"No one, to my knowledge, has ever attempted to imitate the delicate mechanism of the bee so closely, as to construct artificial combs *for the ordinary uses of the hive. If store-combs could be made of gutta-percha, they might be emptied of their contents, and returned to the hive."*
-- L.L. Langstroth, Langstroth's Hive and the Honey-Bee (1878)

"While an artificial comb, with cells of the full depth, and practical in all respects, has not yet been offered for our consideration, I must express my belief that such will yet be made. In 1870 Mr. Quinby experimented largely in this direction, and although complete success did not crown his efforts, he established some curious and interesting facts. He succeeded in manufacturing combs of very light tin….This was placed at the center of the cluster, where the queen occupied it, filling it with eggs, just as she did the natural cells adjoining; and in due time the young bees matured in both equally well. There were manifest advantages in combs so constructed… but after thoroughly testing them, it was evident that the weight and expense of such combs would render them impracticable. The fact was demonstrated, however, that bees would accept and occupy combs of foreign material."
-- L.C. Root, Quinby's New Bee-Keeping: The Mysteries of Bee-Keeping Explained (1911)

My daughter's science teacher, who was, incidentally, a normal person (nonbeekeeper), once told me how amazing honey bees are because they make perfect hexagonal cells, all alike, all the same size and all continuously connected. I just smiled and said something like, "Imagine that!" What I should have done is invite her out to my bee yard so she could teach my bees the proper way to draw comb. The reality is that given a chance to be creative, my bees will draw comb the way that Picasso used to draw people: any way they want to.

I can't blame my bees for being creative. It comes with being a bee. That's why modern beekeeping with moveable frames didn't really take off to its full potential until the process of making foundation was invented. Moveable frames are only moveable if the comb is properly aligned both vertically and horizontally, and the only way to ensure that happens is to provide the bees with a template.

An attempt at foregoing foundation in this honey super had disastrous results. The bees constructed comb perpendicular to the frames rather than parallel to them. The frames could not be removed without destroying the comb and making an extreme mess. Photo courtesy of Karen Bentley.

Beekeepers have experimented with many types of such templates, what we call foundation. Finely milled wax sheets embossed with the outline of the desired cell size are an obvious choice but can be brittle or can melt, depending on the time of year, and are subject to damage from wax moths, hive beetles, mice and the bees themselves. To improve durability, Pellet[1] tells us that manufacturers tried coating wax onto wire mesh, thin sheet metal, celluloid, cloth and cardboard. In more modern times, wax-coated plastic has been used very successfully and is very popular among many beekeepers. For wax "purists", foundation is available with pre-embedded vertical wires; horizontal wires are typically added by the beekeeper for additional stability. For producing cut-comb honey, foundation is also available as

[1] Pellett, Frank, History of American Beekeeping, Collegiate Press, Inc, Ames Iowa (1938)

pure wax without wires.

Langstroth and Quinby's vision of completely artificial comb (not just foundation) has not been abandoned. Plastic foundation drawn out into deep plastic cells is available under the brands PermaComb and HoneySuperCell. However Quinby's observation that "the weight and expense of such combs would render them impracticable" is a challenge that remains relevant today, and artificial combs are simply not popular.

Lots of options

The February 2016 article "Standard Equipment: How Standard Is It?" discussed the dizzying array of options available for "standard" hive boxes. So it is no surprise that simple items like "standard" frames and foundation also come in a ridiculous number of possibilities. For example, the Dadant website explains *seven* different product types they carry just for foundation!

Aside from proprietary tweaks and products that aren't really used, there are four main options for frames and foundation that are commonly seen:

1) Wooden frames and wax foundation

This is the classic set-up. For frames, we need "wedge top bars" (WTB) and either slotted bottom bars (SBB) or grooved bottom bars (GBB). Slotted bottom bars are open all the way through in the middle, allowing foundation to slide into the frame from the bottom. Some slotted bottom bars are a single piece with the slot cut almost, but not quite, from end to end; others are actually two separate pieces that affix independently to the end of the side bars, creating a gap between them. Grooved bottom bars have a deep groove where the foundation fits. Either approach works equally well with wax foundation.

Wax foundation may come with vertical wires already embedded in the wax, but for deep frames additional support is a really good idea. Otherwise the foundation may twist or bow, which will result in twisted and bowed comb. The arguably best way to reinforce

A well-constructed frame with horizontal wires embedded in the foundation.

foundation is to install horizontal wires in the frames and embed the wax foundation into the wires.

To wire frames, we need a few extra tools:

1. Form board: A wooden board, a little larger than a frame, with slots cut into it such that the foundation inside the frame can lay flat against a firm surface.
2. Frame wire
3. Brass eyelets: These insert into holes in the end bars and prevent the wire from digging into the wood, which would create slack.
4. Eyelet punch: A handy metal rod that is used to insert the eyelets into holes in the end bars. It is designed to be whacked with a hammer to firmly seat the eyelet into the hole.
5. Wire crimper: This device has two ridged rollers. Once the wire is firmly installed in a frame, the wire is maneuvered between the rollers and the device is pulled along the length of the wire, creating a crimped wavy pattern. This makes the wire shorter and therefore tighter.
6. Spur embedder: Looking like the spur from a cowboy's boot, this is rolled along the wire to embed the wire into the wax foundation.
7. Small tacks
8. Pliers/wire cutter
9. Hammer

The process is simple but somewhat tedious:

1. Using the eyelet punch, insert an eyelet into each of the two center-most holes in the

end bars. The eyelets should face outward.
2. Tap a small tack into the edge of an end bar, halfway between the two center-most holes. Leave about 1/8 inch protruding.
3. Starting from the end with the tack that was installed in step 2, thread wire through an eyelet. Pull it across and through the eyelet directly opposite, then out and back in through the other eyelet. Bring the wire back across and through the last eyelet on the side where we started.
4. Wrap the loose end of the wire several times around the protruding tack.
5. Pull the other end of the wire to make it as tight as possible, then secure it by twisting it around the protruding tack. Clip the wire to release it from the spool.
6. Hammer the tack securely into the wood.
7. Holding the frame horizontally, run the wire crimper along both wires to ensure they are tight.
8. Insert the sharp end of a hive tool into the slot in the frame's top bar where the wedge strip (cleat) is partly attached.
9. Pull the hive tool along the slot. The wedge should cleanly pop off.
10. Weave a sheet of crimp-wired foundation over-and-under the frame's two wires and into the groove or slot in the bottom bar. Make sure that the L-shaped hooks at the top of the foundation are facing outward and rest in the channel created when the top bar's wedge strip was removed.
11. Replace the wedge strip into the channel that it came from, pressing close against the top bar. It now pins the L-shaped hooks into place, securing the foundation.
12. Use a couple of tacks to firmly re-secure the wedge to the top bar.
13. Lay the frame onto the form board such that the wax lays flat against the board.
14. Roll the spur embedder along the wire so that it is pressed into the wax.
15. Flip the frame over and repeat for the other wire.

Whew! That's one! Only nineteen more to go for this hive….

Bobby pins support wax foundation quite well, are easy to install and are cheap!

Or… instead of using horizontal wires, try bobby pins!

1. Do not get any of the extra tools and supplies mentioned above.
2. Put the foundation into the frame as described in steps 8 through 12, minus the wires.
3. Insert a bobby pin into each of the four center-most holes of the end bars, ensuring that the pin grasps the wax sheet between its two tines.
4. Do the same for the other 19 frames.

If you don't like the fact that bobby pins are very cheap (I bought a pound of them on-line for $7), you can do the same thing with special-purpose foundation support pins purchased from bee supply stores.

Advantages of wax foundation:

1. Bees will typically build on pure wax foundation more readily than waxed plastic foundation.

Disadvantages:

1. New comb must be handled carefully. For example, frames that you are inspecting should not be held horizontally or else the comb can easily sag, especially in hot weather.
2. Bees can chew away the bottoms of the comb in times of dearth.
3. Mice can easily ruin comb.

4. Small hive beetle and wax moth larvae can easily traverse the comb from one side to the other.
5. In honey super frames, care must be taken when extracting wax-foundation comb because at high speed, the comb can "blow out" in the extractor.

2) Wooden frames and wax-coated plastic foundation

This set-up is extremely popular among its fans. I must admit that almost all of my frames are this way (400-plus frames). The frames use grooved top bars (GTB) and grooved bottom bars (GBB). The plastic foundation simply pops into place into the frame; no special equipment is required.

Advantages:

1. Easy assembly with no special equipment.
2. Beetle and moth larvae and mice don't have quite the free reign they do with pure wax foundation.
3. Comb can handle rough treatment – it can be held at any angle, dropped or extracted at full speed without damage.

Disadvantages:

1. Bees will not accept plastic foundation, wax-coated or not, unless there is a strong nectar flow underway. So the window of opportunity for getting comb drawn out is short: April and May.
2. If they don't accept it, clever bees will build complete combs off-set from the plastic on either side of the foundation. This comb must be removed.
3. Once bees refuse to build on a section of plastic foundation, they typically will not return and complete it later -- it will stay empty forever.
4. Buyer beware: many vendors sell "wax coated" plastic foundation that has about as much wax on it as *<fill in the blank with something that doesn't have wax on it!>*. We should be able to scratch wax off of the surface with a fingernail. If we can't, we'll need to paint melted beeswax onto the surface. It is possible to buy uncoated plastic foundation but the bees will not work it unless it is coated with beeswax.

3) One-piece all-plastic frames and wax-coated foundation

In my experience, these can warp, don't quite fit right (a bit too narrow) and have slots in the end-bars that are perfect for small hive beetles to hide and breed. However they are extremely popular with many commercial beekeepers. Their advantages include all of the advantages already mentioned for plastic foundation, plus they are as no-hassle as possible: they are ready to go straight out of the box. Their disadvantages are the same as for any plastic foundation, plus the fact that the frame cannot be reused separately from the foundation.

4) Wooden frames, no foundation

The invention of foundation was a big leap forward in the history of beekeeping, in the same category as moveable frames and centrifugal extractors. It makes life for the beekeeper much easier and much more productive. But if ease, productivity and reducing headaches are contrary to your goals, then the use of foundation is by no means mandatory.

For no-foundation frames, we need a grooved top bar frame (GTB). Any type of bottom bar will do. Insert a starter strip into the full length of the groove in the top bar – a strip of wood as wide and thick as a Popsicle stick works well. There are many variations on starter strips; they all work. The key point is to provide a low-hanging *something*. The bees will draw comb starting from the low point and fill up the space within the frame.

If we don't provide a low point, the bees themselves will choose where they want to hang their comb. That choice may be very odd with respect to what we would have chosen. For example, a friend who experimented with this technique, sans a starter strip, discovered that her bees had drawn a beautiful sheet of comb all along the far right-hand edge of the

top bar. And they drew another beautiful sheet of comb all along the far left-hand edge of the same top bar. The bees must have thought they were very clever, giving two for one, but that comb was difficult to handle and impossible to fully inspect. Another friend's bees built comb at right angles to the frames rather than within them (see photo on page 1).

The way to get no-foundation frames to reliably work is insert a no-foundation frame between two frames that already have fully-drawn comb. Those frames will act as a guide for the foundationless comb.

However this still doesn't address the problem of getting cells drawn that are the desired size. A mature colony wants about 10% of its brood to be drones. Commercial foundation is typically imprinted with worker-sized cells. That's why bees often build drone cells between the frames of the top and bottom boxes and in any other random space that will suit the purpose. So if we have two brood boxes full of frames that are drawn out with worker-sized cells, give the colony an empty frame and say, "Go to it," they will invariably fill the empty frame with drone-sized cells. That's not the end of the world but it does not support our goal of having lots of worker bees.

Wait, there's more that can go wrong! If we use the "reliable" method and put a no-foundation frame between two already-drawn frames, the bees may choose to extend the depth of the cells in the two already-drawn frames into the empty space rather than filling it with new comb. This can create a terrible mess. This problem is unlikely to occur when the no-foundation frame is put into the middle of the brood nest but it can easily happen among honey frames.

Advantages:

1. Saves the cost of foundation.
2. Careful use may be appropriate in honey supers intended for cut-comb honey and not extracted honey.

Disadvantages:

1. High likelihood of getting useless and inappropriate comb that must be removed.
2. Comb is even more delicate than comb built on wired-wax foundation.

The bees have done a fairly good job with this no-foundation frame. However note the large patches of drone cells along the top and bottom edges.

Which is best?

As with almost everything else in beekeeping, frames and foundation are designed to serve the needs of the beekeeper, not necessarily the bees. Therefore the question of which configuration is "best" is subjective and depends on the goals, experience and preferences of each beekeeper. Fortunately there is no real downside to experimenting, since once the comb is drawn out, the bees don't know or care what the original foundation was. So there is no problem with mixing frame and foundation types in the hive. However, don't mix empty foundation types – without comb – or the bees will preferentially choose one type to work on and ignore the other.

I have an eclectic mix of all four configurations that have been discussed here. I'm still trying to decide which I like best, and conversely, which I hate worst!

Randall Austin is a NC Master Beekeeper keeps a few honey bee hives in northern Orange County. He can be reached at s.randall.austin@gmail.com.