Chapter 1
Big Picture: Broad and Surprising Findings

Can't see the forest for the trees. -common English idiom

Opening Questions:

How did the research team coalesce around this project?
What perspective and expertise do the team members bring?
What are the broad findings of this study? What is new or different?
Will these findings accelerate the pace of sustainable housing adoption?
Given this fresh review, what new challenges and hopes are identified?

Mutual interests brought our primary research team together. We each carry a deep concern for humanity's damaging impact on natural ecosystems, and we each believe that faster progress toward broad adoption of sustainable housing is both needed and possible. If you share these concerns and interests, you will certainly find hope in this resource. We found hope in the outcomes of this study, but in very different places than we expected. We represent three perspectives on the housing industry; one research partner is an architect with specific training in building science and energy management. We also had a residential builder on our team; he has a regional reputation for environmental sensitivity, and his experience spans from low-income housing (Habitat for Humanity) to high-end custom homes. I represented the homeowner perspective, and is a university business professor, brought financial analysis and the tools of environmental and ecological economics. All three perspectives were critical to melding conventional wisdom to new data and analysis; this first chapter will highlight the broad findings and the big picture of sustainable housing in the United States. The chapters that follow provide the detailed analysis that support these broad findings as well as to offer guidance on the myriad choices encountered when designing and building a sustainable home.

The lifestyle of most Americans causes a disproportionately large share of damage to natural ecosystems, ranging from local pollution, to resource depletion, to global climate change, and a significant component of the American environmental footprint is housing. Addressing the operational energy footprint from residential housing would reduce greenhouse gas emissions in the U.S. by more than a third, and pollution from local and regional power plants would fall dramatically as well. As with many of the wicked problems facing humanity in the 21st century, the challenge of sustainable housing requires integrative thinking, and progress on many disparate, but related parts. We demonstrate that the starting point needs to include distributed solar in active photovoltaic (PV) systems that change the trajectory of how we design and construct houses. The simple inclusion or exclusion of onsite solar PV impacts so many of the choices in building materials and operational systems and equipment. Distributed solar PV is so crucial to this analysis that we dedicate two full chapters (three and four) to explaining its merits.

While residential solar has been available for many years, the combination of improved technologies, recent price reduction below critical thresholds, and more accommodating regulatory environments have changed the game on home solar PV installations. Electric utilities did not warmly embrace the idea of home-grown renewable energy generation initially, with most viewing it as a threat to their primary revenue base and overall business model. Public advocacy from customers, various levels of government, and civil society groups has been needed in many pockets of the country to encourage utilities to allow net-metering, eliminate taxes on solar equipment, and remove other barriers, such as debilitating standby fees, any of which diminish the economic argument for home solar. In nearly every area of the country today, solar PV is not only a good choice environmentally, but it is also a really strong financial investment, with higher returns than what might be expected from a diversified portfolio in U.S. equity markets. Unfortunately, this is difficult to both understand intuitively, and to communicate, because the financial model for solar PV requires a significant and known initial cost, while a predicted set of benefits accrue over many years. In Chapter 3 we break this down for clarity and offer some ideas for framing choices and messaging.

With onsite solar PV both economically and environmentally advantageous, it sets up three different scenarios for building the most sustainable house possible from a combination of embodied and operational energy. The most ideal condition is where solar PV is fully available within local utility and regulatory environments, and with adequate onsite mounting space (often roof or ground-mount), to generate all of the annual energy demand of the home and transportation. We refer to this as a SOAR situation or solution, denoting conditions where SOlar is Available and Ready. The second scenario is where solar PV is available, but limited in some way. This could be from limits to a potential capture area for sunlight (roof too small or partially shaded), or limitations by local utility or regulation. For this intermediary position we use the acronym SORTA, indicating that SOlar is Ready, but with Tempered Availability. The third scenario is where solar PV is simply not available in any size or capacity; an example might be a home that does not have a suitable roof for solar or sufficient space for a ground-mount array, or where local utility or regulation blocks access. We term this third condition the SNAIL (Solar Not AvaILable) home. While each of these scenarios point to a different set of best practices to reduce overall environmental impact, we will begin with a few broad principles that should span across all three:

1. Eliminate direct use of fossil fuels in favor of 100% electric equipment and appliances. When fossil fuels are burned, the emissions pollute locally and contribute to climate change globally. Grid-distributed electricity in the U.S. is still generated with a mix of fossil fuels, and these are slowly being displaced by cleaner and renewable energies. Where on-site solar PV is possible, electricity is the preferred energy medium. There is no clean fossil fuel option; burning fossil fuels pollutes locally and contributes to climate change no matter the form of fossil fuel.
2. When designing for new construction, spaces and rooms should be sized for practical need. By U.S. standards and averages, this should result in small-modest sized floor

plans and building footprints, use fewer dollar and environmental resources to build, and require less energy to operate. Working with an architect is key at this step, as they can help make spaces functional and right-sized in the design phase.

3. Orient the building to allow for maximum solar gain to the south (in northern hemisphere locations) and, to the extent practical, buffer the building to the north and northwest; this is especially critical in colder climates with a high number of heating days.
4. The first priority in design should be to provide for adequate solar PV gain; this will include sufficient space for an array of panels, orientation (azimuth) to the south, and location-dependent angle (pitch). Passive heat gain may also be considered in design, though advances in building technologies are making that concept less important.
5. Aim to produce as much renewable energy on-site as is possible or practical, up to 100% of the annual energy needs of the home and private transportation. If space and regulation permit, size PV to produce a surplus that can offset the embodied energy of the building, incurred mostly during construction.

This analysis focuses primarily on the broad goals of sustainability, both in terms of energy use in a home and resource use in construction. While there are many other reasons for choices in the home building and buying process, other factors such as comfort and health will be addressed in the building envelope chapters. However, on the primary basis of overall sustainability, we will review the three scenarios, beginning with the highest environmental impact and working toward more sustainable packages.

SNAIL house - Solar PV not available in any size or capacity:

If there is any possibility of solar PV becoming available in the future, the design and orientation of the home should reflect that eventuality from the outset. Refer to the two other scenarios for orientation and design, and think about ways to prepare for adding solar later, such as installing empty conduit through interior walls or chases for future connections between PV components. However, with initial and near-term conditions prohibiting solar PV, the aim should be to reduce the operational energy of the home, but only where benefits exceed the cost of upgrades; the best choice is to reduce floor plan and footprint. Conventional wisdom suggests heavy investments in the building envelope, mechanical systems, and appliances, even as those choices require more damaging environmental impact in manufacture and construction. A robust building envelope typically entails thicker and more insulated walls and higher-performing windows and doors. What is the economic return on such upgrades, and do they return net environmental benefits?

Building envelope upgrades are the conventional wisdom and orthodoxy of the green building movement for any house; unfortunately, they add significant cost, which effectively prices many homeowners out of the market. The significant initial cost differential alone, further complicated by residential appraisal and financing norms in much of the U.S., helps explain why so few homes are built to green building standards. Furthermore, reducing operational energy through building envelope upgrades adds significant and increasing costs that yield progressively poor environmental and economic returns. Our analysis challenges this orthodoxy on all but the weakest links of the building envelope. At current and projected energy rates in the U.S., most elements of a premium building envelope and HVAC system cannot be justified on a pure economic basis; the initial cost premiums are too large to be offset by a lengthy stream of marginal cost-savings. Premium upgrades are also questioned on environmental grounds because marginal energy savings in reduced operational costs are offset by increased material and resource impacts during construction. Other than advocating for the ideal outcome of changing the availability of solar PV, our analysis suggests just a few targeted upgrades for SNAIL homes, and they address only the weakest links in the building envelope; these are analyzed in Chapters 5 and 6.

To summarize SNAIL homes with pros and cons, an upgraded building envelope is the most costly of these three scenarios (both economically and environmentally), it still relies on grid-based (fossil fuel-laden) energy in the near term, and there are very few options to reduce overall environmental impact. Our analysis demonstrates that environmental and economic harms can be avoided by eschewing most of the prescribed building envelope upgrades. The calculus for the SNAIL scenario applies similarly to equipment and appliances, with the most efficient units usually coming with a significant cost premium; this discussion is picked up in Chapters 7 and 8, and we offer calculators to help homeowners evaluate economic and ecological returns over different time periods.

SORTA house - solar PV ready, but with tempered availability:

Homeowners with these conditions should plan to maximize solar PV within their context-specific limitations. If the limits are due to space, higher density monocrystalline modules should be considered, whereas if the barrier is regulatory, the system should be sized up to that limit. Since SORTA barriers may limit solar production to levels less than 100% of household energy demand, much less contribute to transportation, upgrades to the building envelope may be made selectively in an attempt to reduce operational energy to those limits. This is a case of selecting from a menu, choosing first those upgrades that offer the best value or return, combining both economic and ecological interests, and our analysis will provide fresh wisdom about these choices. This limited approach to reducing operational energy demand is less costly and less environmentally damaging than the SNAIL home, but it is more costly and more damaging than SOAR, to which we now turn.

SOAR - solar PV available and ready:

Knowing that solar PV can be sized without limit to meet 100% of annual household operational energy needs, plus power EV transportation, these homeowners have the full range of choices in envelope and mechanical systems. Constructing a house to building code standards in the U.S., assuming with a relentless focus on quality and integrity, is a reasonable choice, and is actually the least environmentally damaging at the construction phase. Our analysis suggests that very few upgrades are worth selecting on either economic or ecological grounds. Further, the overall reality of net zero (or surplus) energy via onsite renewable power generation means that a standard (code-minimum built with quality and integrity) envelope is sufficient from a big-picture perspective. The embodied energy in a larger solar PV system to achieve net zero energy with a standard building envelope is far less than the embodied energy of most envelope upgrades. This whole-house, life-cycle analysis was surprising to us because the recommendations that flow from the data grind against the conventional wisdom of the green building industry, which continues to advocate for energy savings.

> Industry Perspective
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> The building code is a set of rules and requirements that set minimum standards for building structure and insulation. The purpose of the building code is to protect health, safety, and general welfare in the construction and occupancy of buildings. Most local building codes are adapted from the International Building Code and the International Residential Building Code. They set standards for wind loads, snow loads, occupancy, fire safety and other aspects that ensure minimum levels of safety and energy use. Throughout this book, industry professionals will examine the virtues and vices of the building code and the processes and protocols of enforcement and compliance.

The most encouraging advantage we see from this assessment is that sustainable housing does not need to be costly; in fact, the most sustainable scenario is the *least* costly. On that basis alone, this understanding should encourage rapid widespread adoption of sustainable housing. However, it must include onsite renewable energy generation, and it's worth reiterating here that solar PV costs less today for most Americans than NOT installing solar. Additionally, homeowners are more likely to invest in--and design for--solar PV, even if the economic payback model is not fully understood, if the costs of construction is relatively low. If solar PV is sized sufficiently, this scenario renders a home climate-neutral in operation, minimally, and possibly net neutral over the life cycle of the structure if operational surpluses offset embodied energy and decommissioning at end of life. One concern we hold about this approach is that it could encourage larger homes, which we know to have a heavier tax on the environment from a materials perspective.

The summary of SOAR is to design the building--especially the roof--for solar capture, and the envelope for low environmental impact in embodied energy. Then plan for a solar PV system sized to meet at least 100% of the annual household energy load, and ideally for transportation as well. This package also presents counter-intuitive tradeoffs with HVAC and appliances, which we describe in Chapters 7 and 8, respectively. The following table summarizes some of the key criteria and impact of these three scenarios:

Scenarios and Criteria	SOAR Home Solar PV available	SORTA Home Solar PV limited	SNAIL Home Solar PV not available
Building envelope	Code-minimum with quality/integrity	Weak link upgrades only to PV limit	Weakest link upgrades (up to windows & doors)
HVAC systems	Economics-driven	Possible upgrades	Environment-driven

Appliance choices	Basic and simple	Possible upgrades	Environment-driven
Cost to build & equip	Least costly	Mid-range cost	Most costly
Overall envir. impact	Least impact	Mid-range impact	Most impact
Available to who?	All homeowners	Moderately wealthy	Very wealthy

Surprises and Ironies:

This analysis uncovered two enormous surprises and one big irony. The first surprise is that recent improvements in solar technology and cost, in addition to more amenable provisions from electric utilities, make residential PV installations not only viable, but financially lucrative. The second surprise is that many upgrades to the building envelope, historically done in the interest of environmental responsibility, actually return relatively smal environmental benefits that are most often outweighed by environmental harms, not to mention high economic costs and poor financial return. Conventional wisdom has everyone thinking that the first step is reducing energy demand, and then add solar as a secondary step. Unfortunately, very few homeowners can afford the investments needed to achieve energy savings from building envelope upgrades, and they never get to the solar step; most also do not understand the true costs (and overall benefits) of onsite solar. The outcome is predictable; almost no progress in reducing harmful environmental impacts from the residential sector.

Current realities suggest a rethinking and reorienting of this sequence and priority; we need to think of onsite solar as the first priority rather than the afterthought. When household energy use is met by onsite production of cleaner and cheaper solar energy, suddenly the building envelope becomes much less important even if one believes that upgrades have net environmental benefits, an assumption we analyze and challenge later in this text. Every dollar invested in solar PV has direct, known, and significant impact in reducing environmental harm, at least when displacing fossil fuel-derived energy. That claim cannot be made for any building envelope upgrade, most of which have negative financial return, and net negative environmental impact; this assumes a benchmark of code-minimum construction built with quality and integrity.

The enormous irony is that the answer has been right in front of us, yet seemingly elusive. Because we have been looking at the various components independently (envelope and energy) rather than integrated and interdependent (see Chapter 5), and because our decisions are too often driven by short term knowledge or interests (immediate costs) without a full understanding of longer term results, we've missed the integrated and life-cycle whole. Our focus on the trees in front of us veiled the trees behind and the forest as a whole. In this book we demonstrate with data and analysis that the most responsible environmental choice in most U.S. housing markets is the basic, least-costly, code-minimum house, with solar PV providing annual energy needs. If solar is recognized as the lucrative investment that it is, as demonstrated in Chapter 3, it will sell on economics alone and drive widespread adoption.

Whereas the green building movement has generally advocated very expensive upgrades, our analysis firmly suggests that the most responsible choice environmentally happens to be the least costly option, not only initially at construction, but operationally through its life cycle, and at decommissioning. Another irony is that environmental interests in the industry still advocate robust, premium building envelopes and this, unfortunately, limits action to the wealthy few and drives a belief that nothing meaningful can be achieved except with enormous financial investments. It surprised us that the scenario that taxes the environment least on an overall basis is also the least costly; that is encouraging news for more rapid and widespread adoption of sustainable housing in new construction, and it offers hope and rationale for making existing homes sustainable without crushing renovations costs.

In summary, this is worth itemizing to avoid confusion and possible conflation of the issues:

1. Installing solar PV today on a residence in the United States (except Alaska and a small corner of the Pacific northwest[1]) is advisable on economic grounds alone. For most homeowners, investing in solar PV offers the prospect of better returns, on average, than investing in the stock market.
2. Residential building codes in the U.S. require a minimum insulation value in walls that strikes a reasonable cost-benefit trade-off, both in economic and ecological terms, and insulation requirements in ceilings are already beyond reasonable. Adding more insulation is costly in dollars and materials, with only fractional benefit in reduced energy.

This seems counter-intuitive. We are environmentalists; in fact, it was this shared interest that brought our team together and sparked this project. Each of us, in our professional and personal lives, has been working to reduce our harmful impact on the planet. We have studied environmental science and the green building movement, and the strong imperative to reduce energy consumption seemed reasonable, consistent, and the most responsible choice. We still support the negawatt revolution, a grassroots movement encouraging less consumption of energy in the first place, rather than scrambling to clean up the mess in the aftermath. The great irony is that when applied to the residential home industry, these principles work to stall adoption of sustainable housing because, while people are doing what seems best on a system-by-system basis, they often *can't see the forest for the trees*. It took a new view--a bird's eye view of the whole forest--to discover a new set of realities and assumptions; this leads to our case study.

Case Study:

While this project and book are about residential housing broadly in the United States, we embarked on it while working together on one specific house as a way to test ideas and offer real-world examples and analysis. In many ways the case house is an average[2] American

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[1] Geographical endowments for solar PV are detailed in Chapter 3.
[2] The average size of residential homes built in the U.S. in 2015 was 2,687 square feet (Perry, 2016)

home, with 2,500 square feet of living space, three bedrooms, and typical common areas. However, it was designed from the outset to be climate neutral or positive in operation, including powering household transportation with an electric vehicle. As an added twist on the climate objectives for this project, the home is expected not only to generate enough clean and renewable energy onsite for annual home operations and family transportation, but also provide net energy back into the grid to offset its embodied energy and decommissioning impacts over the life of the structure. Throughout this book, we will offer this case as example and illustration of the interesting and difficult choices and tradeoffs, as well as lessons learned.

Newly constructed Case Study home, located in Virginia at 38 degrees north latitude. Note 7.2 KW solar PV array on southern roof; there are also passive solar elements on three levels.

On the basis of building science, building experience, and careful study of environmental best practices, we designed and built this house with a very robust thermal envelope. Walls were insulated concrete forms (ICF), ceilings had 12-14 inches of open cell spray foam insulation, windows were fiberglass-framed and triple-paned, and the doors were some of the best in the industry; this was to be one of the tightest and most insulated building envelopes available. Even though solar PV was planned from the beginning, we believed that we were designing the most responsible house from an environmental perspective, even though we knew it was costly, both in dollars and embodied energy. We were designing each tree in the forest to have the least negative impact. Unfortunately, our epiphany moment on envelope upgrades and whole house (forest) analysis, came too late in planning to scale back the structure. As a result, we have many lessons to share, both successes and regrets. What we learned in the process, but lacked at the outset, was a view and analysis of the whole forest and the tradeoffs between embodied energy from construction (resources and materials) and operational energy (production and use) over many years of useful life; this was an expensive lesson which we will expound upon as we share more about this case throughout the book.

Summary and Conclusions:

Mutual interest in the combined integrative space of housing and environmental concern brought our research team together for this project, and our different perspectives and areas of expertise contributed to new discoveries in sustainable housing. The broad findings are that solar PV has recently become a game-changer in this quest, due to lifetime costs falling below grid parity, and it changes many of the trends and assumptions about how to make a home sustainable. It does not require more resources and materials, other than the solar PV system, to eliminate climate emissions. The discovery that the most sustainable homes are also the least costly provides hope for rapid and widespread adoption of these principles and practices, and it democratizes the movement, making it available to all income groups.

Dos and Don'ts:

Dos related to the big picture

1. Learn of onsite solar PV capacity before site selection and design with the aim of finding a site that accommodates sufficient onsite renewable energy generation for household energy, and ideally also for EV transportation.
2. SNAIL homeowners might consider a different site that accommodates solar PV; otherwise, plan for a few targeted recommended envelope upgrades, starting with the weakest links, and a non-sustainable overall outcome.
3. SORTA homeowners should plan to maximize solar PV within site limitations, then select building envelope upgrades at the weakest links with the goal of reducing energy needs to within onsite power production limits.
4. SOAR homeowners can size solar PV for 100% of annual household energy needs plus EV transportation, then build a code-minimum house with quality construction to ensure integrity and longevity; we offer a few targeted upgrades for consideration.
5. Consider adding solar PV to existing structures as priority before envelope upgrades.

Don'ts related to the big picture

1. Don't build new housing where solar PV is not available, or where it is too limited.
2. Don't assume the most energy efficient option is always the best environmental choice.
3. Don't assume that building (or living in) a sustainable home is more expensive; it is not!

4. Don’t compromise the richness of history and culture in existing homes with invasive renovations if solar PV is available.