water usage demand will be in the house. To do this, we will add up all of the house's water demand sources (e.g., water taps, showers, toilets, washing machine, etc.). We then apply 1 gpm for each water demand source. The total is called "peak demand."

Rarely will all of these demand sources be on at the same time. In the U.S., the average water usage per person is roughly 60 gallons per day. If the peak demand is higher than the average water usage per person, use the higher figure. On average, a family of four would use roughly 10 gallons per hour. Keep in mind that this is an average. For instance, a person taking a shower can use 20 gallons in 10 minutes.

Sizing the Water Pump and the Pressure Tank

Based on the average usage for a family of four, a pump that is capable of pumping 15 gallons per minute with a head lift of 110-182 feet will be a good fit.

To consider the size of the pressure tank, use the following formula:

Flow rate of the pump x Minimum runtime factor = Drawdown amount in gallons

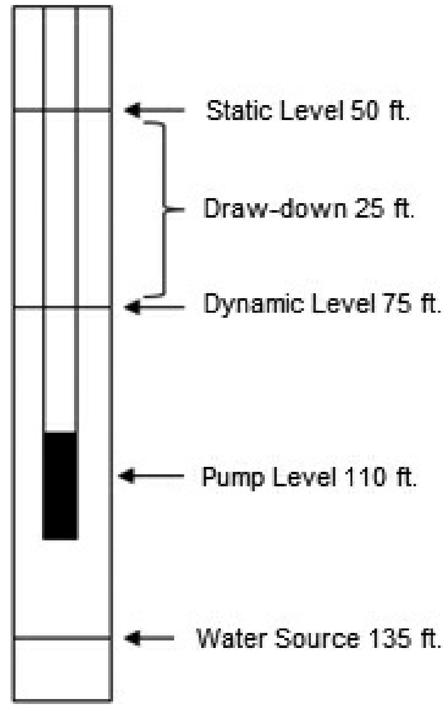
- Flow rate of pump = 15 gpm
- Minimum runtime factor = 1.5*
- 15 gpm x 1.5 = 22.5 drawdown gallon size for pressure tank
- 81-gallon tank = 25 gallon draw down capacity at 30-50 psi

*Note: (<10 gpm for pump = minimum runtime factor of 1)
(>10 gpm for pump = minimum runtime factor of 1.5)

Water Levels

Based on the water level parameters and the pressure tank drawdown capacity of 25 gallons, the depth needed for the pressure pump can be determined.

- Water source found: 135 feet
- Bottom of drilled well: 150 feet
- Flow rate of well: 10 gpm
- Static water depth: 50 feet
- Drawdown: 25 feet (~1 gallon/foot in casing)
- Dynamic water depth: 75 feet (50+25)
- Pump depth: 110 feet (35 feet below dynamic depth)



Submersible Pump

If possible, it is best to select a pump with enough flow rate to meet the peak demand for the home and be able to fill the pressure tank in roughly 1–1.5 minutes. Other specifications that should be considered are the voltage, wattage, max head lift capability, dimensions, and horsepower.

The submersible pump selected for this example has the following specifications:

- Power draw: 12 amps
- Dimensions: 30" long x 3" wide
- Horsepower: ½ hp
- Required voltage: 120 VAC
- Flow rate: 15 gpm
- Rated head lift: 110 feet
- Max head lift: 182 feet

Pressure Tank

The pressure tank is an important part of a well water system. You do not want the pump coming on every time you turn on the tap, as that would drastically reduce the life of the pump. Instead, a pressure tank is used to store water under pressure and provide consistent water pressure each time the water is used.

There is a rubber diaphragm in the center of the tank. Above the diaphragm is the air chamber. Water enters the bottom of the tank, forcing the diaphragm up, compressing the air. This compressed air is what provides the water pressure. Please note that the amount of water in the pressure tank (drawdown capacity), is only about 1/3 of the total tank gallon size. The other 2/3 is air.

A pressure switch is part of the system and is calibrated so that the pump is turned on to fill the tank when the water pressure gets down to a specific pressure and then shuts off when the pressure arrives at a higher preset pressure. The typical pressure settings are 20–40 psi, 30–50 psi, and 40–60 psi.

The pressure switch is generally set at a low pressure of 30 psi and a high pressure of 50 psi. When the household uses water, the water level in the tank will go down, thus diminishing the pressure. When a pressure of 30 psi is reached, the pump will turn on. The tank will continue to fill until a pressure of 50 psi is reached, which will cause the pressure switch to turn the pump off.

The amount of water that is used in the tank before the pump is turned on again is called the "drawdown" amount, which we used earlier to determine how low to set the pump in the well.

Since the tank water supply is only "drawn down" when water is being used in the house, the frequency of times the water pump needs to cycle on and off is greatly reduced with this type of system.

Installation of Water Delivery System

Submersible Pump and Water Line

The water pipe is generally PVC pipe and is connected to the submersible pump. The pump wiring is taped to the PVC pipe every 10 feet or so.

The pump and corresponding water PVC pipe are lowered into the well casing, one stick at a time. Rubber torque arrestors are clamped to the pipe at 50- to 75-foot intervals. These torque arrestors are designed to prevent the motor start-up torque from banging the pump against the side of the well casing.

Once the pump and piping have been lowered to the desired pump depth, the pipe, in most cases, is extended through the well cap and then locked into place with couplings. The pump is then turned on and allowed to run until clear water comes out of the pipe.

Pressure Tank

The water pipe can then run from the well cap over to the pressure tank, but often is run underground to prevent freezing. This would require digging a trench starting next to the casing and running horizontally over to the pressure tank. This trench would need to be deep enough to be below the frost line.

A hole would need to be cut with a cutting torch into the side of the casing, where the well pipe would then angle off at 90 degrees to go into the trench. Inside the casing, a 90-degree "pitless" adapter is attached to the water pipe and to the well casing, to provide a sanitary and frost-proof seal between the casing and the water line running to the pressure tank.

Before attaching to the pressure tank, the water line would first be attached to a check valve, water valve, pressure switch, and pressure gauge. From there, the water pipe would go to the pressure tank and from the pressure tank to the house.

Cost Analysis

The cost for drilling a well is not cheap, but when you consider the importance and value of a stable, clean, long-term source of water, most people believe it to be a worthwhile investment.

There are several things to consider when counting the costs for a drilled water well. The most expensive part, of course, is the drilling. There are additional costs that will also come into play: well casing, submersible pump, water piping, pressure tank with accessories, and so on.

Cost for Our Example Well

Item	Cost
Drilling of well (150 feet)	$3,000 @ $20/ft.
Casing (100 feet)	$800 @ $8/ft.
Grouting	$550
Submersible pump	$ 865
Water pipe (125 feet)	$62 @ $5/10 ft.
Pitless adapter	$65
Well cap	$60
Pressure tank	$950
Pressure switch	$20
Pressure gauge	$10
Check valve	$25
Permit	$350
Total	**$ 6757**

Cost per Drilling Type

Type of Drilling	Cost per Foot
Auguring	$10–$25
Jetting	$25–$35
Driving	$15–$40
Drilling	$25–$100

Cost per Depth

Depth in Feet	Price Range
50	$1,750–$3,000
100	$3,500–$6,300
150	$5,350–$9,300
200	$7,000–$12,500
250	$9,000–$15,000

Cost per Well Type

Type of Well	Cost per Foot	Total Cost
Irrigation well	$10–$50	$1,000–$5,000
Residential	$25–$100	$3,500–$15,000

CHAPTER 2

Surface Water Concerns

When it comes to surface water, there are two issues that must be part of your water source planning: water rights and impact on fish and wildlife. In most cases, it is possible for surface water to be used for domestic/household use, but these concerns need to be appropriately addressed in order to remain legal.

Water Rights

Lakes, ponds, creeks, and streams are classified under the category of what most U.S. states and counties call “surface water.” Almost all states and/or counties have laws and regulations relating to surface water. For that reason, you will need to check what “water rights” permits and/or licenses might be required in your location.

Some states subscribe to a “doctrine of reasonable use” that allows private landowners to use surface water on their property for domestic use. Nevertheless, check with your county and/or state to see which laws apply to surface water on private land.

Fish and Wildlife Impact

Anytime surface water is used, an environmental impact study may need to be done to verify that there will not be an adverse impact on fish and wildlife. The best way to approach this is to address the water rights issue first, and then talk to your state’s Fish and Wildlife department to see if such a study is necessary. In most cases, reasonable use should not be a limiting factor, as long as the surface water supply is not adversely diminished.

CHAPTER 3

Lakes and Ponds

If you have a lake or pond on your property, and you have the necessary water rights permits, you may have a useable source of water for domestic use. Extracting the water from a lake or pond is actually quite easy. All you need is a submersible pump, a water line, a holding tank, and a pressure tank.

Water Extraction

Pumping water from a lake or pond is a very simple arrangement. For the project, you will need to dig a trench and decide on the size of submersible pump, the type of water pipe, the type and size of water holding tank, and the size of pressure tank to use.

Submersible Pump

For most scenarios, a pump that delivers 25 gallons per minute with a head lift of 40–150 feet will work very well. This particular pump has the following specifications:

- Power draw: 670 watts
- Dimensions/diameter: 25.3” long, 4” diameter
- Horsepower: ½ hp
- Required voltage: 115 VAC
- Flow rate: Up to 25 gpm

Water Pipe into Water Source

The water pipe can be PVC, PE, HDPE, or, for small applications, even a large water hose could work. The water pipe should be connected to the water pump, and the pump wiring taped to the pipe. The pump can then be lowered into the lake or pond. This is generally done 20–30 feet out into the water, and should be a depth of at least 5–6 feet, if possible.

The pump should be covered with a mesh sock to avoid moss, and algae, from being sucked into the pump. If there is a deep layer of silt on the bottom of the lake or pond, the pump may need to be raised a foot or so off the bottom and supported by a rope and buoy, or support stand.

Water Pipe into Trench

A trench should be dug in order for the water pipe to be protected from damage and from freezing. The trench can be dug with a trenching machine and should be deep enough to be below freezing level. The water pipe should be laid into the trench, then buried.

Water Storage

Holding Tank

The water holding tank can come in a multitude of sizes, shapes and materials. The most common type of water holding tank is a round plastic one, with an access hole on top, that holds about 250 gallons. This is a good size, and this type of material works well.

The tank can be positioned above ground or buried underground. There is an advantage to burying the water storage tank. Being underground, the water will stay much cooler for drinking and even for a cooling system in the house.

The water line going from the lake or pond would fill the holding tank from the top. When the pump is turned on, the holding tank should fill in about 10 minutes when empty.

The water line to the house would exit the holding tank at the elevated outlet at the bottom and extend to the pressure tank. The outlet at the very bottom would be used to periodically void any sediment or contaminants collected at the bottom of the tank.

Water Delivery

In-Line Pressure Pump

At the pressure tank, you will need to have an in-line pressure pump that takes water from the holding tank and pumps it into the pressure tank. The following pump is a good fit for this purpose.

- Power draw: 977 watts
- Horsepower: 3/4 hp
- Required voltage: 115 VAC
- Flow rate: Up to 16 gpm

Pressure Tank

The pressure tank system works the same as for the water well system. For a family of four, an 81-gallon pressure tank with a 25-gallon drawdown capacity will work well.

With a 16-gpm in-line pump, the drawdown tank capacity would fill in about 1.5 minutes.

You will need a check valve, pressure switch, and pressure gauge. The common psi settings for the pressure tank is 30 psi at the low pressure setting and 50 psi for the high setting. The water line, then, would normally run from the pressure tank to the house.

Water Safety

Anytime surface water is used for drinking, it should be filtered and sometimes treated. In any case, the water should first be tested to see what contaminants are present, then you will have a better idea if the water needs to be treated. A chapter at the end of this Part is dedicated to this subject.

Cost Analysis

Item	Cost
Submersible pump (25 gpm)	$145
HDPE pipe	$200 (100 ft.)
Water line (1.5" Schedule 40 PVC)	$12 (10 ft.)
Storage tank (250 gallons)	$400–$800
Check valve	$25
Pressure switch	$20
Pressure gauge	$10
In-line pump	$390
Pressure tank	$950
Total cost	$2,152–$2,552

CHAPTER 4

Streams and Creeks

If you have a stream or creek on your property, this can usually be a very good source of drinking water. Because the water is flowing, the water is generally cooler and cleaner than lake or pond water.

As mentioned, before surface water can legally be used, you must adequately deal with the water rights and fish and wildlife concerns and requirements.

Surface Water at or below House Elevation

If the creek or stream is at or below the house elevation, then the means of extraction, storage, and delivery will be the same as that for a lake or pond. The only difference would be that the pump placement would probably need to be closer to the shoreline.

There is another way to economically pump water uphill without the need for electricity—by the use of a device called a hydraulic ram pump, or "hydram" for short. The hydram system is a water-pumping device capable of pumping water uphill, by using potential energy from a combination of downhill water flow and feet drop (head). This downhill flow is used to create an oscillating water hammer effect in the pump, resulting in a pulsating water delivery system. The system is capable of raising water 7–10 feet for each foot of head. For more information on the hydram device, go to *https://www.LandtoHouse.com/*.

Surface Water above the House Elevation

If the creek or stream is above the house elevation, the means of extraction will be roughly the same as that described for the hydropower system. In fact, if you have enough flow rate and head, you might be able to do both—produce electricity and store water for domestic use.

Since you would not be returning all of the water to its source, as in the case with the hydropower system alone, but retaining a portion for storage and use, the main concern would be to allow adequate flow for fish and wildlife to remain at the source after extraction.

As in the hydropower system, an intake box would be needed at the source. If hydropower is not part of the system, then the flow rate and head might provide enough pressure to fill the holding tank.

The method for water storage and delivery would be the same as that for the lake and pond extraction system.

CHAPTER 5

Spring Water

If you have a spring on your property, you are very fortunate. It is like having a natural well. Because the water originates on your property and has a continual replenishing flow, it is possible that the rules and regulations that cover this form of surface water may be different from other forms.

If the spring is the only surface water available on your property, the local wildlife may be dependent upon the spring as a water source, as you would be. Therefore, in your extraction design, you should allow for a portion of the water to remain available for the wildlife as it was originally.

Water Extraction

Whether the spring is above, at, or below the house elevation, an intake box will be needed for extracting the water. If the spring is at or below the house elevation, a pump will be needed to get water into the holding tank. If the spring is above the home elevation, a pump may not be needed, but the flow rate will probably be too low to serve as both a source of hydropower and water storage.

Water Storage and Delivery

The water storage system, and the subsequent delivery system, would be the same as that mentioned for lakes and ponds.

CHAPTER 6

Rainwater Catchment

If you live in an area that gets a reasonable amount of rainfall, you're in luck. Rainwater catchment may provide a good portion, if not all, of your household water needs.

Rainwater is an excellent source of water with many benefits: It is the easiest and cheapest source of water. It is clean, fresh, and free. Additionally, in most cases, rainwater catchment does not require a permit. All you need is a rain gutter system on your house, a storage tank, and a delivery system.

For information regarding rainwater harvesting rules and regulations for each U.S. state, visit *https://www.energy.gov/eere/femp/rainwater-harvesting-regulations-map*.

Rainwater Storage Estimation

Determining how much water storage you can expect to get from rainwater is relatively easy. Every square foot of roof surface yields .623 gallons of water for every inch of rainfall. With that in mind, all you have to do is find out what the average annual rainfall is for your area and determine the square footage of your roof, and you have the information you need. Just use the following formula:

Roof sq. ft. x .623 gallons x Annual rainfall in inches = Annual gallons of rainwater

This will give you the minimum number of gallons to size your storage tank.

Rainwater Storage System

If you have another surface water storage system already installed, you can use the same storage and delivery system, if you wish. The only difference is this: The storage tank for other surface water sources can work well in the 250–500 gallon range, but a rainwater catchment storage tank will probably need to be larger than that.

Therefore, if you want to combine both systems and you receive a reasonable amount of rainfall, you might need a much larger storage tank—maybe 5,000 gallons or more. With that in mind, it might be easier to have a storage tank for each system.

Rainwater Delivery System

Even if you have more than one storage tank, you should be able to use one delivery system to service the house. Other than the size or number of the storage tanks, the delivery system works the same for all of the water sources described here in Part 3.

CHAPTER 7

Buying/Hauling Water

Buying and hauling water is always an option and may at times be useful to serve as a backup source of water. It is relatively easy; it just requires a portable storage tank mounted on a trailer and a delivery system to the pressure tank.

Storage Tank

The portable water tank is generally in the 275–330 gallon range. It should be reinforced so that it can be easily mounted and supported on the trailer. A 250-gallon portable tank will cost around $250.

Water Delivery

You should be able to "tee" off of the existing line between the permanent storage tank and the pressure tank, and run that water line to the portable tank. All you would need to do is close the line from the permanent holding tank and open the line to the portable tank, and allow the in-line pump to draw water from the portable tank to the pressure tank on demand.

CHAPTER 8

Water Testing, Filtering, and Treatment

Anytime surface water is used as a potable water source, the water should at least be tested and filtered. If the test results show that harmful contaminants that filters may not remedy are present in the water, water treatment may be warranted as well.

Water Testing

Water quality is just as important as water quantity. Because there are so many types of contaminants that can be present in surface water, having a water test done is strongly advised.

Your water sample can be tested for a variety of contaminants, such as minerals, metals, nitrates (fertilizers), lead, mercury, arsenic, volatile organic compounds, inorganic chemicals, pesticides, microorganisms (protzoans), bacteria and viruses. The three most common types of bacteria tested for in surface water are fecal coliforms, streptococcus, and total coliforms.

There are a number of elements that are considered normal for water, such as harmless metals and even some bacteria that are considered good and necessary for food digestion. However, if your water sample contains any of the harmful elements, you want to know! Filters and water treatment can generally eliminate harmful contaminants.

Lab-Tested

You can have a water test done by a state-certified lab, or you can have a qualified lab at a local water quality company do the test. Some water softener companies will even do the test for free.

It is also possible to buy send-away test kits, whereby you take the sample and send it to the lab addressed in the kit. This is an excellent way to get viable results.

DIY Test

The self-administered "do-it-yourself" test kit is another way of testing your water, but these are more limited in what they can test for. In most cases, you will have to decide what you want to test for. As an example, some can test for lead, bacteria, pesticides, chlorine, copper, nitrates, nitrites, and iron, but are not as accurate or detailed as lab-administered tests.

Cost Analysis

Item	Cost
Send-away kit	$230–$270
DIY kit	$25

Water Filtering

Water filtering is essential for having safe, potable water. Water filters can consist of ceramic filters or activated carbon filters (charcoal or carbon), or both. These types of filters can be quite effective in filtering out all contaminants, but if your water test reveals that you have bacteria in the form of fecal coliforms, you may want to treat your water as well.

There are generally two types of water filters for off grid home use: in-line filters and gravity filters.

In-Line Filtering

In-line filters are installed in the water line between the pressure tank and the house. Most are simply installed under the sink, since drinking water is your major concern. By being in the house, the canisters can be replaced easily and the system isn't exposed to outside weather.

Gravity-Fed Filtering

This type of filter is commonly referred to as a countertop water filter. There are some excellent filters available that are quite effective at filtering out most contaminants. The only drawback to this type of filtering is that, to be used for drinking, you have to continually fill the reservoir.

Cost Analysis

Item	Cost
Under-the-sink in-line filter	$150–$450 (2–3 filter system)
Gravity-fed countertop filter	$175–$200

Water Treatment

There are a number of disinfectants that can be used to treat water before use. This normally is done after the water has been filtered. The most common forms of treatment are iodine, chlorine, ultraviolet (UV) light, and boiling.

Iodine

Iodine is one of the oldest forms of chemically treating water. For water purification, iodine comes in two forms: liquid and tablets. For liquid, it is recommended to use 5–10 drops per quart of water. Tablets can vary but generally are 20mg each, and 2 tablets are required per quart. One normally needs to wait 30 minutes before drinking. Iodine is generally more expensive than chlorine.

Chlorine

Chlorine is another widely used form of water purification treatment. It can be found in liquid or tablet form. For liquid, it is recommended to use 10 drops per quart of water. Tablets can vary in size and strength, but one example is to use one 49mg tablet for 2 quarts of water. Like iodine, you need to wait 30 minutes before drinking.

Of course, bleach is a form of chlorine that is often used for this purpose. The recommended dosage is 1/8 of a teaspoon of bleach per gallon of water.

UV

Ultraviolet (UV) light is an effective way to purify water. The disinfection process utilizes special UV *light*s that emit particular wavelengths that have the ability to disrupt the DNA of microorganisms. These UV light waves are referred to as the germicidal spectrum or frequency.

UV light has the ability to be very effective in eliminating bacteria, protozoans, and viruses. The only drawback is that the systems can be quite expensive.

Boiling

Probably the cheapest, surest, and oldest way to purify water is to boil it. It is a proven means, and is obviously effective. The drawback is that it is both time and energy consuming.

Cost Analysis

Item	Cost
Iodine	$10 (50 tablets)
Chlorine	$10 (100 tablets)
UV light	$400–$1,800
Boiling	N/A

PART 4

Heating, Cooling, and Plumbing

Part 4 of the book will help you plan for heating, cooling, and plumbing before you commit to a building plan. It is so important to make these determinations early in order to avoid costly mistakes that can be difficult to correct after your home is built.

Part 4 is divided into heating, cooling, combined heating and cooling, and plumbing. The chapter on plumbing is divided into three sections: before, during, and after construction.

CHAPTER 1

Heating

Home Heating with Wood

The most preferred way to heat your home in an off grid scenario is to use a source of heat that can be independent of and non-reliant upon electricity. The most common source for independent heat is wood burned in a fireplace or wood stove.

Fireplace

The fireplace is a very old way of heating a home, but it is not as efficient as a wood stove, as most of the heat goes up the chimney. However, if you have a large, local source for wood, this can still be a very good means for heating. Most people like fireplaces for the ambiance they create in a large room, such as a living room. Obviously, a fireplace should be built as part of the house construction process.

Wood Stove

A wood stove can be a very effective way to heat your home. The stove itself can give off a lot of heat, and the stove pipe is also very effective for radiant heat.

Convective Heat

Some wood stoves have a means to circulate air through an air channel between the fire box and the outer wall. This air is pulled through the channel and pushed into the room by means of a fan. This method can slowly heat very large areas.

Radiant Heat

The wood stove and stove pipe are hot surfaces that will generate radiant heat. Air in the room will slowly be heated by way of heat transfer (hot moves toward cold). If the stove is hot enough, and hot long enough, the process of heat transfer will slowly move the hot air across the room.

Firewood Stove vs. Pellet Stove

There are two types of wood stoves that are commonly used: those that use firewood and those that use wood pellets. Both are effective—it just depends on which option best meets your needs and lifestyle.

Firewood stoves and pellet stoves are sized according to the amount of heat they can produce. This is generally measured in BTUs, which stands for “British Thermal Units.”

You can determine the amount of BTUs needed by the size of the room to be heated.

- 42,000 BTUs = 1,300 sq. ft.
- 60,000 BTUs = 2,000 sq. ft.

Operation

Advantages of the firewood stove are that it simply requires a source of firewood, has no moving parts, and can produce both convective and radiant heat. The pellet stove, on the other hand, does have moving parts and requires electricity to operate. The hopper is filled with pellets, and an auger rotates, pulling pellets into a fire pan at a steady rate in accordance with a thermostat setting. Electric heat underneath the fire pan starts the fire, and the flame is enhanced with a combustion fan. Convective heat is distributed into the room via a distribution blower.

Stove Pricing

Both firewood stoves and pellet stoves come in a variety of shapes and sizes. Prices generally are similar in comparison.

- Firewood stoves: $2,500–$5,000
- Pellet stoves: $2,000–$4,000

Fuel Costs

Firewood is generally sold by the cord. A cord of wood is a stack 4 feet x 4 feet x 8 feet, which is roughly 128 cubic feet of wood. Pellets are sold in 40-lb. bags, but for operating cost comparison purposes, I am using a ton of pellets below.

- One cord of firewood: $225–$400
- One ton of pellets: $250–$350

Please note: firewood prices per cord vary according to wood type, content (e.g. split, rounds, split and rounds, etc.), piece length, seasoning, distance for hauling, etc.

Fuel Performance

The rate at which firewood burns in a wood stove depends largely on the type of wood being used. Softer woods burn rather quickly, and hardwoods tend to burn slower and produce more heat.

Pellets, on the other hand, burn at a steady rate and produce a steady, predictable amount of heat. Most pellet products are of the same or similar composition.

There are a lot of variables to consider when comparing the performance of the two types of stoves, but on average, the following figures can be used:

- One cord of firewood = ~15.6 million BTUs
- One ton of pellets = ~13.0 million BTUs

As you can see, firewood is about 20% more efficient than a similar amount of pellets. With that in mind and all things being equal (ambient temperature–wise), you could expect to use around 1.5 cords of wood in a winter season, compared to 2 tons of pellets.

Availability and Storage

One big decision-making factor in choosing the right stove is availability. Firewood can be very accessible in some areas, while not in others. In comparison, one can generally find wood pellets being sold in most hardware and farm supply stores.

Storage is another factor to consider. Firewood will need to be stacked and covered. Finding a suitable place to stack firewood may be more difficult than storing bags of pellets, which can easily be kept in a garage or on a porch.

Ease of Replenishment

A firewood stove will need to be stoked with a replenishment of firewood on a fairly regular basis, whereas filling the pellet stove hopper with pellets is easier and does not have to be done as often. The pellet stove is faster and simpler to get started as well.

Advantages and Disadvantages

The main advantage of a firewood stove is that it does not require electricity. In contrast, the pellet stove does. The amount of power required for the pellet stove is about 100kW per month (on average).

Home Heating without Wood

Propane heating is a common way to heat your home that does not rely upon electricity. However, propane is becoming more and more expensive. Radiant heat is another viable heat source, and free heat from solar is always an option worth planning for.

Propane Heaters

The use of propane heaters is a way to heat a home or to heat rooms that are far away from the fireplace or wood stove. Propane heaters come in a variety of shapes and sizes. One drawback is that an exhaust pipe will need to be vented out of the home, either through a window or wall, due to the carbon monoxide fumes.

Radiators

Another way to heat your home is by using hot water radiators. Radiators give off radiant heat and can be quite effective—especially for smaller rooms, such as bedrooms. The hot water can come from pipes running under or around the wood stove or fireplace, or from a propane water heater. The pipes would then need to be routed through the walls to each room that has a radiator. Radiators should be installed during the construction of the house.

Solar Windows

A very good way of providing heat in the winter is to have lots of windows on the sun-facing side of the house. This can raise the temperature as much as 15 degrees Fahrenheit. Some sources report that the free energy that comes through the windows is equivalent to 2kW of heating energy.

With that said, it would be a good investment to plan for as many windows on the sun-facing side of the house as is practicable. Of course, this is applicable mostly in geographic areas where the winters are long and cold.

Since the main purpose of this book is to assist you with your home building planning, I invite you to consider early in your planning which room will be on the sun-facing side of the house. Probably the most practical room to have a lot of solar windows to yield the best advantage for house heating would be the living room.

CHAPTER 2

Cooling

Air Conditioners

The common types of air conditioning we are all familiar with are Freon air conditioners—both the window variety and the larger central heating and air type.

Most off grid homes do not use these typical types of air conditioning because of the amount of electricity they require. For that reason, we must look to alternatives, one of which is the evaporative cooler.

Coolers

The evaporative cooler, sometimes referred to as the "swamp cooler," has been around for a long time. While these coolers can be quite effective, they only work well in dry, arid climates. The principle used for cooling is evaporation. As hot, dry air is exposed to moisture, it causes the moisture to evaporate, resulting in a cooling process.

The unit is a large metal box roughly 30 inches square. Each of the four sides has a removable, vented wall that has a cooling pad attached to the inside. The cooler also has a water reservoir at the bottom of the box, with a water pump. When the cooler is turned on, the pump circulates water to the top of each of the four cooling pads. A large drum-type fan in the center of the box pulls air through the wet pads. As hot, dry air is pulled through the pads, the evaporation process cools the air 15–25 degrees, and the cooler air is blown into the house. One gallon of water can remove up to 7900 BTU's of heat from the air. This is pretty efficient, but it also requires a fair amount of water.

The cooler can be mounted for a window installation or on the roof. The unit does need water and electricity, but the amount of electricity used is minimal compared to a Freon-based air conditioner.

Considerations

Pros	Cons
Relatively inexpensive	The pads need to be replaced each year.
Nice smell from the wet pads	Calcium buildup may also need to be removed annually.

Cost Analysis

Item	Cost
Evaporative cooler	\$550–\$850

CHAPTER 3

Combined Heating and Cooling

Heating and Cooling from Underground Source

There are a number of ways to heat and cool your house, and one of them is passive and all but free. That method, known as geothermal heating and cooling, is a process of thermal conduction through the use of underground ducting, and should be implemented during the construction phase. The only costs are for the initial installation and some circulation fans.

Geothermal Heating and Cooling

Geothermal heating and cooling is an ingenious way of taking advantage of natural means to heat and cool your house. This method will deliver air at roughly 55 degrees F year-round (depending on geographic locations).

For summer, 55-degree air is not cold, but when the temperature outside is in the 90s or higher, 55-degree air can be quite effective in cooling the home. The same applies to the winter. In and of itself, 55 degrees does not feel warm, but when temperatures are near freezing outside, 55 degrees can feel relatively warm. It will at least help make the temperature more comfortable during the night until you can get the wood stove started in the morning.

How It Works

The way geothermal heating and cooling works is relatively simple. It basically consists of ducting that originates in the house and is then routed underground for a certain distance to allow temperature transfer to take place. The ducting is then routed back up into the house. The temperature of the incoming air will be relatively consistent throughout the year.

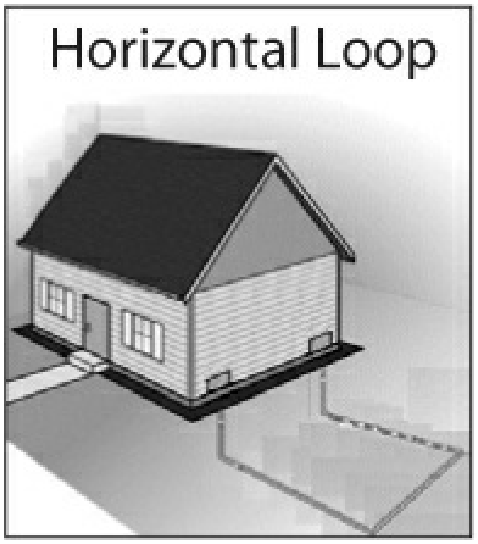
Earth Closed-Loop Systems

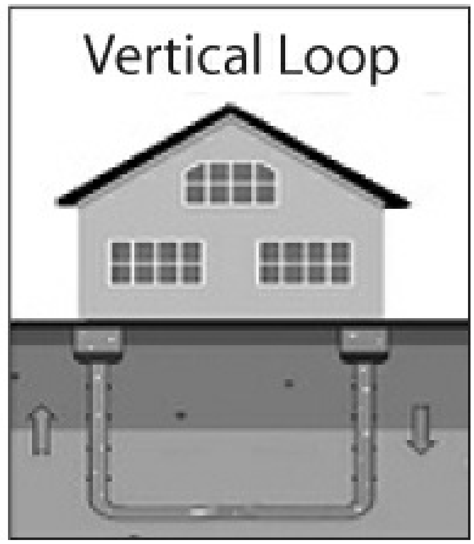
There are two types of earth closed-loop systems: horizontal and vertical. Both the horizontal and vertical loops are normally in the shape of a "C." They work the same way; the difference is just a matter of which direction the trenches are dug.

The system begins and ends with a box in a corner of a room, near an outside wall, which allows for the ducting to be supported as it exits and re-enters the house.

The "exit box" is stationed in one corner of the room through the floor near an outside wall, or through the bottom of the wall itself. An "entrance box" is stationed in the opposite corner, allowing the duct to re-enter the room in the same fashion—either through the floor or the bottom of the wall.

Just above or in front of the exit ducting, a fan is positioned to draw air out of the room and push it into the duct. Conversely, a fan will also be positioned just above or in front of the entering duct to draw air out of the ducting and into the room.





The ducting should be a type of material that will allow soil temperature to conduct easily through the duct wall, to heat or cool the air inside the duct. Flexible corrugated HDPE drain pipe can work well. This type of pipe can be accommodated with all kinds of fittings and is relatively inexpensive.

The size of the ducting should be large enough to allow the air to circulate easily and accommodate heat transfer quickly. Typical sizes are in the 6–8 inch range.

The trench in the horizontal system should be at least 5 feet underground, in order to achieve a stable temperature in both summer and winter. The trench in the vertical system should be at least 6–8 feet deep.

Water Closed-Loop System

Another variation on the closed-loop system is to use water from a lake or pond as the heat transfer medium instead of earth. The temperatures with this type of system would probably be more variable and less constant throughout the seasons. This type of system would work well for the summer but probably not so well for the winter.

The installation for this type of system would be similar to the horizontal earth closed-loop system. Once at the water's edge, you would need to extend the loop out into the lake or pond far enough to allow for at least 5–6 feet of depth. To stay submerged, a heavier, metal pipe might serve as a better option in the water, but this would need to be airtight. Or, you would need to sink the ducting and arrange for it to be held underwater by some sort of anchor system.

In-Floor Heating and Cooling

Hydronics

There are number of ways water pipes can provide convective heating and cooling of a home by routing water tubes in the flooring. This method is often referred to as "hydronics" and should be implemented during the construction phase.

The same hydronic looping system would be used for heating in the winter and cooling in the summer. The designated hydronic piping system runs under the heat source and then loops in the floor. The heat source heats the water in the hydronic tubes in the winter, but not in the summer. The cool water entering from outside would act as a cooling source in the summer. All closed-loop hydronic systems should also include forced water purging valves for bulk air removal.

Heating Source

The hydronic pipes are installed underneath the support bricks for the wood stove or underneath the fireplace bricks. Copper pipes are best because of the high temperatures involved. After exiting the heat source, the copper pipes can be connected to tubes that loop back and forth in the floor and return to the heat source to make a big loop.

Cooling Source

Water for cooling can come from either a water well or an underground water storage tank. Water pipes entering the house from either of these sources can have a designated line that extends over to the hydronic floor system, to provide cool water during the summer months.

Floor Tubing

PEX is the best choice for tubing that needs to loop back and forth throughout the floor. PEX is light, easy to use, easy to bend, inexpensive, and conducts temperature well.

Metal piping for looping in the floor is not a great choice, because metal pipe is generally rigid, heavy, difficult to cut, and requires fittings at every turn. Metal piping is also somewhat expensive and can rust.

Tubing in Concrete

One common method for the hydronic installation is to lay out the looping pattern of tubes on top of rebar or wire mesh before the concrete is poured. In theory, the tubing would be roughly in the middle of the slab (thickness wise). Convection from the tubing would cause the floor to be warmer in the winter and cooler in the summer.

Tubing in InfloorBoard™

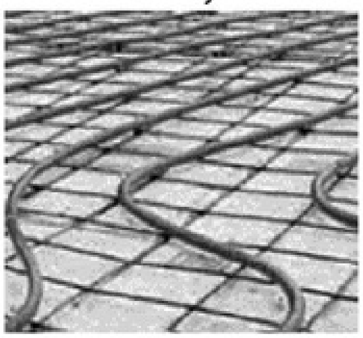
InfloorBoard is a hydronic floor heating and cooling system that is designed to be installed on top of a subfloor or concrete. It is constructed of a dense composite board covered with aluminum, which allows for the heat to spread evenly and quickly. InfloorBoard provides a quicker heat response time than standard concrete or gypcrete systems.

The InfloorBoard is 5/8-inch thick and can be installed on top of an existing floor, whether a subfloor or concrete, with minimal changes to existing floor heights. Almost any type of floor covering can then be laid on top. This allows the system to be used in new construction or with existing flooring.

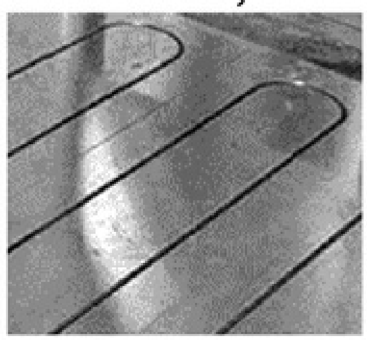
Tubing in Gypcrete

Gypcrete is another system that can be applied on top of existing flooring. Here, the PEX tubes are attached to the subfloor, and a gypsum slurry mixture is poured on top of the tubing layout, with enough depth to cover the tubing. The slurry topping is then floated to end in a flat surface. Generally, two layers are applied.

Concrete Hydronics



InfloorBoard Hydronics



Gypcrete Hydronics

Cost Comparison

Method	Cost per sq. ft.
Concrete	$4–$8
InfloorBoard	$6–$20
Gypcrete	$2–$2.50

CHAPTER 4

Plumbing

Plumbing Before Construction

Plumbing before construction can consist of water lines, drain pipes, and sewer lines. This will require trenches and the appropriate types of piping.

Water Lines

More than likely, you will want to have water lines available to the kitchen sink, bathroom sinks and showers, toilets, and laundry room. The most common type of pipe used for water lines is PVC pipe. Sizes can vary, but the most common size from the pressure tank to the house is 1” Schedule 40 PVC.

Drain Pipes

Drain pipes are generally coming from the sinks, showers, and laundry. PVC pipe is the most common type here as well, and the sizes can vary.

Purpose	Type of Pipe	Typical Size
Kitchen sink	PVC	1½″
Bathroom sink and shower	PVC	1¼″–1½″
Laundry standpipe	PVC	2″

Sewer Lines

If you plan on having a flushable toilet, then a sewer line will need to be installed before the house construction begins. The sewer line pipe can be PVC or ABS, and the size is generally 4-inch. This line would probably be extended to a septic tank, which might also need to be installed before construction of the house.

Plumbing During Construction

The main variance in the plumbing during the construction phase is that the water lines will more than likely be reduced from the 1-inch line that enters from the pressure tank. These lines will probably be reduced from the floor up, according to the following chart.

Water Lines

Purpose	Type of Pipe	Typical Size
Kitchen sink	PVC	½”
Bathroom sink	PVC	3/8″
Shower	PVC	½”
Laundry sink	PVC	½”
Toilets	PVC	3/8″

Plumbing After Construction

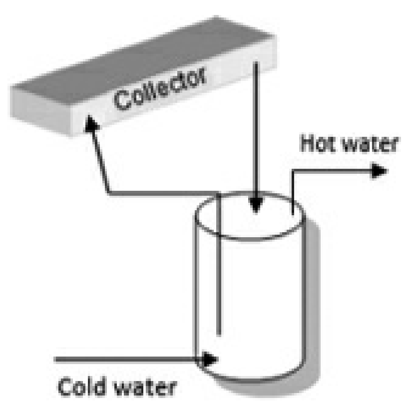
Hot Water for Showers

One thing most people cannot do without is hot water for showers. There are typically three sources for hot water used in off grid settings: solar, wood-stove, and propane on-demand water heaters.

Solar Water Heaters

There are two basic types of solar water heater systems: active and passive. Active systems come in two variations: direct and indirect. Passive systems also have two variations: the integral collector storage system and the thermosyphon system.

Active-Direct



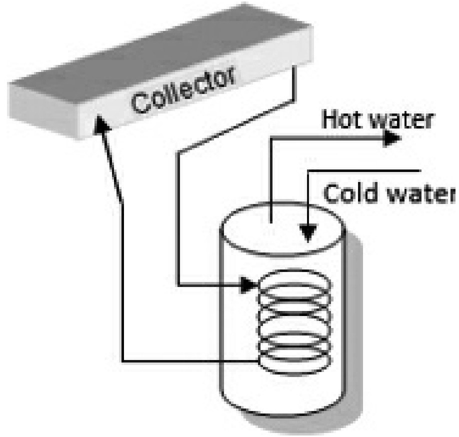
The active-direct system, considered an open-loop system, consists of a “collector,” a hot water storage tank, sensors, and a circulation pump. The collector is a black panel that has a series of tubes running through it. This is where the sun heats up the water.

Cold water enters the bottom of the hot water tank. Sensors are located in the bottom of the water tank and on the top of the collector. When a predetermined temperature differential is reached, the circulation pump turns on and circulates water through the solar collector until the proper temperature throughout the system is achieved.

Hot water from the hot water tank enters the house on demand, under pressure from the pressure tank. Because the water on the roof could freeze in the winter, the water in the collector may need to be drained in the fall and refilled in the spring.

Pros	Cons
No nighttime heat loss	Water can freeze in winter
Simple system	More expensive than passive

Active-Indirect



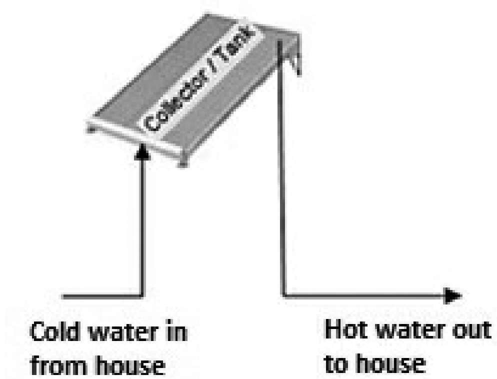
The active-indirect system is similar to the direct system. The difference is that the indirect system is a closed-loop system. The closed loop is a series of tubes that run through the collector and then into a "heat exchanger" tank, then back to the collector. The fluid inside the closed loop is anti-freeze, to prevent freezing in the winter.

Like in the direct system, sensors in the bottom of the heat exchanger tank and the top of the collector sense the temperatures and will turn on a circulation pump at a predetermined temperature differential.

Potable water enters the heat exchanger tank, is heated by a set of coils inside the tank, and then exits the tank to the house on demand under pressure from the pressure tank.

Pros	Cons
No nighttime heat loss	Expensive
No wintertime freezing	

Passive–Integral Collector Storage

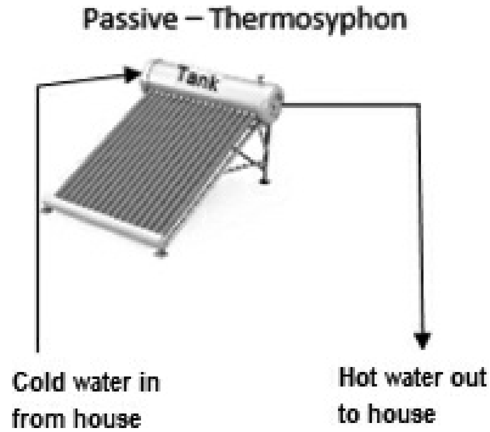


The integral collector storage (ICS) passive system combines the solar collector and the water storage tank into a single component. This system eliminates the need for sensors, a circulation pump, and a heat exchanger tank. Because the water is stored on the roof, the water should be drained in the fall to prevent freezing in the winter, and then be refilled in the spring.

The ICS system is basically a flat box with a glazed, transparent plexiglass top mounted on the roof. The flat box contains either a flat black tank/bladder or a system of large metal tubes to hold the water. Cold water is piped from the house system to the bottom of the collector/tank, and the circulation is provided by household system pressure. Hot water exits the top of the flat storage system and is delivered to the tap or shower on demand.

Pros	Cons
No sensors, pump, or heat exchanger tank	Nighttime heat loss
Inexpensive	Wintertime freezing
Can be homemade	Heavy (275–400 lbs.)

Passive-Thermosyphon System



This system is the most pragmatic and cost-effective of all the options. It consists of a collector that is mounted on the roof and slanted at an angle, with a round storage tank at the top of the collector. The collector consists of tubes that are connected on the bottom of each end of the storage tank, with a series of loops in the middle.

Water is automatically circulated through the tubing, by way of the thermosyphoning principle. The system has to be arranged at a 45-degree angle, with the storage tank at the top. This allows the cold water to fall by gravity into the tubing, and for hot water to rise into the tank.

As hot water is removed from the solar storage tank on one end, cold water from the house system enters the solar storage tank at the opposite end. Hot water is piped back into the home and is then delivered on demand under pressure from the pressure tank.

The storage tank generally holds about 40 gallons and can be insulated to reduce heat loss at night. One drawback to the system is that it can freeze in winter.

Pros	Cons
No sensors, pump, or tank	Heavy (275–400 lbs.)
Inexpensive	Wintertime freezing
No nighttime heat loss	Unsightly apparatus on roof

Solar System Cost Analysis

Solar System	Cost
Active-Direct	$2,000–$3,000
Active-Indirect	$3,000–$4,000
Passive-ICS	$1,000–$2,000
Passive-Thermosyphon	$1,500–$3,000

Wood Stove for Heating Water

Getting hot water for showers from a wood stove is relatively easy. All you have to do is route a water pipe under or around the wood stove and then to the hot water tank. This can be a source of hot water during the winter when the solar system is inoperable.

This would, in most cases, be done during the construction phase, since the water line would need to be embedded either in the cement slab or under the subflooring.

Tankless Propane Water Heater

The tankless propane water heater is a very effective option for hot water. It can serve either as the main source of hot water or a backup to the solar and/or wood stove sources. It is basically a wall-mounted rectangle box, roughly 27 inches tall, 15 inches wide, and 6 inches deep. Tankless water heaters provide hot water at a rate of about 3–8 gpm.

The propane heater ignites and heats water on-demand, meaning only when the hot water tap or shower is turned on. It is very efficient—it turns on immediately and heats the water quite quickly. Because you are only using the propane when hot water is demanded, a bottle of propane can last a long time.

Cost Analysis

Item	Cost
Propane on-demand heater	$300–$500

Indoor Toilet

There are a few basic choices for indoor toilets for off grid living: flushable toilets, biogas toilets, incinerator toilets, cartridge toilets, and composting toilets. This section will describe each option in order to help you decide which would best suit your overall plans.

Flushable Toilet

A normal, flushable toilet is the style that everyone is used to, and thus is the preferred choice if you have enough water. Depending on the size of the family, most toilets will use about 19–24 gallons of water per day.

Septic Tank

If you have enough water supply to justify the use of a flushable toilet, you will also need to plan for a septic tank. You will first need to check with the local authorities to see if septic tanks are allowed in your location. If they are, you will then need to acquire the necessary permits and plan for a septic tank to be installed.

Most septic tank systems include a tank and a leach field for the excess water to drain as the solid wasted, called effluent, settles to the bottom of the tank. With that said, the typical septic systems will need the following: soil percolation test, excavating for tank placement, backfilling of the tank, proper plumbing for the leach field leaving the tank, and plumbing of the sewer lines from the house to the tank. Once everything is installed, then it will need to be inspected.

Biogas Toilet

For those who like the idea of a flushable toilet but do not have the water capacity to make it feasible, the biogas toilet may be an option. The system consists of a flushable toilet, a large rubber bladder called a "biogas digester," drain pipes to and from the digester, gas pipes and filter, and a biogas stove.

The system works by collecting gray water into a bucket near the toilet. When you need to flush, grey water is syphoned or poured into the toilet, and the water and fecal matter are pumped via a hand pump into the biogas digester, which is sealed. In time, the fecal matter will begin to decompose in the digester bag. The decomposition process will produce methane gas along with the remaining solid, or effluent.

From the digester, the methane gas is piped through a filter to a biogas stove. The remainder of the system works somewhat like any other flushable toilet/septic tank system: The excess water will need to be drained off to a leach field, and when full, the remaining effluent will need to be drained into a septic tank. With that said, the same sort of permitting process will need to be investigated and pursued.

Incinerating Toilet

Incinerating toilets are self-contained units that burn the mixture of urine and solid waste. The incinerator toilet can be fueled by electricity, propane, gasoline, or diesel. The remaining residue after a single use consists of only a teaspoon of ash.

The standalone toilet will need to be vented for the exhaust fumes, wired for electricity, and the appropriate fuel piped into the bathroom to the unit, if fuel is used for burning.

The bowl can either have a paper liner or be cleaned with water after each use. The liner or small amount of water would then go into the burn chamber with the waste to be burned.

Electric versions use approximately 1.5–2kWh per use. For the propane version, a 20-lb. bottle of propane will last roughly 75–100 uses.

Self-Sealing Cartridge Toilet

The self-sealing cartridge toilet is sometimes called a “dry flush” toilet. It comes with a 12v battery system for operation. This is a simple unit that does not require water or venting.

The unit consists of toilet frame, an inside canister, toilet top, and seat. To prepare for use, place a black garbage bag inside the canister and secure it with a rubber band. Next, place the cartridge on top of the canister, and then re-insert the toilet top and lower the seat.

To operate, one simply pushes a button. The cartridge material lining the bowl, wraps itself around the waste, and pushes itself down into the canister. At the same time, the toilet bowl is effectively re-lined with more cartridge material ready for the next use.

After the cartridge material has been depleted, it is time to empty the canister. Take off the top, and lift out the black bag containing all of the sealed waste with the depleted cartridge, and then place the black bag in the trash. One cartridge will yield around 15–25 uses.

Composting Toilet

The composting toilet separates the urine by diverting the liquid into a bottle at the front of the toilet. The bottle can be removed and emptied after each use. The solid fecal matter drops into a container under the toilet, which contains sawdust or peat moss. There is a crank on the side of the toilet that is to be turned over and over a few times after the toilet is used, to cause the waste to be well covered by the moisture-absorbing organic material.

The toilet compost bin will hold multiple uses. The back of the bin is vented to the outside to help dissipate excess moisture and odor. When the bin is full, the contents can be dumped into a 15-gallon composting bag, which can be added to a compost bin. The bin needs to be in the sun to remain warm. After about 18 months, the compost will have decomposed into an organically enriched soil.

Cost Analysis

Item	Cost
Biogas toilet kit	$1,500–$2,300
Incinerator toilet	$3,500–$5,000
Self-sealing cartridge toilet	$850–$1,000
Composting toilet	$1,000

Outdoor Toilet

Outdoor toilets have been around forever. For permanent solutions, the outhouse is the most common type. They can be as nice or as rustic as you want. They are simple in concept and easy to build.

All you need is a small building with an enclosed bench built at the back of the inside, with one or two holes cut in the bench. You can even mount a toilet seat, if you like. The building itself needs to be only 4 ft. x 4 ft. x 7 ft., with a roof, and open underneath the bench.

A slightly smaller hole, roughly 3.5 ft. x 3.5 ft. and 4 ft. deep, would need to be dug. Then the building is moved to sit over the hole. After the hole fills with waste, all you have to do is dig another hole and move the building over the new hole, covering up the old one.

Conclusion

By now, you hopefully have an idea of where you would like to begin. Because there are so many pieces to off grid planning, it is always good to have a checklist. This will help you know what to do sequentially and to visualize progress in the strategizing, planning, and implementation.

While your project can be daunting and seem like it entails a lot to do, it is best not to focus on the whole, but rather on the first step, and then move on to the next, and so on. One good first step for this kind of endeavor is to choose the best possible property for your off grid dream. There might be a number of real estate issues that need to be navigated (e.g., deed, permitting, etc.), which is beyond the scope of this book, but once that is done, the next step would be to choose your home type. After that has been accomplished, the next step would be to formulate the design of what you would like your home to look like. Then the fun begins.

Once you begin the home building process, simply use this book to help plan the remaining options for electrical power, water source options, heating, cooling, and plumbing. The most important thing to remember is that it is doable. Yes, it will be a lot of work, but just take it one step at a time, and try your best to enjoy it. This is your journey. With the help of this book, your journey can be an enjoyable, lifetime memory-making experience!

About the Author

John Utterback grew up on a 400-acre farm in New Mexico, and has enjoyed his various careers as a wildlife biologist, range conservationist, missionary pilot, airline pilot, agriculture business owner, and county agriculture inspector.

He enjoys compiling and organizing technical data and explaining it in an interesting and understandable manner. Technical writing is his passion; helping others is his calling.

Reviews

If you have enjoyed this book and found it helpful, please let me know your thoughts by way of a “Book Review.” It is always good to hear how people are progressing in their pursuit of their off grid dream!

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Figure 2,2,1: Mirage Novelty World
Figure 2,2,2: Raptor G4-11 (Missouri Wind & Solar)
Figure 2,2,3: Tqing Vertical Wind Turbine
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