North American Steel & Hybrid Steel and Mass Timber Structural Systems: A comparative study of embodied carbon, structural depth, and approximate cost.

Study Author: KL&A, James C Hohmann PE
Study Commissioner: Nucor Vulcraft Nebraska

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Executive Summary

In recent years there has been a rapidly growing focus on the importance of embodied carbon – generally expressed as Global Warming Potential (GWP) – in the built environment. This newly focused attention has been inspired by the fact that materials used in the construction industry account for over one third of worldwide annual global greenhouse gas emissions[1]. The urgency of climate change together with commitments made to reduce embodied carbon by such organizations as the ASCE Structural Engineering Institute (SE 2050 Challenge[2]) and federal and State governments[3] are encouraging design and construction professionals to explore innovative designs and materials to reduce GWP at a rapid pace.

One such innovative structural system that has seen significant growth is mass timber[4]. Mass timber is made from an inherently renewable material, and mass timber structural systems have low embodied carbon impacts relative to other construction materials, especially when considering their ability store carbon (50% of the dry weight of wood) over the life of the material. While some mass timber solutions may be highly desirable, there are significant impediments to mass timber structural systems for many building types and locations. These can include, importantly, material cost and limited supply chains relative to conventional materials. Perhaps the biggest impediment to lowering embodied carbon by using mass timber construction is the challenge spanning long distances with an acceptable structural framing depth. In this case, one solution is to create hybrid structural systems that combine the best qualities of steel, which excels at long spans, with mass timber components such as cross laminated timber panels.

The purpose of this study is to quantify the benefits, if any, of hybrid systems in terms of embodied carbon, structural depth, and cost relative to conventional steel systems. To that end, a range of bay layouts for conventional steel and hybrid steel and mass timber framing systems for commercial and residential applications were investigated. Three key performance indicators were quantified for each system:

- Global Warming Potential, with stored biogenic carbon reported when applicable.
- The required structural depth, and
- An estimate of relative material and construction costs

The study included floor and roof systems comprised of both wide flange beams and girders and open web steel joists with wide flange girders. In conventional floor systems, steel beams are spanned by concrete filled metal deck acting compositely with steel framing, and in roof systems beams were topped by unfilled metal deck. Hybrid systems for both floors and roofs were topped by cross laminated timber (CLT) panels. Hybrid floors included a cast-in-place concrete topping slab over an acoustic mat on CLT panels.

Results of this study indicate that hybrid framing systems contain significant stored biogenic carbon. If stored biogenic carbon is not considered in the embodied carbon accounting,

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[1] https://architecture2030.org/embodied-carbon-actions/
[2] https://se2050.org/
[3] https://www.sustainability.gov/buyclean/
[4] https://www.woodworks.org/learn/mass-timber-clt/

hybrid framing systems have comparable embodied carbon impacts to traditional steel framing systems.

Regarding depth and cost, it is well known that composite steel beams in conventional floor systems are generally shallower and lighter than non-composite beams. Because the hybrid systems in the commercial floor systems in this study did not employ composite beam action, while the conventional systems did, the hybrid commercial floor systems were generally deeper than the conventional composite systems. Hybrid systems were also more expensive – by as much as $12 - $31 per square foot – due to a combination of increased steel material and CLT material cost.

All the systems studied utilize concrete in some capacity. For concrete on metal deck in composite steel beam applications, the concrete plays a primary structural role. In hybrid systems studied, the concrete topping serves as a wearable finish and part of acoustic performance. (In some cases, topping on timber panels can play a direct structural role as well, either as part of a composite system with wood or as a structural diaphragm. Neither of these applications were analyzed in this study). In most floor systems – conventional and hybrid, commercial and residential – the largest single contributor to GWP impacts is concrete. With this knowledge, a short study is performed to quantify the effect of using special, currently available concrete mixes that can feasibly reduce the embodied carbon content by 50% (termed “reduced GWP concrete”). Predictably, the significant reduction in concrete GWP has a significant impact on system GWP for relatively low cost. It should therefore be considered as an embodied carbon reduction strategy for both the conventional and hybrid systems.

Introduction

The popularity of mass timber structures continues to grow throughout the United States due to benefits which include lower embodied carbon, greater biophilia, aesthetics, and faster construction. However, limitations of full mass timber systems compared to more conventional structural systems include shorter beam/joist and girder spans, increased floor depth, the limited number of manufacturers, and material cost premiums. For these reasons hybrid systems which combine mass timber components with other structural materials have the potential to balance the advantages of mass timber while circumventing possible shortcomings.

In this study, hybrid systems that utilize mass timber panels (Cross-Laminated Timber (CLT) only in this study) supported by a steel framing are investigated. The steel framing consists of either steel wide flange beams or open web steel joists supported by wide flange steel girders and steel columns. This framing scheme is prioritized, with the assumption that this particular hybrid system would retain many of the benefits of a full mass timber system but allow for greater column spacing at a lower cost.

This study includes bay layouts for both commercial and residential occupancies as these use cases represent the potential largest markets for the use of these systems in the United States. Bay sizes vary based on typical span lengths for these occupancy types. In addition to the proposed hybrid framing, conventional steel framing systems are also analyzed to allow for comparison in terms of Global Warming Potential (GWP), system depth, and construction cost. The conventional steel framing systems consists of composite steel deck supported by composite steel wide flange (WF) sections and non-composite steel deck supported by open web steel joists (OWSJ) and WF girders.

Design Process and Framing Systems

The basis of this research is simple bay studies that encompass the breadth of typical layouts for commercial and residential systems. The scope of work for each of the two studies is outlined in the sections below.

Commercial Systems

1. **Commercial Bay Studies**:
   The design criteria and scope of the commercial bay studies include:
   a. Bays:
      i. 25 ft x 25 ft up to 50 ft x 50 ft
      ii. Adjust in 5 ft increments in X and Y directions independently to get both rectangular and square layouts.
   b. Design loads
      i. Floor: 50psf live load, 20psf superimposed dead load.
      ii. Roof: 30psf snow load, 15psf superimposed dead load
      iii. No wind or seismic loads
   c. Vibration
      i. Design criteria per AISC Design Guide 11/SJI TD 5.
         1. Target acceleration limit: 0.50g
      ii. Electronic Office Assumed, 6psf live load, 4psf superimposed dead load, 3% dampening.
      iii. For the purposes of vibration analysis, CLT is assumed to act compositely with steel beams and open web steel joists in accordance with AISC DG11r2 (Murray, 2016) and SJI TD5 (SJI, 2015). The concrete topping slab is assumed to provide additional stiffness for vibration, but not act compositely in accordance with the U.S. Mass Timber Floor Vibration Design Guide (Woodworks, 2023).
   d. Floor structure: Floor structures for the commercial bay studies were selected based on typical systems used in the U.S. market. Conventional framing systems have typically utilized a suspended ceiling system to visually cover the framing and provide acoustic separation. In the hybrid systems, it is assumed that the framing remains exposed, and that acoustic separation is provided by an acoustic mat installed between a concrete topping slab and the CLT. Typical acoustic separation targets in commercial occupancies are in the range of 45-50 for both STC and IIC ratings. For both systems the finished floor surface could either be the exposed concrete topping slab or an applied floor finish.

i. Conventional Baseline systems:

1. **Conventional Composite Steel WF Floor Assembly, Commercial**: 5 ½" thick composite slab, 3 ½" normal weight concrete topping with WWF6x6 W2.1xW2.1 reinforcement on 18ga 2" VLJ composite metal deck on composite wide flange steel beams and composite wide flange steel girders with a suspended ceiling system. Maximum deck span is 11'-1".

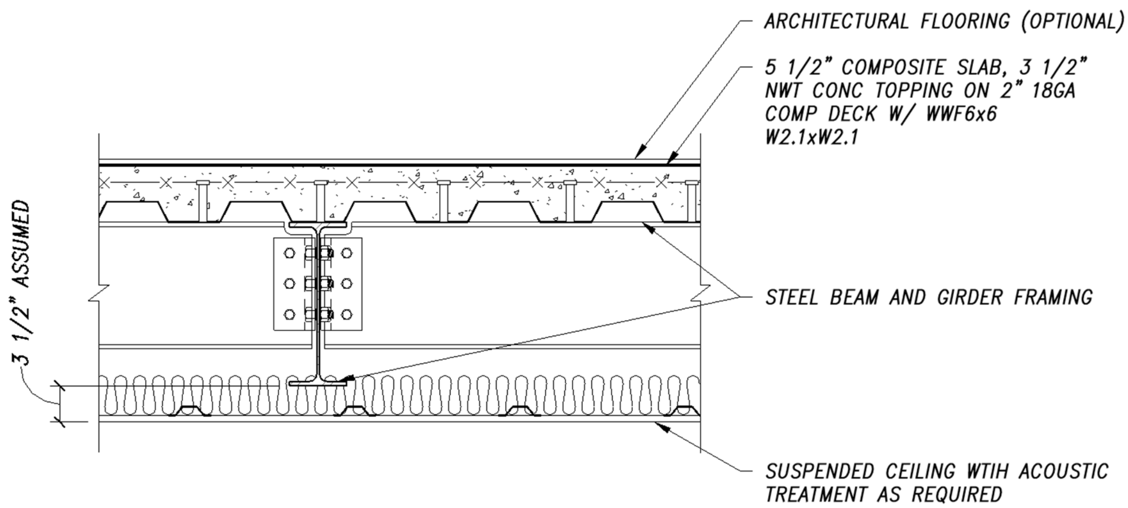

Figure 1 – Conventional Composite Steel WF Floor Assembly, Commercial

2. **Conventional OWSJ Floor Assembly, Commercial**: 4" thick concrete slab on deck, 3" normal weight concrete topping with WWF6x6 W4.0xW4.0 on 22ga 1.0" metal form deck over open web steel joists and wide flange girders with a suspended ceiling system. Maximum deck span is 5'-0".

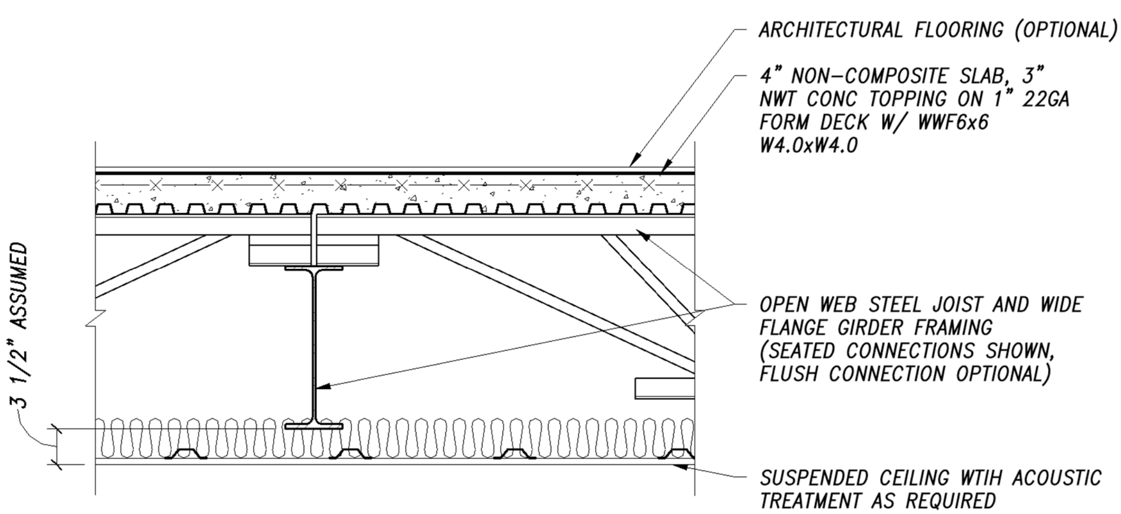

Figure 2 - Conventional OWSJ Floor Assembly, Commercial

ii. Hybrid Systems:

1. **Hybrid Steel WF Floor Assembly, Commercial**: 3” concrete topping slab on ¾” acoustic underlayment over 3, 5, or 7-ply CLT over wide flange steel beams and girders. Visually exposed at the underside. Maximum deck span is 11’-7” for 3-Ply CLT, 17’-1” for 5-Ply CLT, and 21’-6” for 7-Ply CLT.

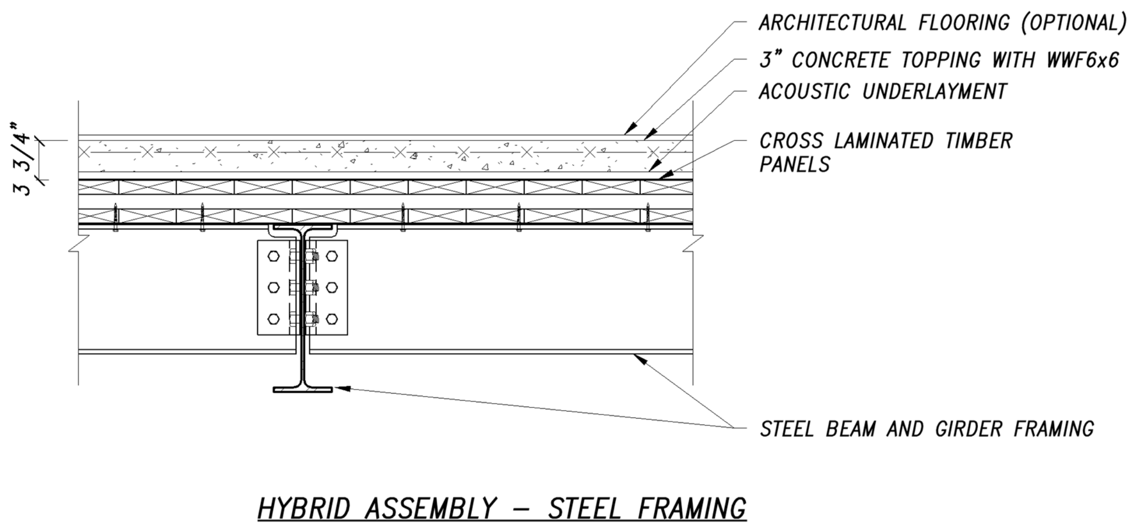

Figure 3 - Hybrid Steel WF Floor Assembly, Commercial

2. **Hybrid OWSJ Floor Assembly, Commercial**: 3” concrete topping slab on ¾” acoustic underlayment over 3, 5, or 7-ply CLT over open web steel joists and wide flange steel girders. Visually exposed at the underside. Maximum deck span is 11’-7” for 3-Ply CLT, 17’-1” for 5-Ply CLT, and 21’-6” for 7-Ply CLT. CLT spans were reduced when span would result in joist load in excess of published joist capacity for standards joists.

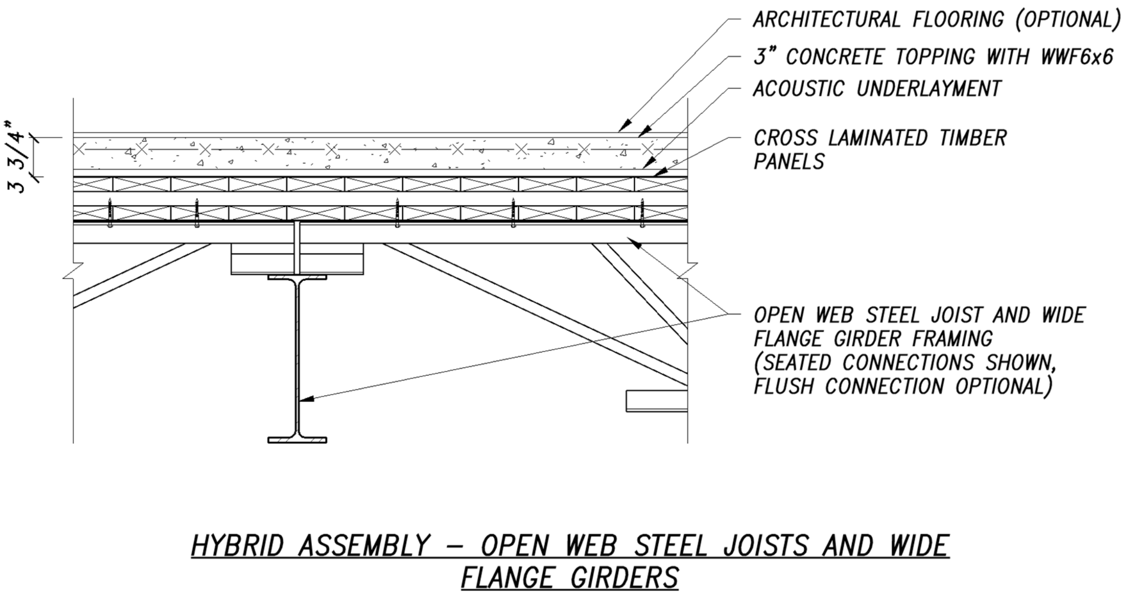

Figure 4 - Hybrid OWSJ Floor Assembly, Commercial

e. Roof structure: Roof structures for the commercial bay studies were selected based on typical systems used in the U.S. market. Conventional framing systems typically utilize a suspended ceiling system to cover the framing. In hybrid systems, it is assumed that the framing remains exposed. For both systems the finished floor surface could be either the exposed concrete slab or an applied floor finish.

   i. Conventional Baseline systems:

      1. **Conventional Steel WF Roof Assembly**: 3" 18ga deep rib metal deck, painted, on wide flange steel beams and wide flange steel girders with a suspended ceiling system. Maximum deck span is 12'-6".

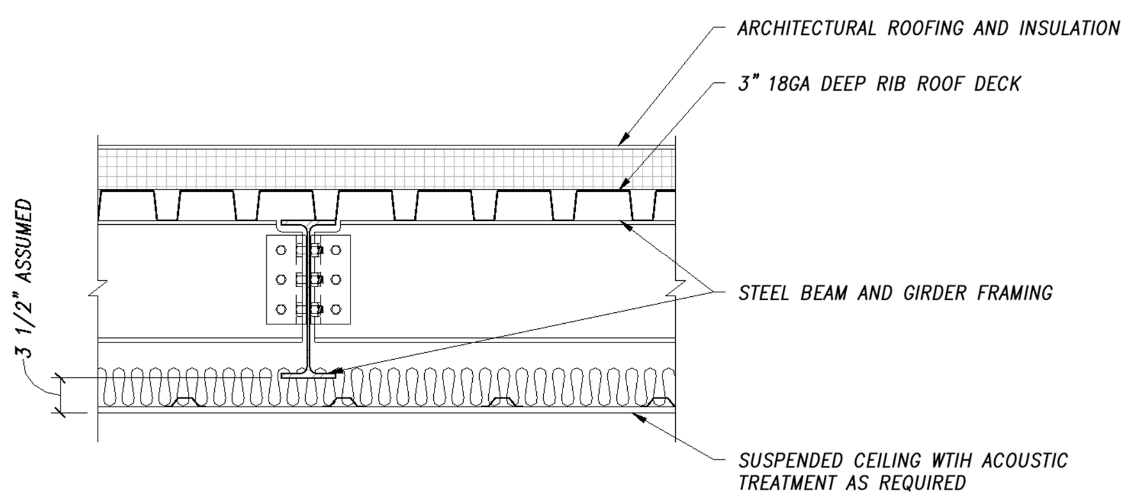

Figure 5 - Conventional Steel WF Roof Assembly

2. **Conventional OWSJ Roof Assembly**: 1.5” 20ga wide rib roof deck, painted, over open web steel joists and wide flange girders with a suspended ceiling system. Maximum deck span is 5’-0”.

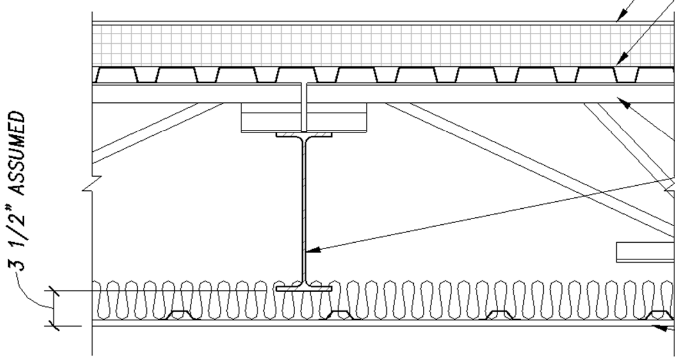

Figure 6 - Conventional OWSJ Roof Assembly

ii. Hybrid:

1. **Hybrid Steel WF Roof Assembly**: CLT on steel framing 3, 5, or 7-ply CLT over wide flange steel beams and girders. Maximum deck span is 12’-4” for 3-Ply CLT, 17’-2” for 5-Ply CLT, and 21’-6” for 7-Ply CLT.

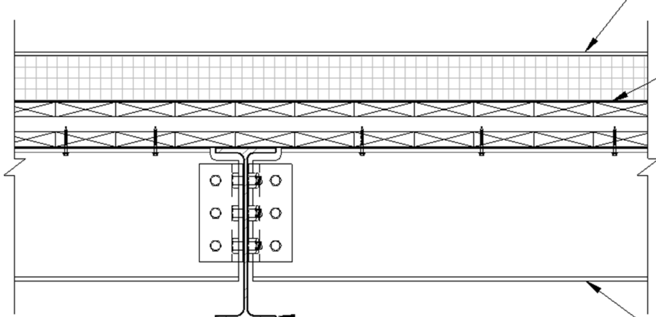

Figure 7 - Hybrid Steel WF Roof Assembly

2. **Hybrid OWSJ Roof Assembly**: 3, 5, or 7-ply CLT over open web steel joists and wide flange steel girders. Maximum deck span is 12’-4” for 3-Ply CLT, 17’-2” for 5-Ply CLT, and 21’-6” for 7-Ply CLT.

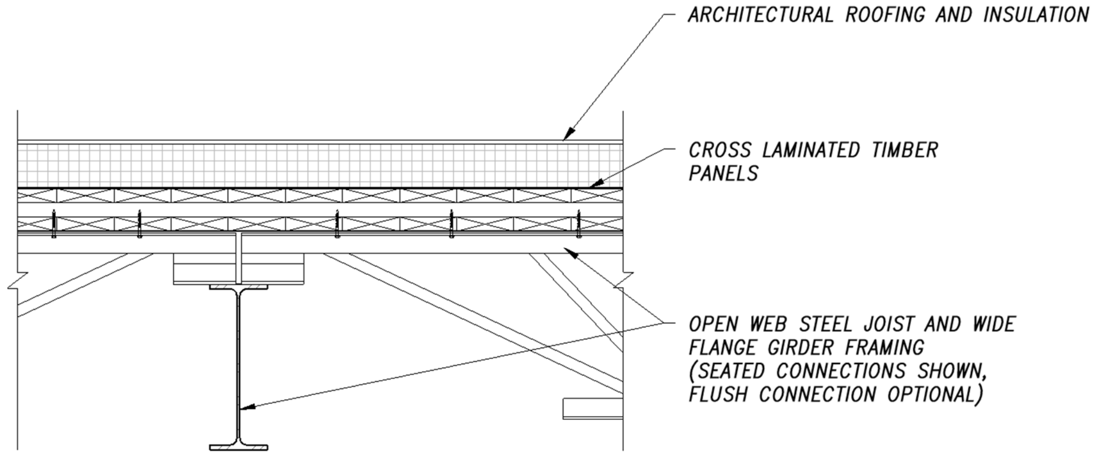

Figure 8 - Hybrid OWSJ Roof Assembly

Residential Systems

2. **Residential Bay Studies**:
   The design criteria and scope of the residential bay studies include:

   a. Bays:

      i. 15 ft x 15 ft up to 30 ft x 30 ft

      ii. Adjust in 2.5 ft increments in X and Y directions independently to get both rectangular and square layouts.

   b. Design loads

      i. Floor: 40psf live load, 15psf superimposed dead load.

      ii. Roof: 30psf snow load, 15psf superimposed dead load.

      iii. No wind or seismic load combinations

   c. Vibration

      i. Design criteria per AISC Design Guide 11/SJI TD 5.

         1. Target acceleration limit: 0.50g

      ii. Residential Use: 6psf live load, 10psf superimposed dead load, 5% dampening.

      iii. CLT is assumed to act compositely with steel beams and open web steel joists in accordance with AISC DG11r2 (Murray, 2016) and SJI TD5 (SJI, 2015). Topping is assumed to not provide additional stiffness for vibration.

   d. Floor structure: Floor structures for the residential bay studies were selected based on typical systems used in the U.S. market. Conventional framing systems have typically utilized a suspended ceiling system to cover the framing and provide acoustic separation. In the hybrid systems, it is assumed that the framing remains mostly exposed, and that acoustic separation is provided by an acoustic mat installed between a topping slab and the CLT. Acoustic separation in residential occupancies is required to meet a code minimum of 50 for both STC and IIC ratings, and a rating of 55 or higher is frequently desired. For this reason, a thicker acoustic underlayment is assumed for hybrid systems. For both systems an applied floor finish is assumed.

i. Conventional Baseline systems:

1. **Conventional Composite Steel WF Floor Assembly, Residential**: 5 ½" thick composite slab, 3 ½" normal weight concrete topping with WWF6x6 W2.1xW2.1 on 18ga 2" VLJ composite metal deck on composite wide flange steel beams and composite wide flange steel girders with a suspended ceiling system. Maximum deck span is 11'-1".

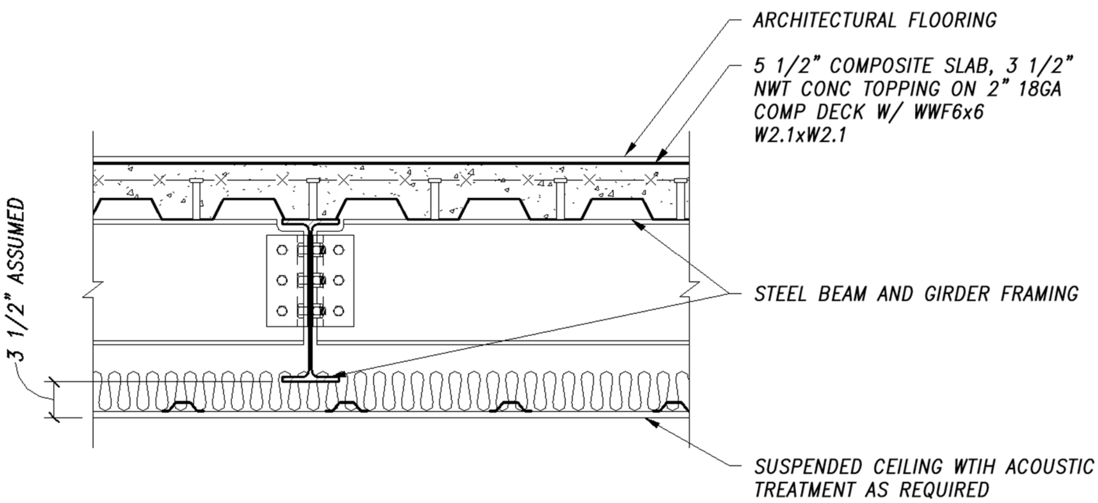

Figure 9 - Conventional Composite Steel WF Floor Assembly, Residential

2. **Conventional OWSJ Floor Assembly, Residential**: 4" thick concrete slab on deck, 3" normal weight concrete topping with WWF6x6 W4.0xW4.0 on 22ga 1.0" metal form deck over open web steel joists and wide flange girders with a suspended ceiling system. Maximum deck span is 5'-0".

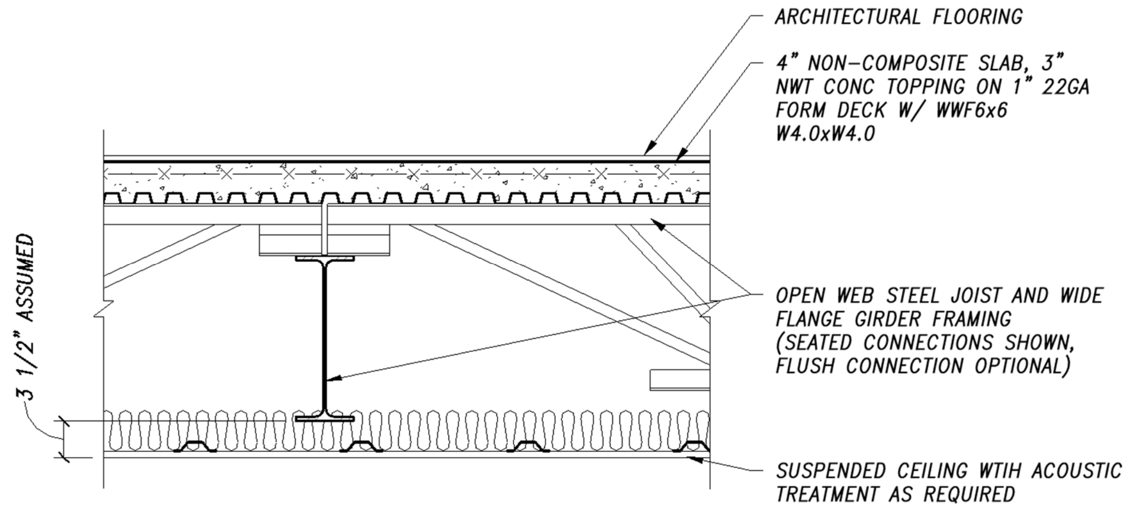

Figure 10 - Conventional OWSJ Floor Assembly, Residential

ii. Hybrid:

1. **Hybrid Steel WF Floor Assembly, Residential**: Steel framing 3" gypcrete topping slab on 1" acoustic underlayment over 3, 5, or 7-ply CLT over wide flange beams and girders. Maximum deck span is 11'-7" for 3-Ply CLT, 17'-1" for 5-Ply CLT, and 21'-6" for 7-Ply CLT.

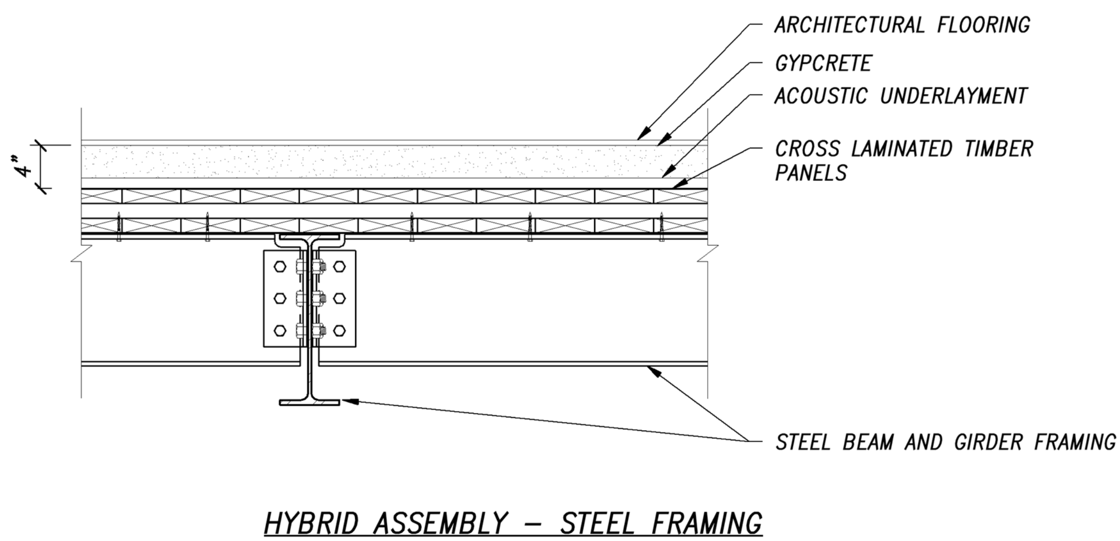

Figure 11 - Hybrid Steel WF Floor Assembly, Residential

2. **Hybrid OWSJ Floor Assembly, Residential**: 3" gypcrete topping slab on 1" acoustic underlayment over 3, 5, or 7-ply CLT over open web steel joists and wide flange girders. Maximum deck span is 11'-7" for 3-Ply CLT, 17'-1" for 5-Ply CLT, and 21'-6" for 7-Ply CLT. CLT spans were reduced when span would result in joist load in excess of published joist capacity for standards joists.

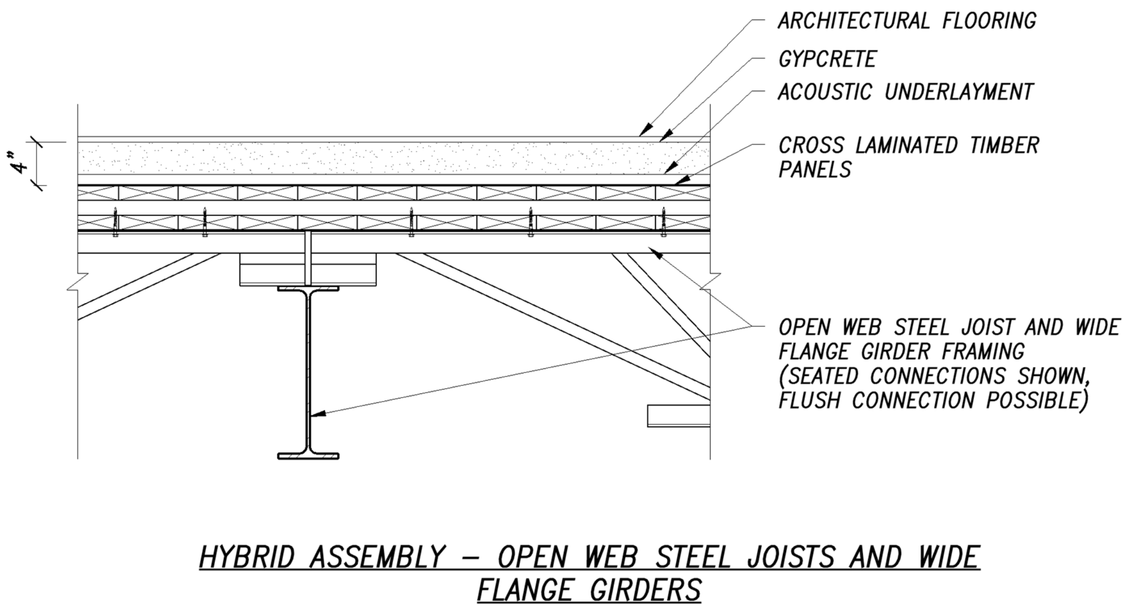

Figure 12 - Hybrid OWSJ Floor Assembly, Residential

e. Roof structure: Roof structures for the residential bay studies were selected based on typical systems used in the market and are identical to the systems presented in the commercial bay studies section.

Embodied Carbon Impact Methodology and Scope

Embodied carbon is the greenhouse gas emissions associated with material and product manufacturing, transportation, installation, and end of life allocation. It is expressed as Global Warming Potential (GWP) with the unit of measurement of kilograms of carbon dioxide equivalent (kgCO_2eq or kgCO_2eq/m^2 when expressed per unit area).

To quantify and compare the potential embodied carbon impact of each system and bay size, structural material quantities (SMQs) were tabulated on a unit basis. These SMQs were paired with embodied carbon data from published Type III Environmental Product Declarations (EPDs), in compliance with ISO 14025 (ISO, 2006) and ISO 21930 (ISO, 2017) to obtain an estimate of total GWP per square meter of floor area.

The reported GWP is a "cradle-to-gate" Life Cycle Assessment, inclusive of Stages A1-A3 (Product). Stages A4-A5 (Construction), B1-B7 (Use), C1-C4 (End of Life), and Module D (Benefits and loads beyond the building system) are excluded from this assessment.

The reported GWP is inclusive of the designed structural materials for each system: steel framing, steel deck or cross laminated timber panel, and cast-in-place concrete topping slab. Exclusions of the embodied carbon assessment are steel reinforcement, acoustic performing materials, and architectural ceiling and floor finishes.

Concrete Reinforcing

The embodied carbon impact of concrete reinforcing, including reinforcing bars (rebar), welded wire fabric (WWF), and headed stud anchors (HSAs), is not included in this study. While the different floor systems have varying quantities of steel reinforcing, the embodied carbon quantity change is less than 3% of the estimated total for each structural system. Therefore, the embodied carbon impact of steel reinforcement is not included in this study.

Ceiling Finish Systems

A distinction between the conventional and hybrid structural systems studied is the architectural treatment below the structure. In hybrid steel and mass timber systems, the CLT panel is assumed to be exposed from the underside and constitutes the finished ceiling. For conventional steel systems, a suspended gypsum ceiling is assumed to provide architectural finish and acoustic separation. Using the established industry average GWP for 5/8" Gypsum Board, Type X, the additional embodied carbon impact is 2.98 kgCO_2eq/m^2 of applied gypsum board (Gypsum Association's Industry Average EPD, published April 28, 2020).

Acoustic Mat

A second distinction between the conventional and hybrid systems studied is the methods utilized to meet acoustic performance requirements. As indicated in the above paragraph, a suspended ceiling provides acoustic separation in the conventional steel systems. In the hybrid systems, an acoustic separation mat is incorporated between the CLT and the concrete topping slab. At the time of this study, there is no established acoustic mat industry average EPD and few manufacturer specific EPDs, therefore it is excluded from the GWP analysis.

GWP Impact Data:

Current Environmental Product Declarations (EPD) were selected to represent this study's GWP impact estimates. The specific EPDs are discussed below and presented in Table 1. All EPDs used are third party verified, Type III Environmental Product Declarations, in compliance with ISO 14025 and ISO 21930. For products other than Nucor produced products, industry average GWP data is utilized.

Steel

This comparative study is performed based on the use of Nucor steel products; therefore, the manufacturer's EPD data is utilized instead of industry average EPD data to calculate the steel material GWP impacts.

Concrete

The concrete GWP impact is calculated using the National Ready Mixed Concrete Association (NRMCA) Member Industry-Average EPD for Ready Mixed Concrete published January 3, 2022 by the NRMCA. The mix design used for this study is a 4000psi strength mix with 0% supplemental cementitious materials (SCMs). This mix design is used for the concrete portion of the steel composite and non-composite decks as well as the topping slabs on the CLT panels.

Concrete GWP data is used to represent the concrete and gypcrete topping slabs. There is little gypcrete GWP data currently available in the industry at the time of this study and no industry average EPD. Gypcrete is considered to be a similar cementitious product type to cast-in-place concrete for the purposes of this comparative embodied carbon assessment.

Cross Laminated Timber

At the time of this study, there is no industry average CLT EPD. GWP impact and stored biogenic carbon content data was collected from seven North American CLT manufacturer EPDs (see list below for EPD references). The data was used to develop an average A1-A3 GWP impact and biogenic carbon content. The average was not weighted based on production volumes and is a simple average. The reported A1-A3 impacts are exclusive of biogenic carbon.

The CLT's stored biogenic carbon is reported separately from the CLT A1-A3 GWP impacts, in accordance with ISO 21930 7.2.7. The reported value is the stored biogenic carbon within the CLT product leaving the manufacturer. This is the maximum stored biogenic carbon of the wood product and does not consider any release of biogenic carbon over the life cycle of the product.

Structural Component	EPD Name	EPD Owner	A1-A3 Total GWP (kgCO2e/Declared Unit)	Maximum Potential Biogenic Carbon (kgCO2e/Declared Unit)	EPD Date
Steel Decking	Fabricated Steel Roof and Floor Deck	Nucor	1740 / 1000kg	0	June 29 2023
Steel Joists	Fabricated Open Web Steel Joists and Joist Girders	Nucor	839 / 1000kg	0	December 21 2022
Steel WF Beams	Fabricated Hot-Rolled Structural Steel Sections	Nucor	1220 / 1000kg	0	Janurary 1 2021
Concrete	Industry Average EPD For Ready Mixed Concrete, 4000 psi with 0% SCMs	NRMCA	383 / 1m^3	0	January 3 2022
CLT	Cross Laminated Timber (CLT)	Average of (6) referenced CLT EPDs	135 / 1m^3	0	Varies
CLT Biogenic Carbon	Biogenic Carbon in Cross Laminated Timber (CLT)	Average of (6) referenced CLT EPDs	0	-868 / 1m^3	Varies

Table 1 - EPDs used for embodied carbon estimates.

Referenced CLT EPDs:

- Vaagen Timbers, Cross Laminated Timber, published April 15, 2021.
- Nordic Structures, Nordic X-Lam, published August 2018.
- Structurlam Mass Timber Corporation, Crosslam CLT, published January 13, 2020.[5]
- Kalesnikoff, Cross Laminated Timber, published March 16, 2022.
- Smartlam North America, Cross Laminated Timber, Columbia Falls, Montana, published January 22, 2021.
- Smartlam North America, Cross Laminated Timber, Dothan, Alabama, published January 22, 2021.

Stored Biogenic Carbon

The ultimate embodied carbon impact of mass timber material on a structural system or building system is dependent on the biogenic carbon flow, building life expectancy, sustainable material sourcing, and end-of-life pathways. There is potential for the stored biogenic carbon to be released to the atmosphere through decomposition or burning at end of life, to be permanently stored within the material, or through alternate scenarios at end of life. End of life allocation is outside the scope of this study, so LCA Stages C and D are not included in this assessment. Biogenic carbon is instead presented as “maximum stored biogenic carbon potential” to represent the full *potential* of biogenic carbon offsetting the structural systems’ embodied carbon impacts.

The biogenic carbon content of a CLT panel is directly related to the panel thickness (material volume). For standard US thickness panels utilizing 1.375” thick laminations, the biogenic carbon content is -96 $kgCO_2eq/m^2$ for 3-ply CLT, -160 $kgCO_2eq/m^2$ for 5-ply CLT, and -224 $kgCO_2eq/m^2$ for 7-ply CLT.

[5] At the time of this writing Structurlam Mass Timber Corporation’s CLT EPD was available and current and was therefore included in the EPD study. However, Structurlam was purchased by Mercer International in 2023.

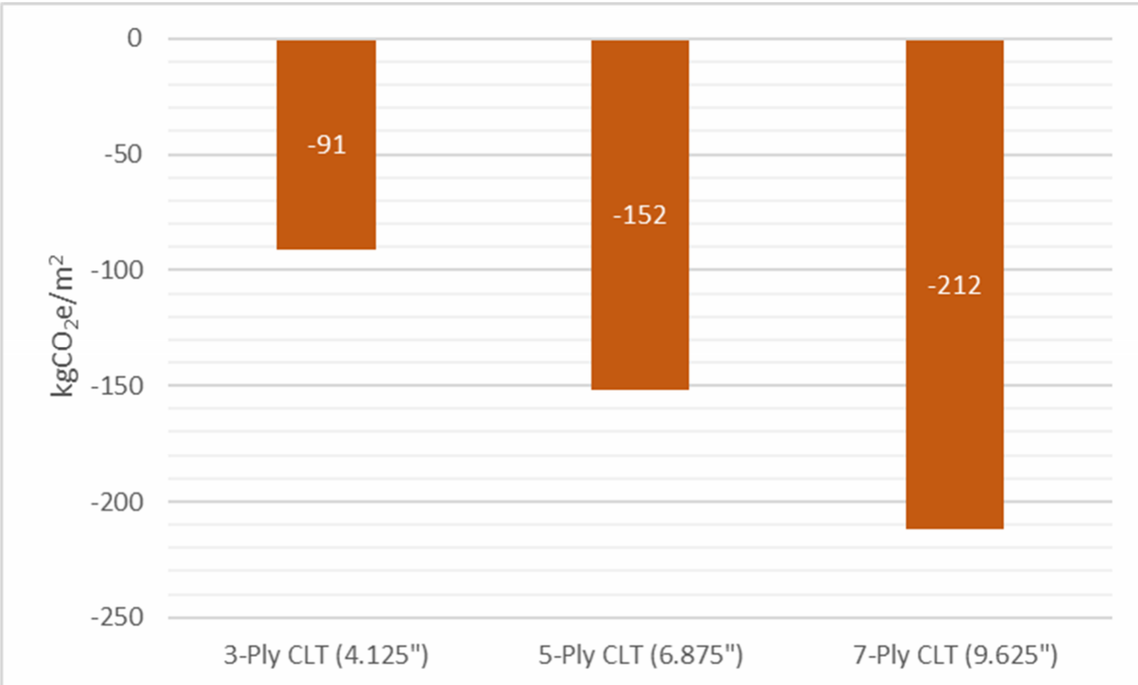

Figure 13 - Maximum Stored Biogenic Carbon Potential of CLT

Alternate GWP Data and Reduction Potential:

This section describes alternate GWP data scenarios and pathways for potential embodied carbon impact reductions of the materials and components themselves. These potential embodied carbon impact reductions do not affect the design of the structural assemblies but can significantly alter the GWP of each system.

Steel

Industry average EPDs could be used to calculate a more generic estimate of the embodied carbon impact of the steel material. The Steel Deck Institute (SDI), Steel Joist Institute (SJI), and American Institute of Steel Construction (AISC) have published Industry Average EPDs that capture a weighted average of contributing product manufacturers in the United States. Nucor is a contributor to the Industry Average EPDs. See Table 2 for industry average EPDs for steel products and Figure 14, illustrating the differences between Nucor and Industry Average GWP values.

Structural Component	EPD Name	EPD Owner	A1-A3 Total GWP (kgCO2e/Declared Unit)	EPD Date
Steel Decking	Steel Deck, Industry Wide	Steel Deck Institute (SDI)	2325.1 / 1000kg	January 21 2022
Steel Joists	Open Web Steel Joists and Joist Girders, Industry Wide	Steel Joist Institute (SJI)	1437.1 / 1000kg	January 21 2022
Steel WF Beams	Fabricated Hot-Rolled Structural Steel Sections, Industry Wide	American Institute of Steel Construction (AISC)	1221.3 / 1000kg	January 1 2021

Table 2 - Industry Average Steel EPDs

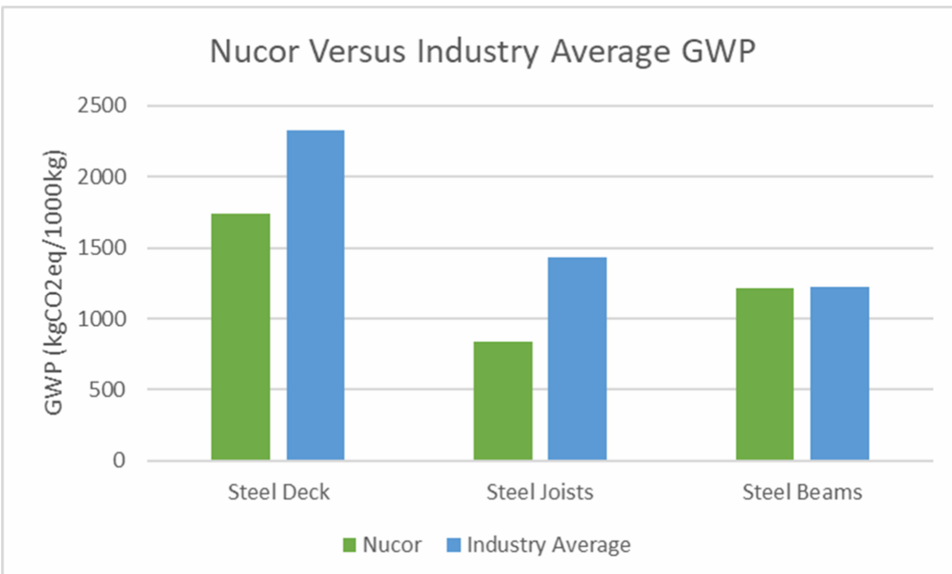

Figure 14 - Nucor versus Industry Average GWP

The embodied carbon impact of steel beam products is comparable between Nucor and Industry Average EPDs. The Industry Average GWP versus the Nucor products has an increase of 25% GWP impact for steel deck and 40% for steel joists. This change can be attributed to two main factors. First, 98.5% of Nucor's raw steel comes from recycled content, which results in a ~30% decrease in embodied carbon in the A1 (Raw Material Supply) stage compared to the industry average. Secondly, the industry average EPD was published in January 2022 and was based on manufacturer data (including Nucor) from 2019 through 2020, whereas the latest Nucor EPD was published in June 2023. It is reasonable to assume the Industry Average GWP value would decrease if the Industry Average GWP is recalculated using current data from manufacturers. Due to the differences of published date of the Nucor EPD's vs the Industry Average EPD's, no tabulation of results with Steel Industry Average EPD data is presented in this report.

Concrete

Concrete is a significant contributor to the embodied carbon of a building or structural system. The mix design specification and cement content influence the embodied carbon impact. Changes to the specification such as compressive strength, cement type, cement content, supplemental cementitious material (SCM) content, and density can have significant impacts on the embodied carbon content of the mix. For this study, 4000 psi normal weight concrete with 0% SCMs is utilized for the project baseline.

The majority of concrete's embodied carbon impact is due to its cement content. Reducing the cement content via SCM replacement, such as fly ash and slag, is the primary strategy currently used by the industry to reduce the embodied carbon impact of concrete. For the baseline normal weight 4000 psi concrete mix, the GWP can be reduced by approximately 40% by replacing cement content with SCMS, increasing from 0% SCMs to 50% SCMs. A second potential GWP reduction strategy is to use Type IL Portland Limestone Cement, instead of the typical Type I and Type II Ordinary Portland Cement. This replacement results in an approximate 10% reduction of the concrete's GWP. The combination of strategies (cement replacement via SCMs and using Type IL) can result in an approximate 50% embodied carbon reduction of the concrete.

Concrete mix design and technology is an ever-evolving industry. Some concrete batch plants have the capability to inject industrialized CO_2 into the ready mix, essentially storing CO_2 throughout the life of the concrete material. Many other process and material technologies are in various stages of testing and development, such as alternative cements, high pozzolanic cements, and various forms of carbon dioxide storage mechanisms. Proprietary mix designs utilizing a combination of specialized cements, admixtures, and aggregates have the potential to result in additional embodied carbon reduction. One preliminary self-declared (not a verified type III EPD) EPD reviewed during this study indicates reduction in global warming potential up to 63% are potentially possible.

This study includes supplemental results that assume a concrete mix with a 50% reduction in GWP from the project baseline (4000psi with 0% SCM) is utilized. While many concrete suppliers are able to supply such a mix, this level of GWP reduction may not be feasible in all markets.

Structural System Depth

Structural System depth is an important aspect to consider as an increase in structural depth requires an increase in overall floor-to-floor height, which in turn increases building skin area, and with it both the cost and the GWP of the skin system. If a building is close to code allowable building height, an increase in floor-to-floor height may potentially limit the number of stories that can be accommodated. For this reason, the overall system depth is tabulated for each bay size and structural system type.

For conventional systems, an allowance of 3 ½” is included to account for an architectural ceiling assembly. For systems utilizing open web steel joists two potential system depths are possible: one depth assuming standard seated joist connections and one depth assuming flush framed connections. This study assumes industry standard seated connections are utilized when calculating system depth.

Predicted Cost

Cost is a major driver for almost all building projects. To determine the relative costs of each system, non-structural elements are required to be considered when they are anticipated to differ between systems. For example, it is assumed that for conventional systems an architectural ceiling assembly is utilized to conceal the structure. For hybrid systems, it is assumed that the structure remains exposed to the greatest extent possible. Reference the Floor Structure section in the commercial and residential bay studies sections, preceding pages, for a discussion of the materials included in each floor system.

Due to the large number of bay sizes and systems analyzed, approximate metrics are used in lieu of a detailed cost analysis for each bay size and system. Metrics utilized to determine costs are as presented in the table below.

System Component	Installed Cost	Unit
Structural Steel	$ 6,000.00	ton
Open Web Steel Joists	$ 6,500.00	ton
Steel Deck - 1.0C22	$ 7.50	sf
Steel Deck - 2VLI18	$ 9.20	sf
Steel Deck - 3N18	$ 9.45	sf
Steel Deck - 1.5B20	$ 8.00	sf
Concrete Fill - 3 1/2" NWT over 2" deck w/ WWF	$ 14.25	sf
Concrete Fill - 3" NWT over 1" deck w/ WWF	$ 13.75	sf
Concrete Fill - 3" NWT over CLT w/ WWF	$ 12.75	sf
Reduced GWP Concrete Fill - 3 1/2" NWT over 2" deck w/ WWF	$ 17.10	sf
Reduced GWP Concrete Fill - 3" NWT over 1" deck w/ WWF	$ 16.50	sf
Reduced GWP Concrete Fill - 3" NWT over CLT w/ WWF	$ 15.30	sf
Cross Laminated Timber - 3-Ply 4.125"	$ 22.75	sf
Cross Laminated Timber - 5-Ply 6.875"	$ 29.75	sf
Cross Laminated Timber - 7-Ply 9.625"	$ 37.75	sf

Table 3 - Approximate Cost Metrics

The above cost metrics are based on average costs in the Denver, Colorado market for a building of approximately 60,000sf. They represent sub-contractor bid costs and are exclusive of costs typically associated with the general contractor. Where possible the numbers are based on actual project bid data received between January 1 2023 and September 15 2023. Where actual bid data was not available, estimated costs were determined by subcontractors routinely involved in the construction of that system component. Obviously, the unit costs assumed for the purposes of this study are specific to the assumed project size, location, and assumed construction timeframe and actual project costs may vary considerably from the costs assumed for this study.

To estimate cost data for reduced GWP concrete utilizing 50% SCM's and type IL cement, cost data provided by ready mix concrete suppliers along with feedback from concrete subcontractors is utilized. We found that material costs for these mixes vary depending on supplier but range from 0-25% higher than for standard mixes. While in theory there should be no cost increase for placing and finishing, conversations with subtractors indicated that current costs were likely higher due to unfamiliarity with the product and in some markets a limited number of pre-qualified mix designs or availability of type IL cement. Therefore, we assumed a cost increase of 20% of the total in place concrete cost for these alternate mixes.

Bay Study Results

Detailed results for each bay study performed are included in tabular form in Appendices A-D:

- Appendix A: Commercial Floor Bay Study Results.
- Appendix B: Commercial Roof Bay Study Results.

- Appendix C: Residential Floor Bay Study Results.
- Appendix D: Residential Roof Bay Study Results.

In each of the following sections, results for embodied carbon content, system depth, and approximate cost are presented for each system type as a function of bay size in 3-dimensional graphs.

Options for 5-ply and 7-ply CLT are not shown graphically, as it was determined that these systems are unlikely to be selected based on cost of the thicker CLT and limitations on standard open web steel joist loading. Complete results for these systems are available in the Appendices.

Embodied Carbon Results

Analysis results for GWP impact are presented in the following figures for each framing system and bay size in units of $kgCO_2eq/m^2$. These charts do not include the stored biogenic carbon, which is indicated for each CLT type in the section "Embodied Carbon Impact" and are included in the appendices.

To present the comparative results in more detail, two common bay sizes were selected for both commercial and residential types. The bay sizes selected for commercial layouts range from 30 ft beam spans / 30 ft girder spans to 45 ft beam spans / 30 ft girder spans. The bay sizes selected for residential layouts range from 30 ft beam spans / 20 ft girder spans to 25 ft beam spans / 15 ft girder spans. The GWP impact of each system and its bay sizes are presented in individual graphs, see Figures 16-19 on the following pages. Next, the comparative results of specific bay sizes per system are presented in Figures 20-21.

The results for the commercial floor studies indicate larger bay sizes result in a higher GWP impact. The conventional OWSJ system is least affected by the increase in span, with a 19% increase in GWP from 25ft x 25ft bays to 50ft x 50ft bays. The hybrid 3-ply CLT on wide flange beams and girders is the most affected by an increase in span, with a 44% increase in GWP over the same range.

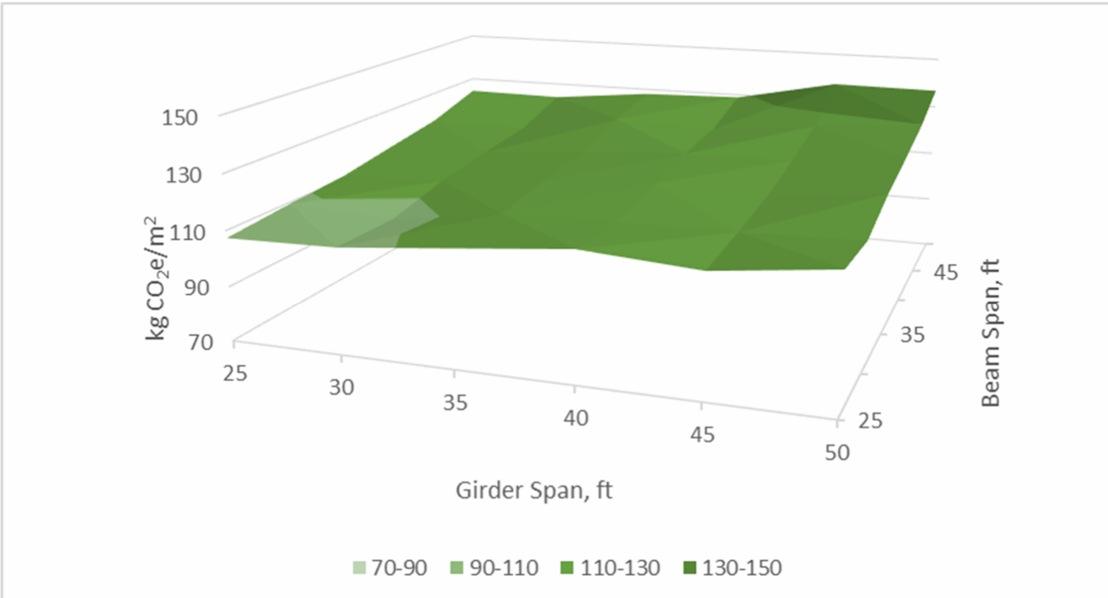

Figure 15 – Embodied Carbon, Commercial Conventional Composite Steel WF Floor

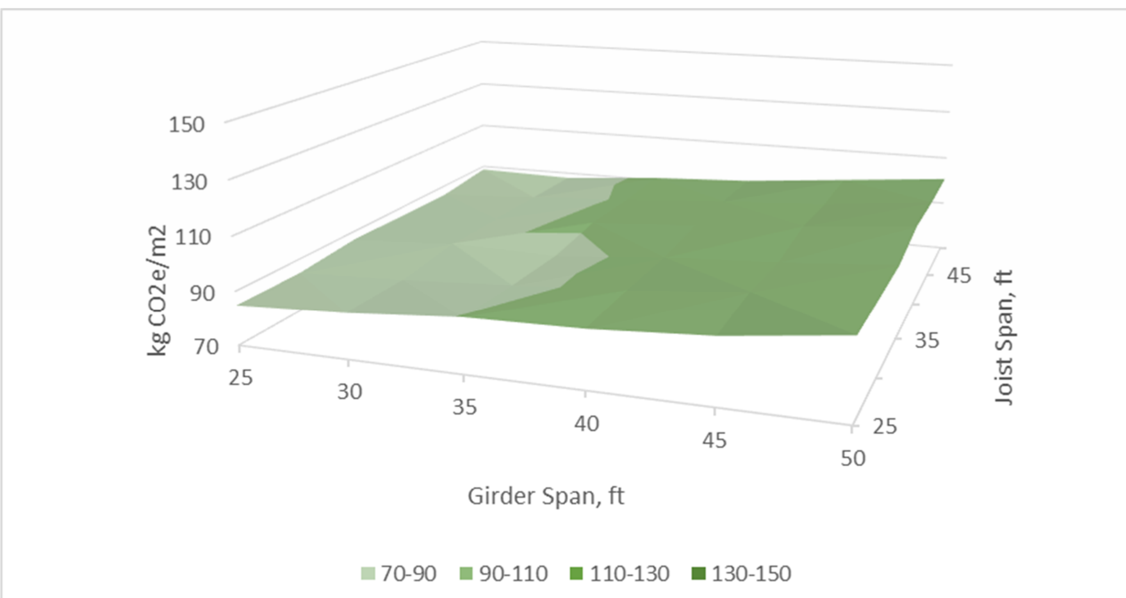

Figure 16 – Embodied Carbon, Commercial Conventional OWSJ Floor

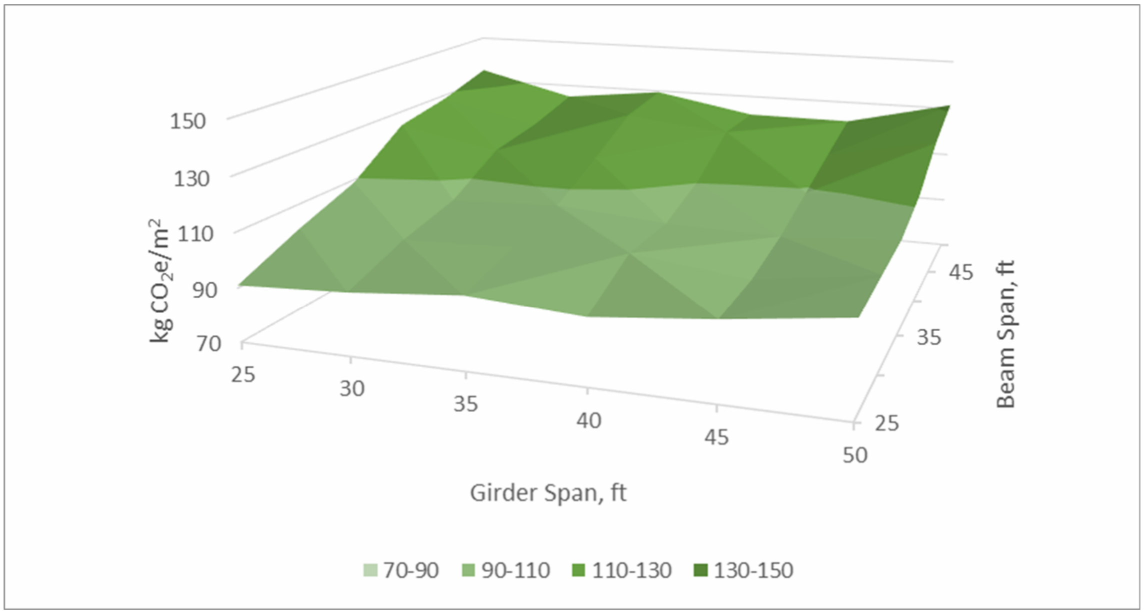

Figure 17 – Embodied Carbon, Commercial Hybrid Steel WF Floor with 3-ply CLT

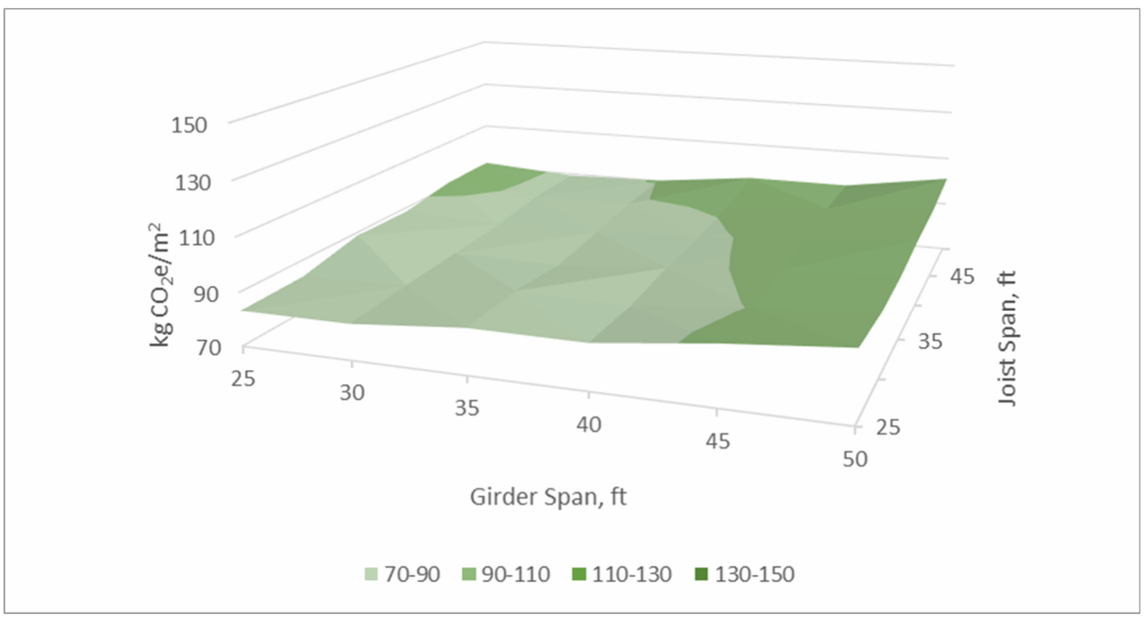

Figure 18- Embodied Carbon, Commercial Hybrid OWSJ Floor with 3-ply CLT

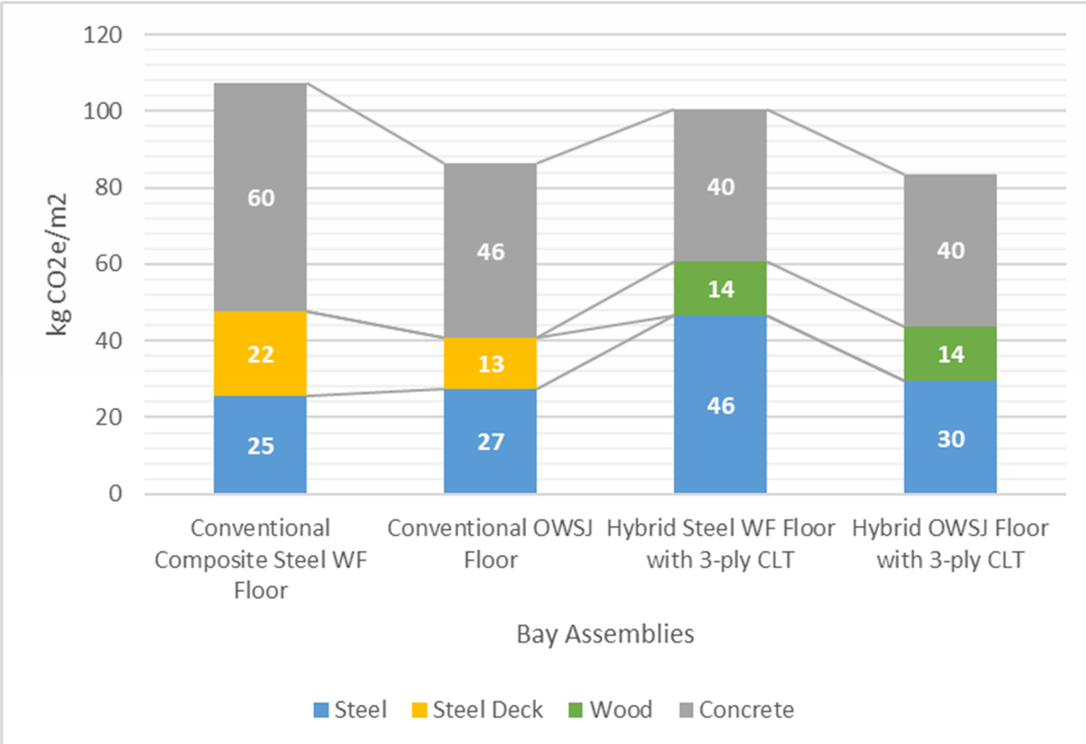

Figure 19 – Embodied Carbon Comparisons for a 30x30 ft Commercial Bay

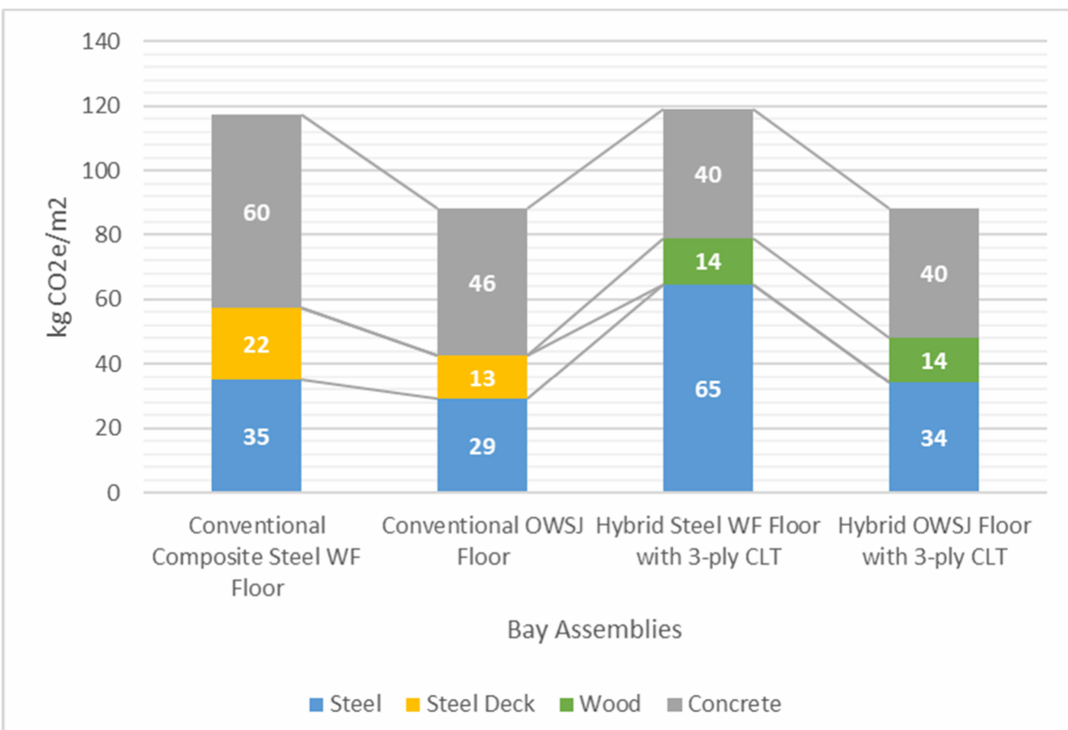

Figure 20 – Embodied Carbon Comparisons for a 30x45 ft Commercial Bay

The GWP impact of the commercial floor layouts is most influenced by:

1. The concrete topping slab provided above the CLT in the hybrid layouts is a significant contributor to the system GWP. For all hybrid bay sizes studied it accounted for 33-48% of the system GWP.
2. In comparing the conventional composite system with the hybrid WF Beam-Girder system, the efficiency in beam and girder size gained by composite design is significant. This efficiency does not exist in the hybrid system. For the 30x30 ft bay size, the GWP impact of the structural steel in the hybrid system increased by 84% over the composite system (the steel volume or weight increased by 84%). For the 30x45ft bay size, the increase is 88%, resulting in a greater embodied carbon content than the conventional system when stored biogenic carbon is not considered.
3. For the two bay sizes studied in detail, the GWP impact for the open web steel joists systems remains nearly constant. Review of the overall data indicates increasing the joist span has minimal effect on GWP, however increasing the girder span results in increased GWP impact.
4. For both bay sizes studied in detail and generally for most of the bay sizes in this study the conventional open web steel joist system equaled or outperformed the hybrid steel WF beam/girder system in terms of GWP impact (excluding the stored biogenic carbon).

Commercial Roof Layouts – Embodied Carbon

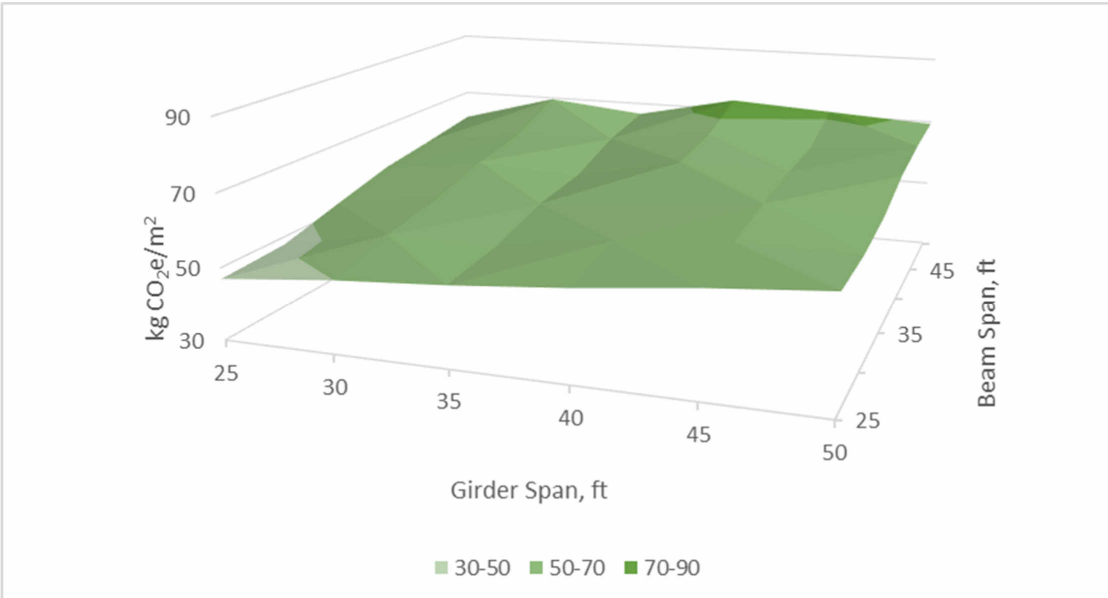

Figure 21 - Embodied Carbon - Commercial Conventional Steel WF Roof

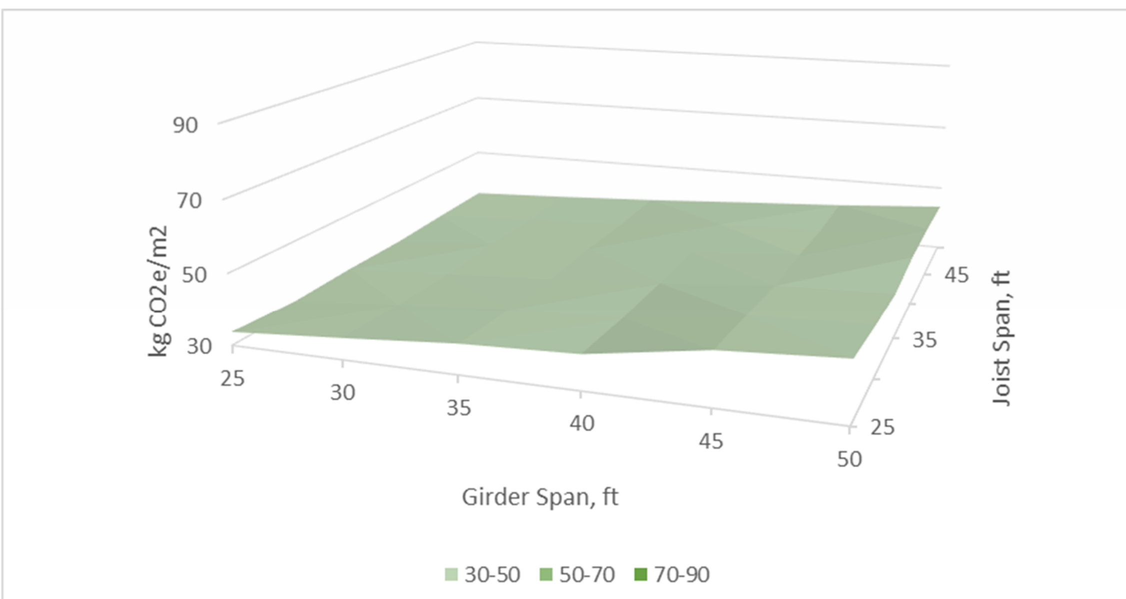

Figure 22 - Embodied Carbon - Commercial Conventional OWSJ Roof

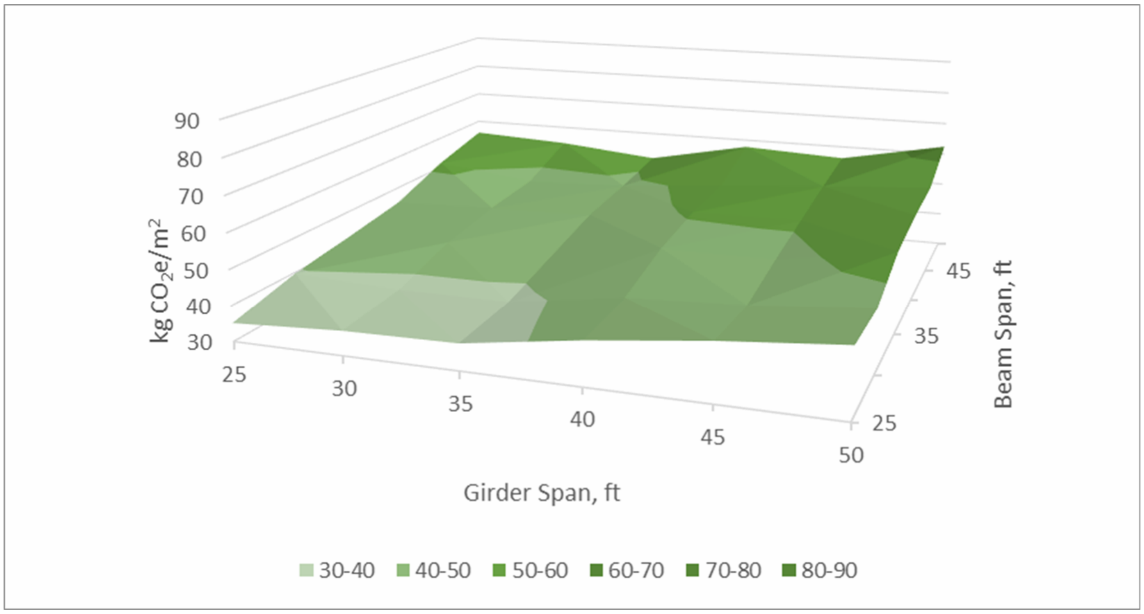

Figure 23 - Embodied Carbon - Commercial Hybrid Steel WF Roof with 3-Ply CLT

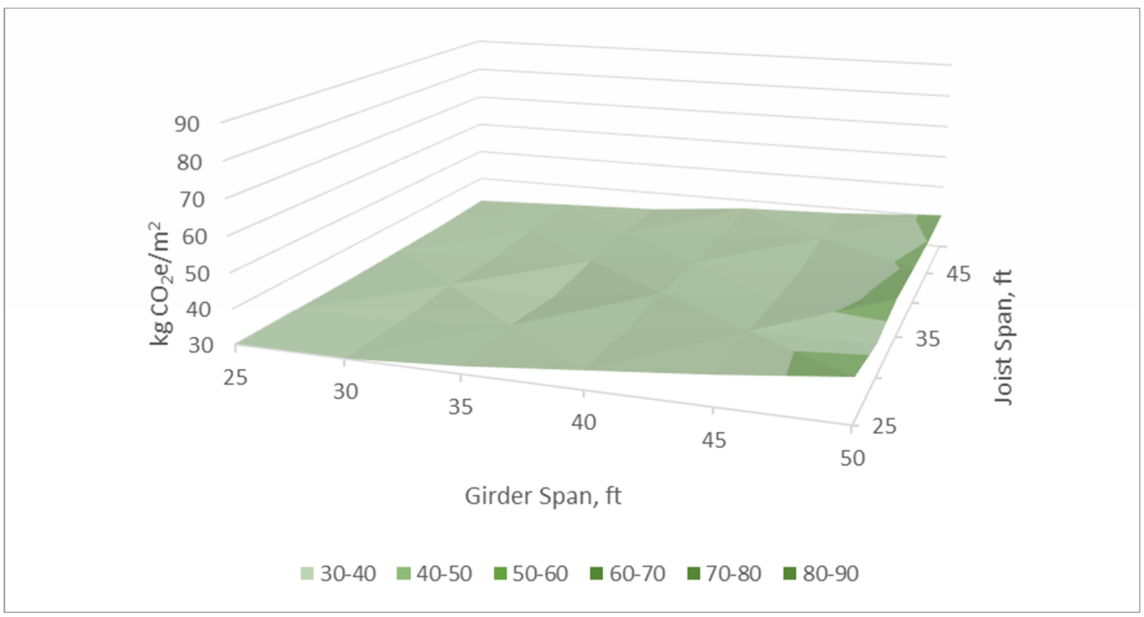

Figure 24 - Embodied Carbon - Commercial Hybrid OWSJ Roof with 3-Ply CLT

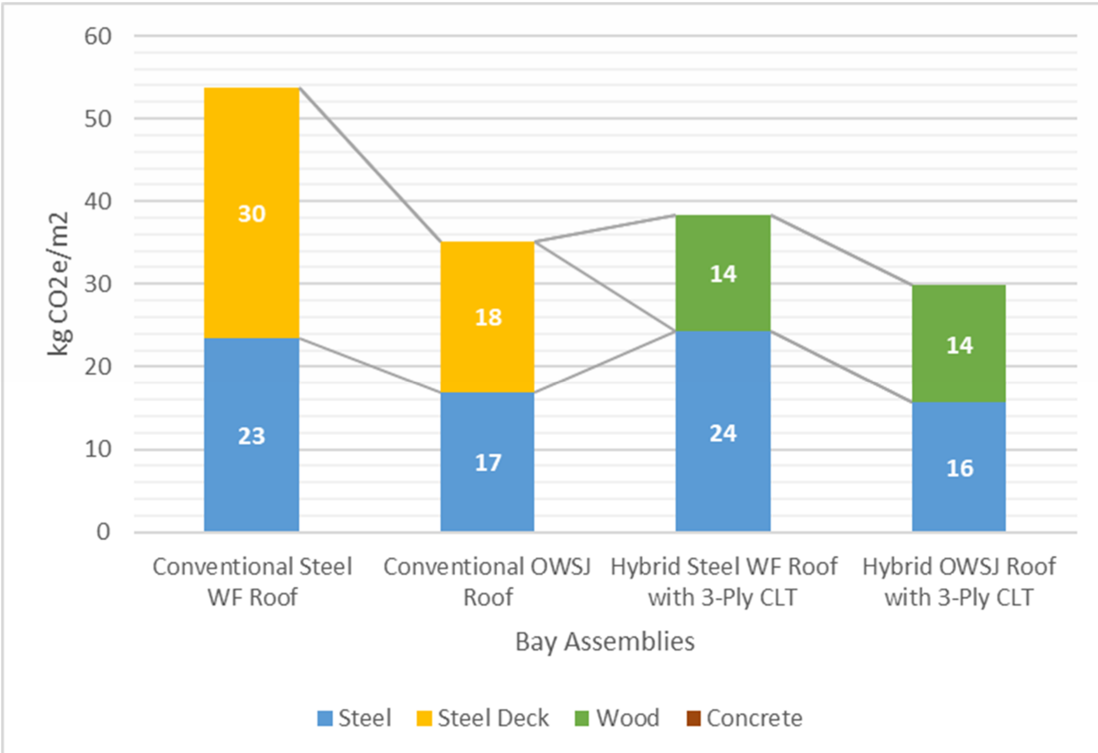

Figure 25 - Embodied Carbon Comparisons for a 30x30 ft Commercial Roof Bay

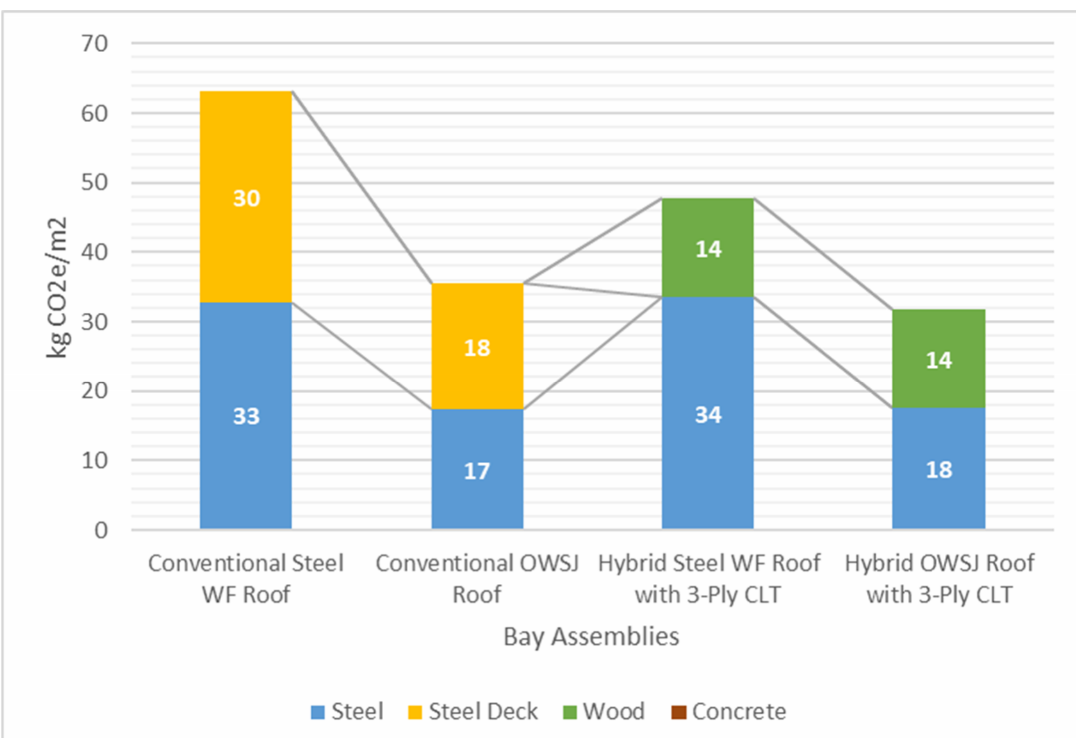

Figure 26 - Embodied Carbon Comparisons for a 30x45 ft Commercial Roof Bay

Commercial roof layouts exhibit similar trends to floor layouts, however with significantly lower embodied carbon due to the lack of concrete topping slabs. The one exception is that since the baseline conventional roof system with wide flange beams and girders utilizes roof deck in lieu of composite deck, the efficiency gains of composite design are not realized in the conventional system. Therefore, the reduction in GWP seen between the conventional and hybrid WF beam/girder systems can be attributed almost entirely to the reduction in embodied carbon of the 3-ply CLT as compared to the 3" 18ga deep rib roof deck. For the open web steel joist systems, the reductions were due to the reduced embodied carbon of the 3-ply CLT as compared to the metal deck and in some (but not all) bay sizes the increased open web steel joist efficiency associated with larger joist spacing. The 3-ply CLT is heavier than the metal deck, which for some bay sizes offset the increased efficiency of the larger joist spacings.

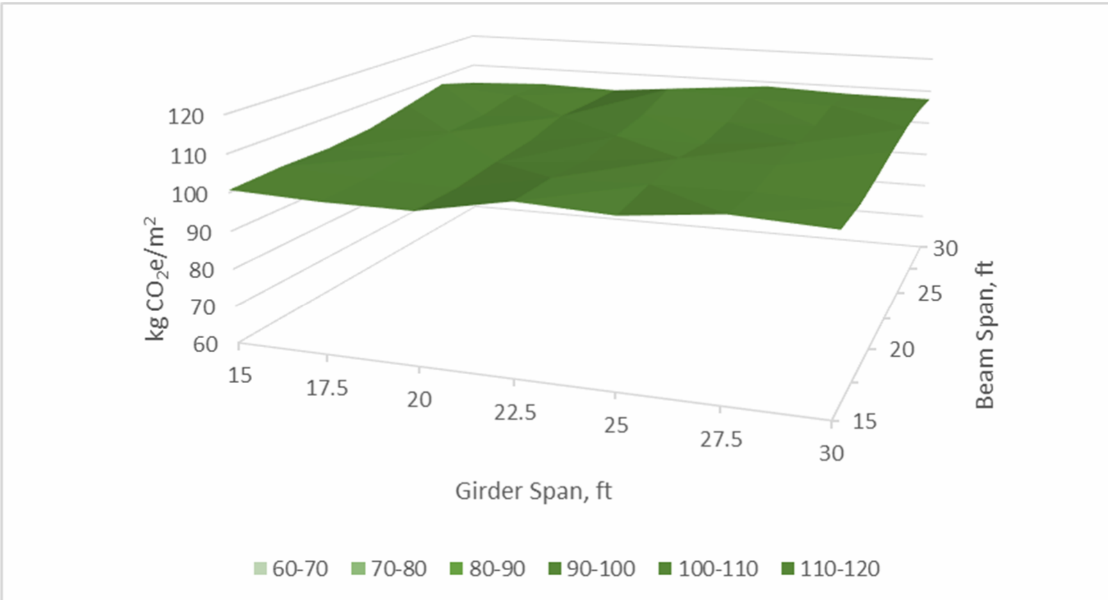

Figure 27 - Embodied Carbon - Residential Conventional Composite Steel WF Floor

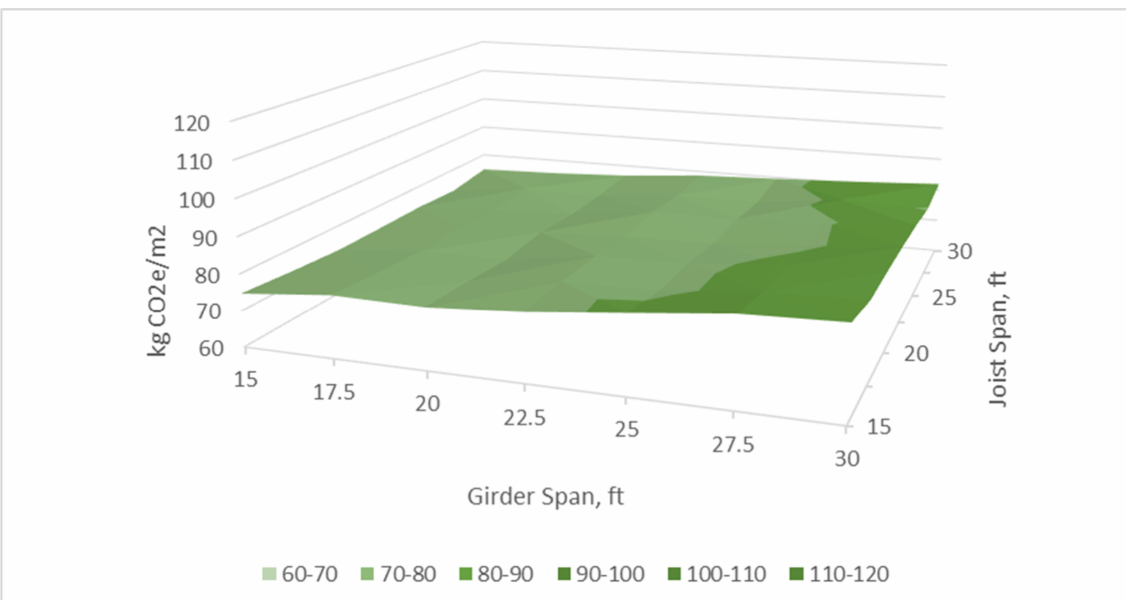

Figure 28 - Embodied Carbon, Residential Conventional OWSJ Floor

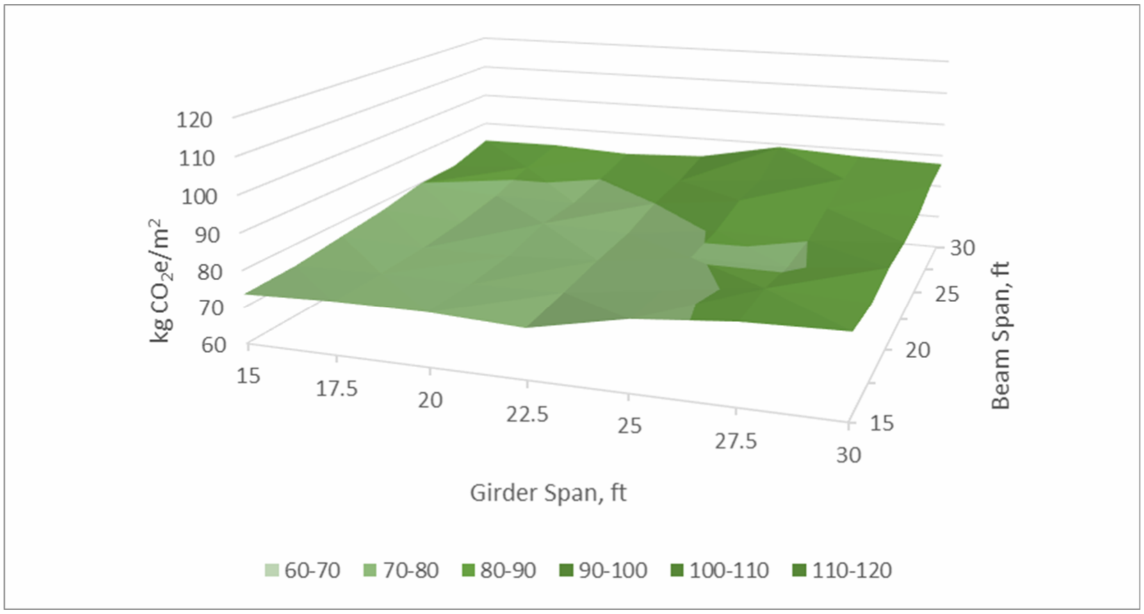

Figure 29 - Embodied Carbon, Residential Hybrid Steel WF Floor with 3-Ply CLT

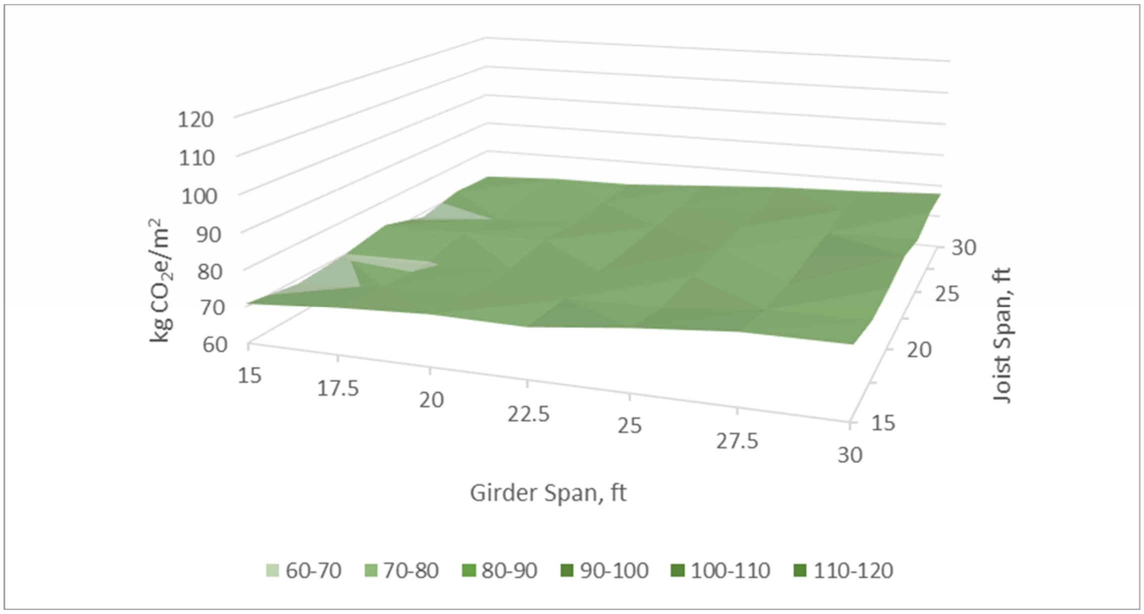

Figure 30 - Embodied Carbon, Residential Hybrid OWSJ Floor with 3-Ply CLT

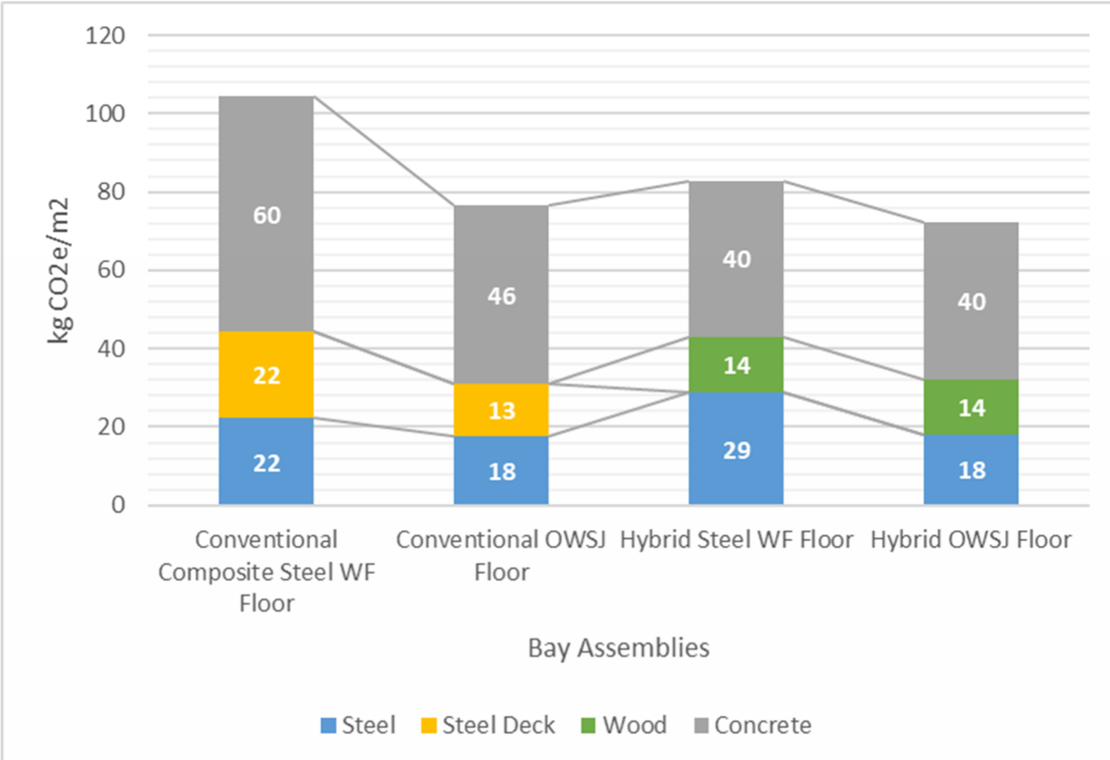

Figure 31 - Embodied Carbon Comparisons for a 20x30 ft Residential Bay

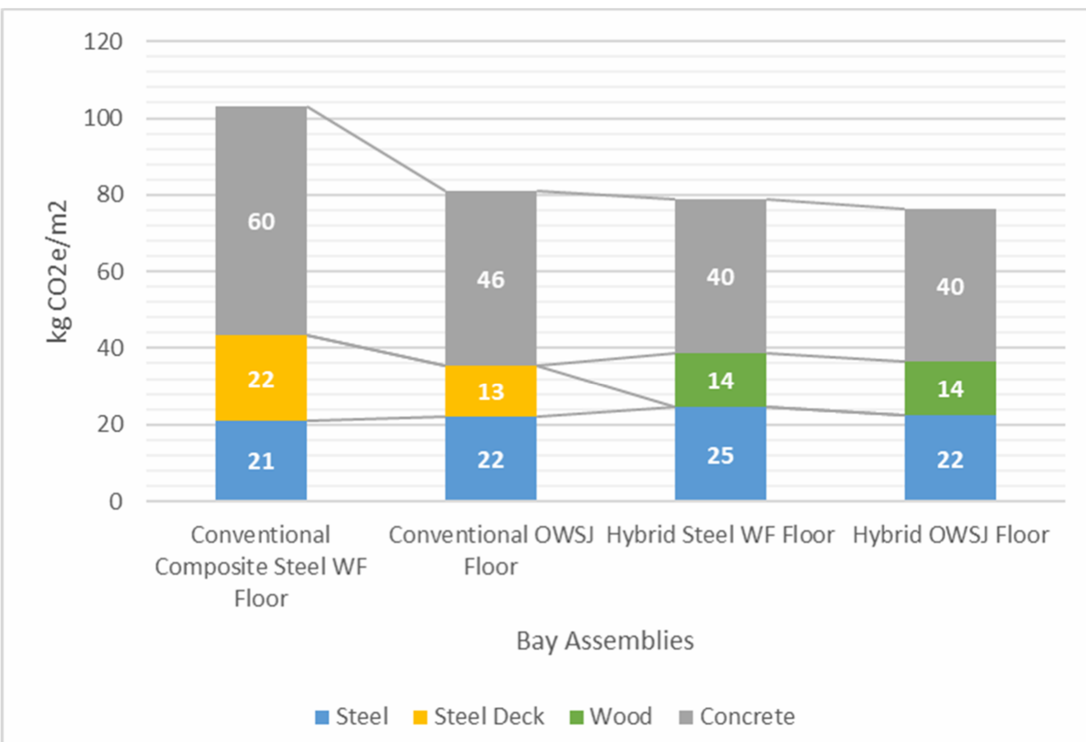

Figure 32 - Embodied Carbon Comparisons for a 25x15 ft Residential Bay

Review of the results for the residential floor bay sizes indicate that for smaller bay sizes there are slightly different trends when comparing the systems. With shorter beam and girder spans, the hybrid WF beam and girder system is closer in steel framing weight and embodied carbon content to the conventional system as compared to the long spans utilized in the commercial bay studies. At shorter spans, the efficiency gains from composite design are muted. Open web steel joist systems (both conventional and hybrid) tend to contain less embodied carbon than wide flange beam systems.

Figure 33 - Embodied Carbon - Residential Conventional Steel WF Roof

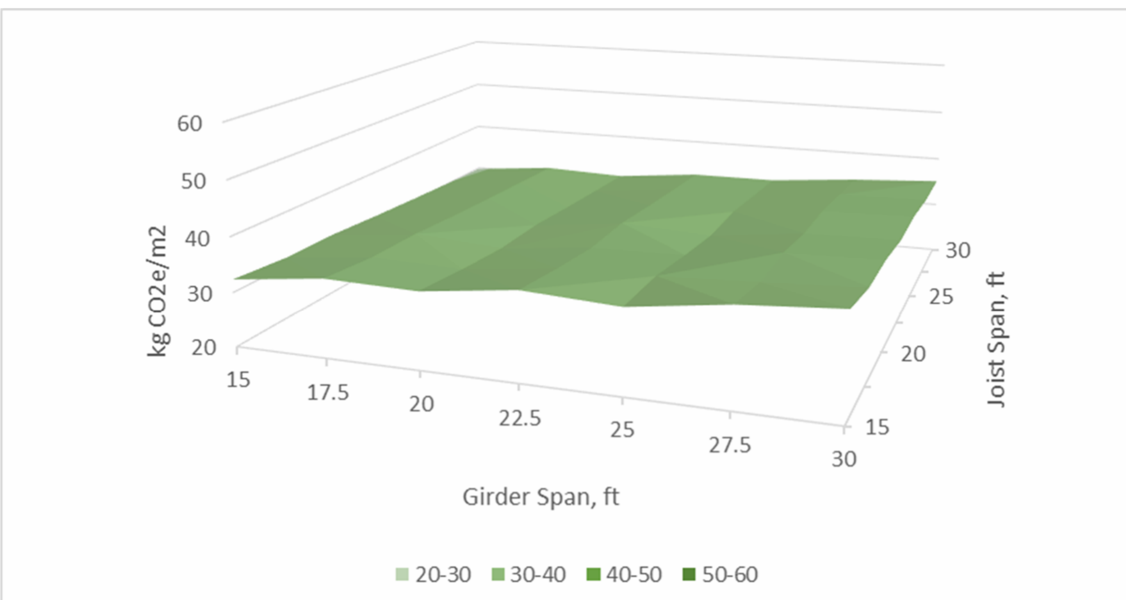

Figure 34 - Embodied Carbon - Residential Conventional OWSJ Roof

Figure 35 - Embodied Carbon - Residential Hybrid Steel WF Roof with 3-Ply CLT

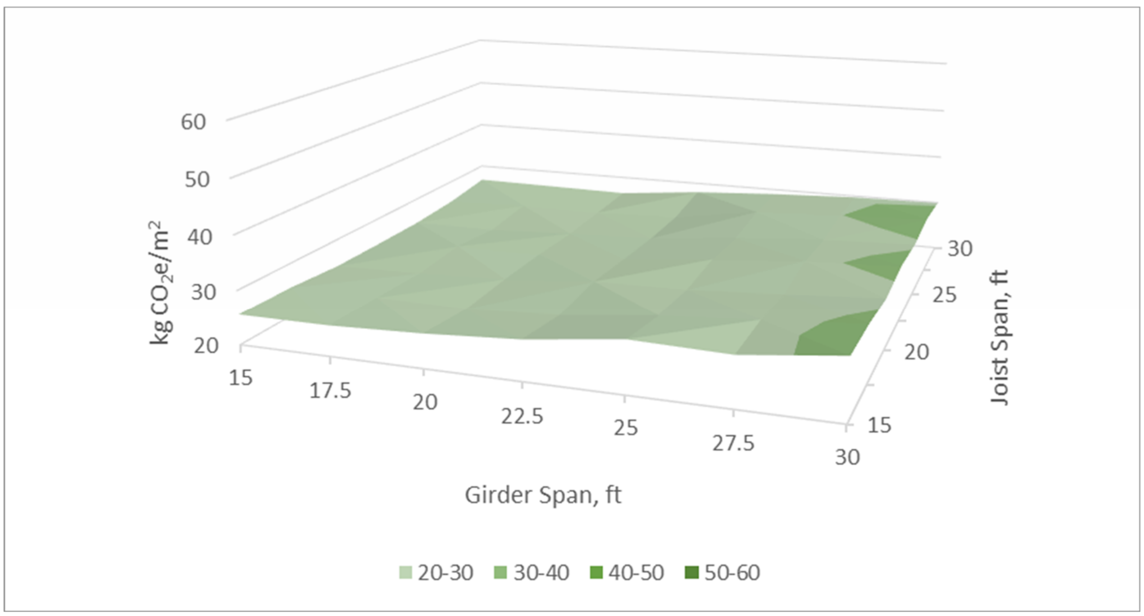

Figure 36 - Embodied Carbon - Residential Hybrid OWSJ Roof with 3-Ply CLT

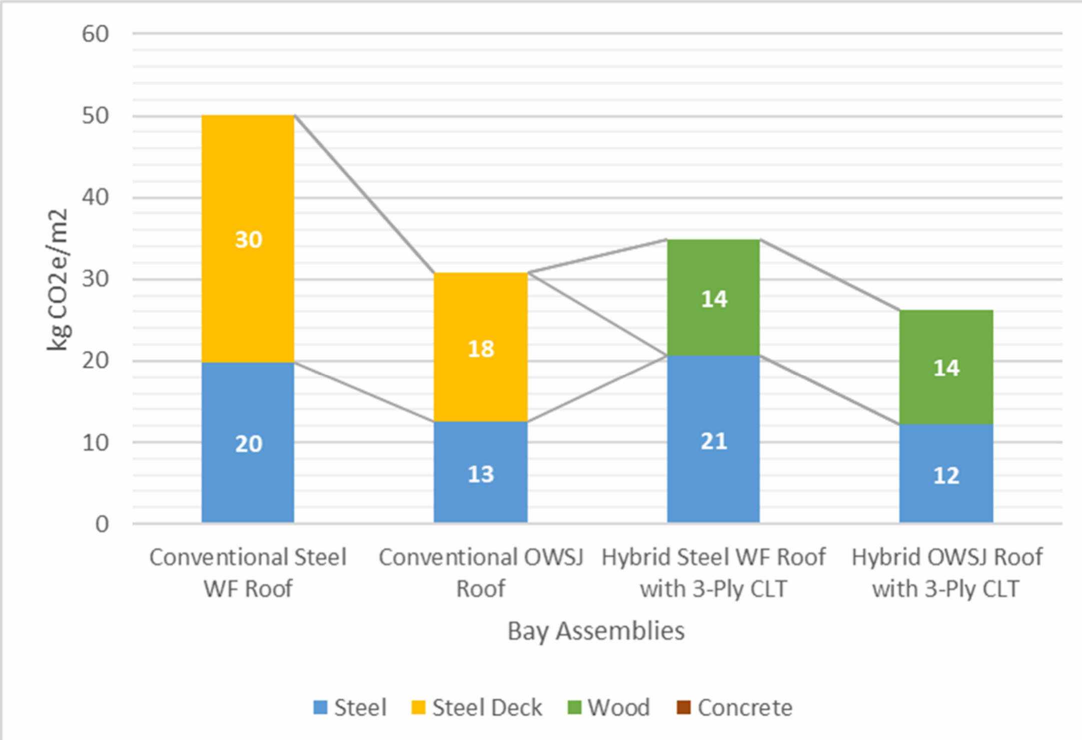

Figure 37 - Embodied Carbon Comparison for a 20x30 ft Residential Roof Bay

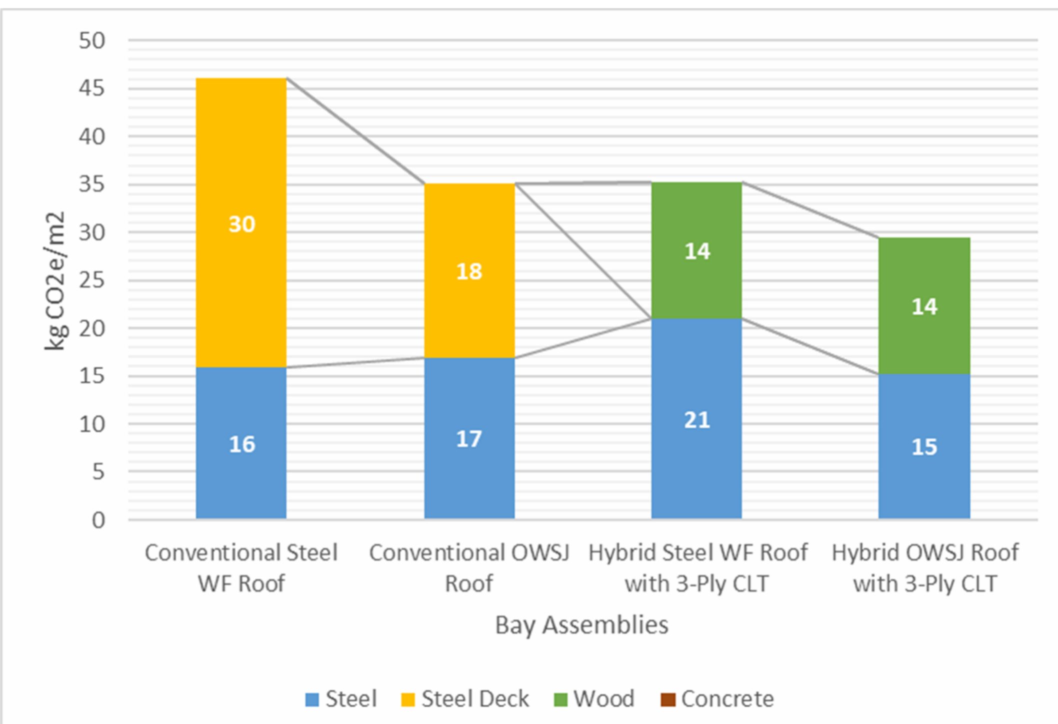

Figure 38 - Embodied Carbon Comparisons for a 25x15 ft Residential Roof Bay

Review of the results for residential roofs indicates similar trends to commercial roofs.

System Depth Results

Analysis results for the system depth, including assumed topping slab and ceiling systems, are presented in the following charts for each framing system.

The general and unsurprising trend is that larger bay sizes result in increased system depth. Generally wide flange beam / girder systems result in shallower system depth as compared to open web steel joist systems. However, this can be offset by the ability for utilities to run within the open webs of the joist systems.

Commercial Floor Layouts – System Depth

Analysis results for the system depth, including assumed topping slab and ceiling systems, are presented in figures 40-43 for each framing system.

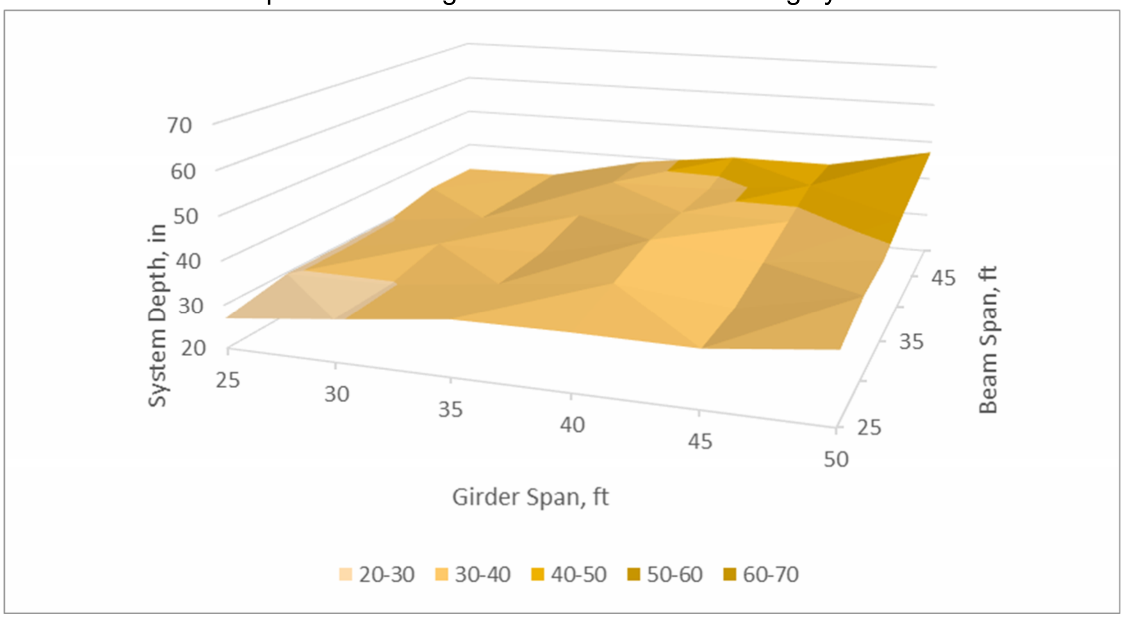

Figure 39 - System Depth - Commercial Conventional Composite Steel WF Floor

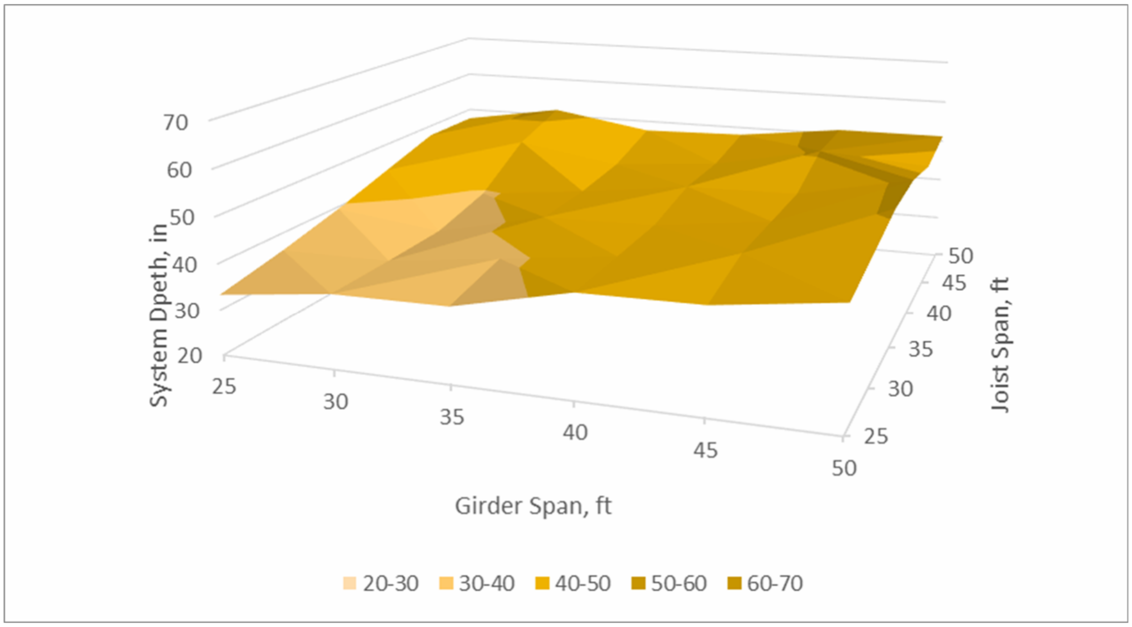

Figure 40 - System Depth, Commercial Conventional OWSJ Floor

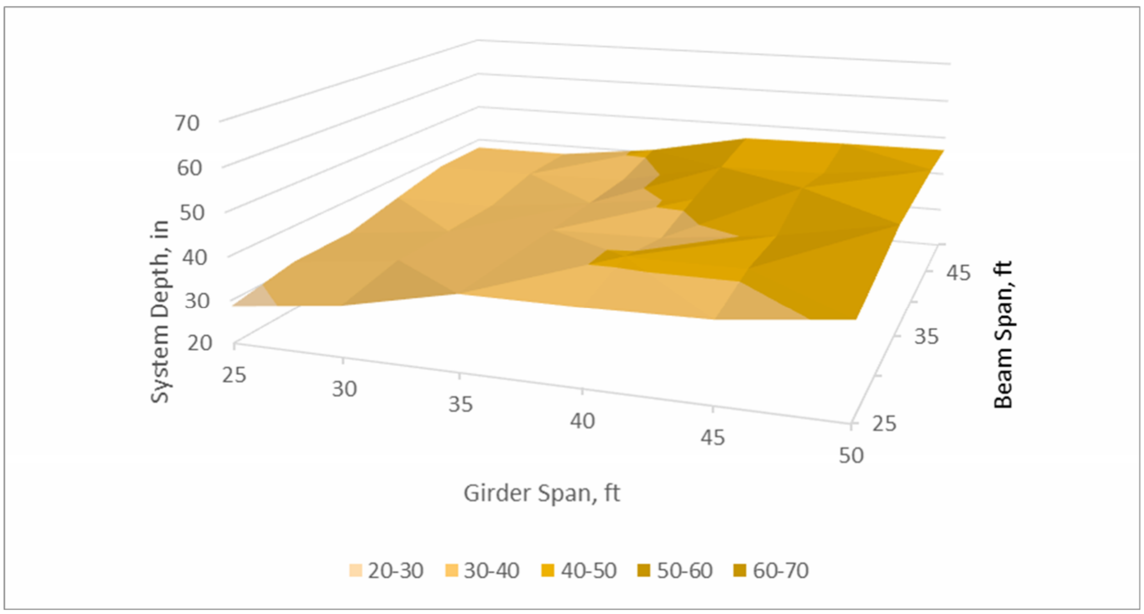

Figure 41 - System Depth, Commercial Hybrid Steel WF Floor with 3-Ply CLT

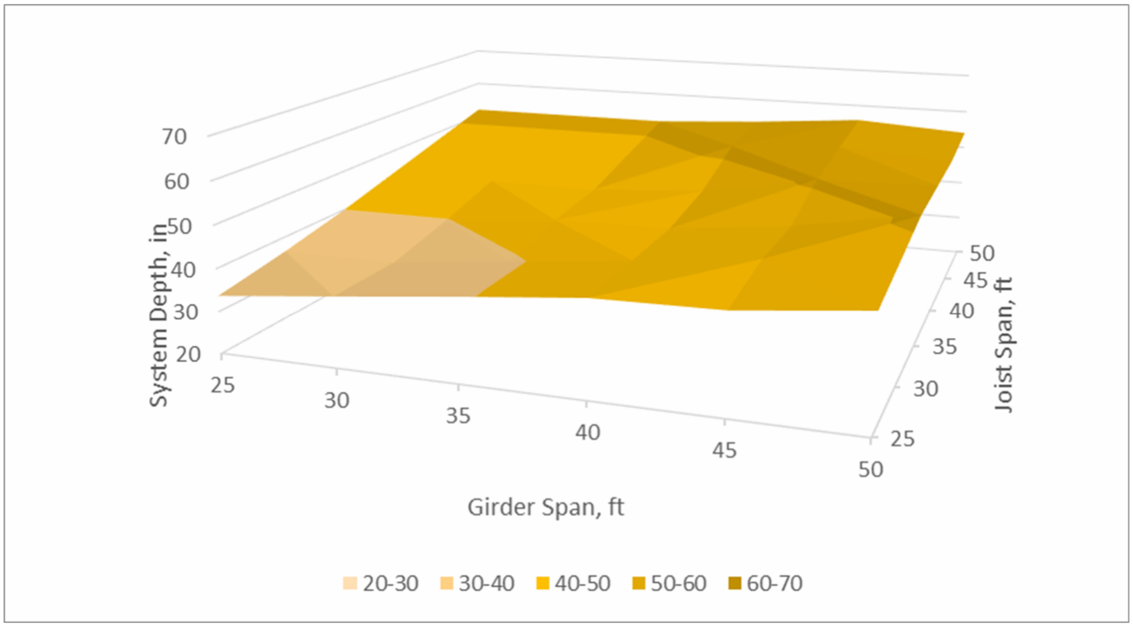

Figure 42 - System Depth, Commercial Hybrid OWSJ Floor with 3-Ply CLT

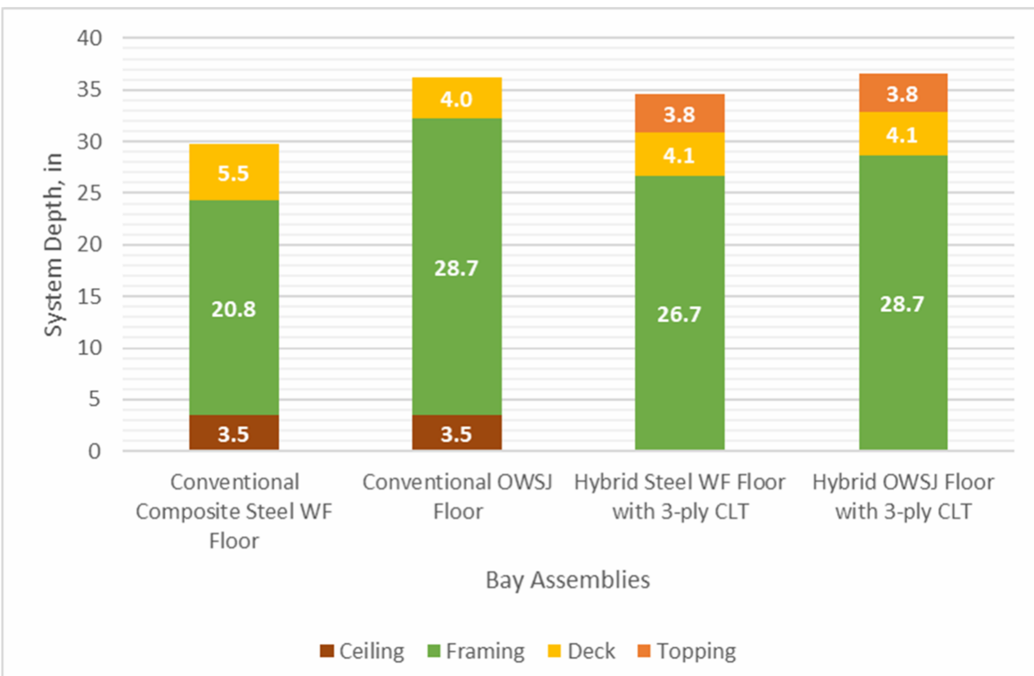

Figure 43 - System Depth Comparison for a 30x30 ft Commercial Floor Bay

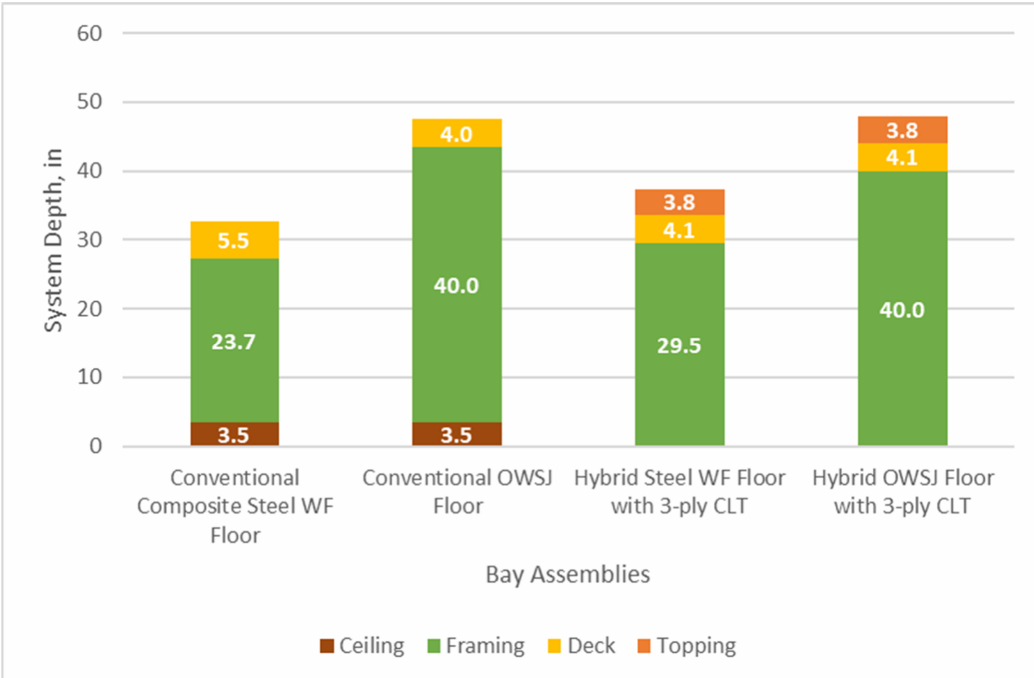

Figure 44 - System Depth Comparison for a 30x45 ft Commercial Floor Bay

Review of these graphs indicates the increased depths associated with open web steel joist systems as compared to wide flange beams. As bay size increases, this difference is increased. The hybrid systems utilizing wide flange beams are also deeper than the corresponding conventional systems. For systems utilizing OWSJ, depth is nearly identical between conventional and hybrid systems. It should be noted that beam and joist sizing for this study is based on selecting the lightest member for a given span and deck span, and system depth is not optimized for. Shallower system depth is possible in most cases with a tradeoff of greater member weight, increased GWP, and cost.

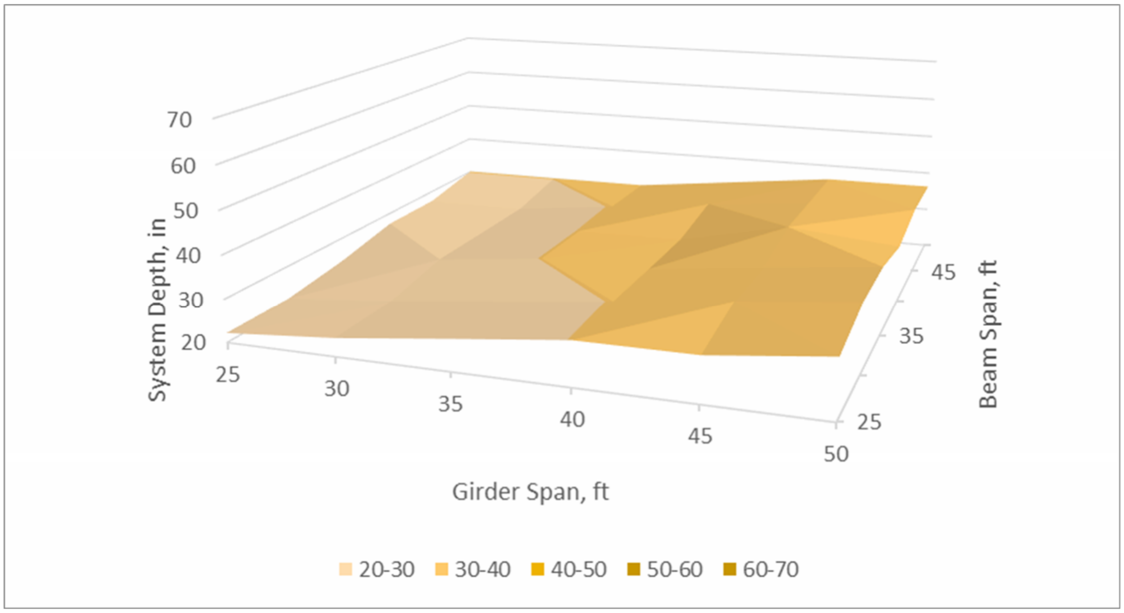

Figure 45 - System Depth, Commercial Convention Steel WF Roof

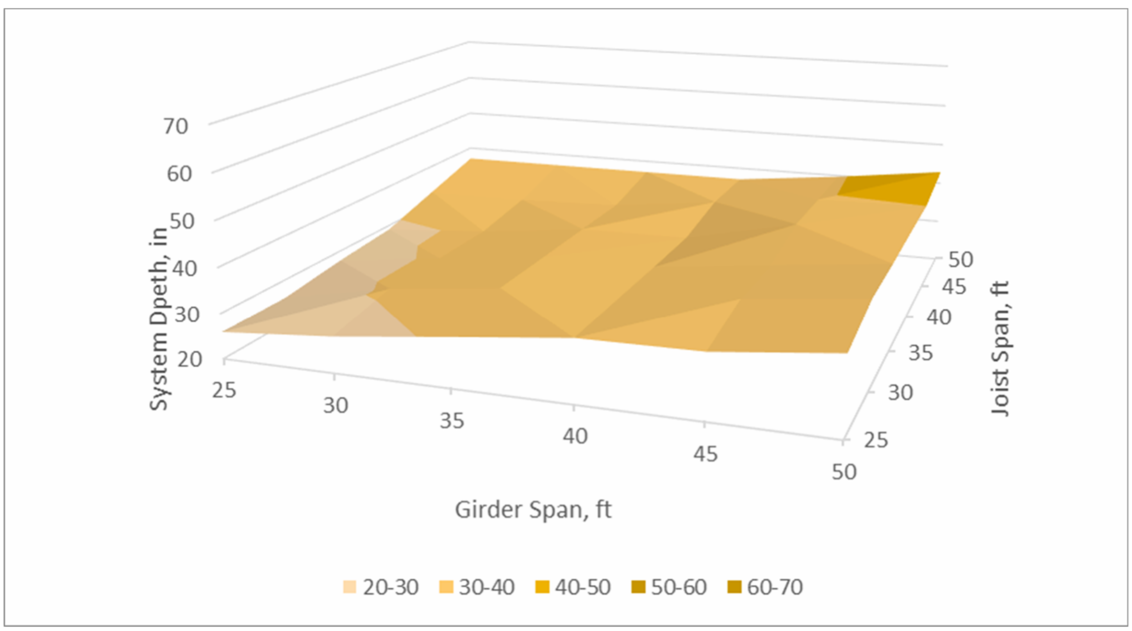

Figure 46 - System Depth, Commercial Conventional OWSJ Roof

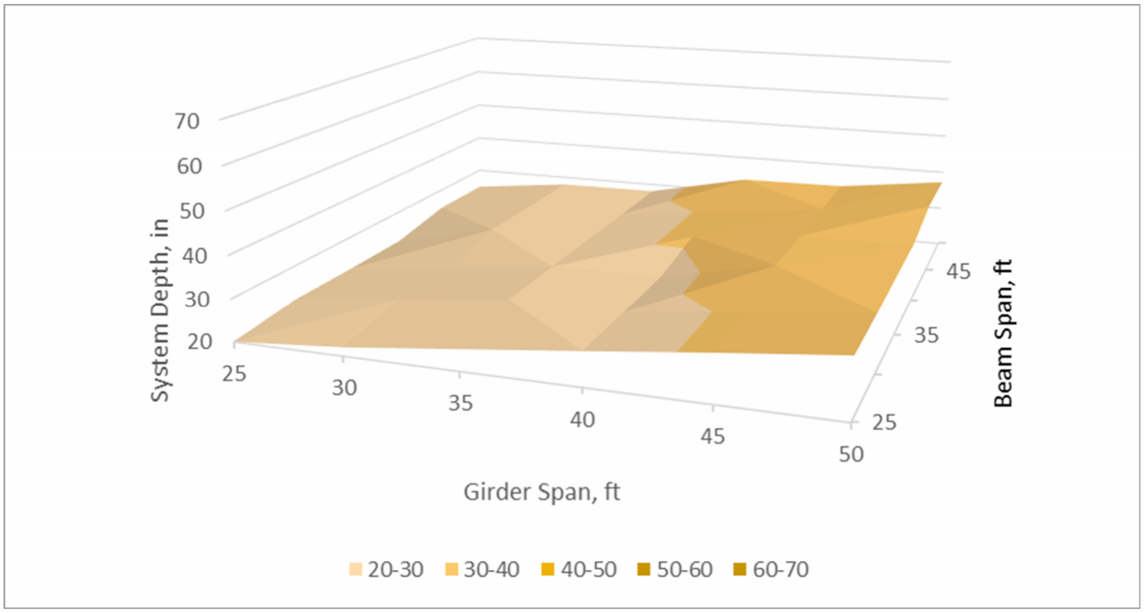

Figure 47 - System Depth, Commercial Hybrid Steel WF Roof with 3-Ply CLT

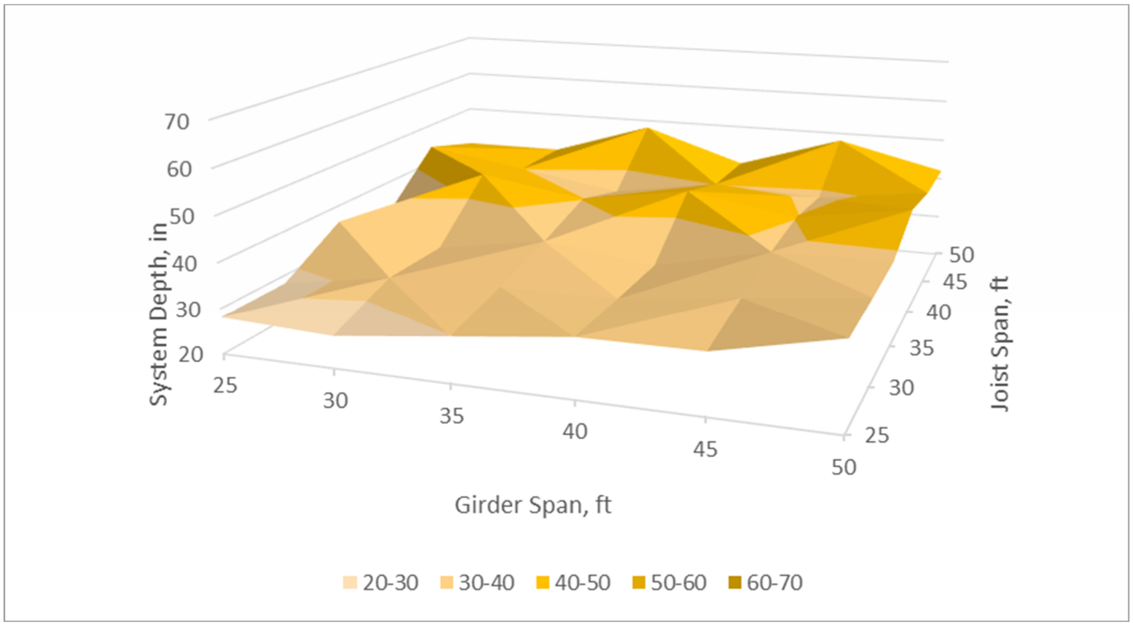

Figure 48 - System Depth, Commercial Hybrid OWSJ Roof with 3-Ply CLT

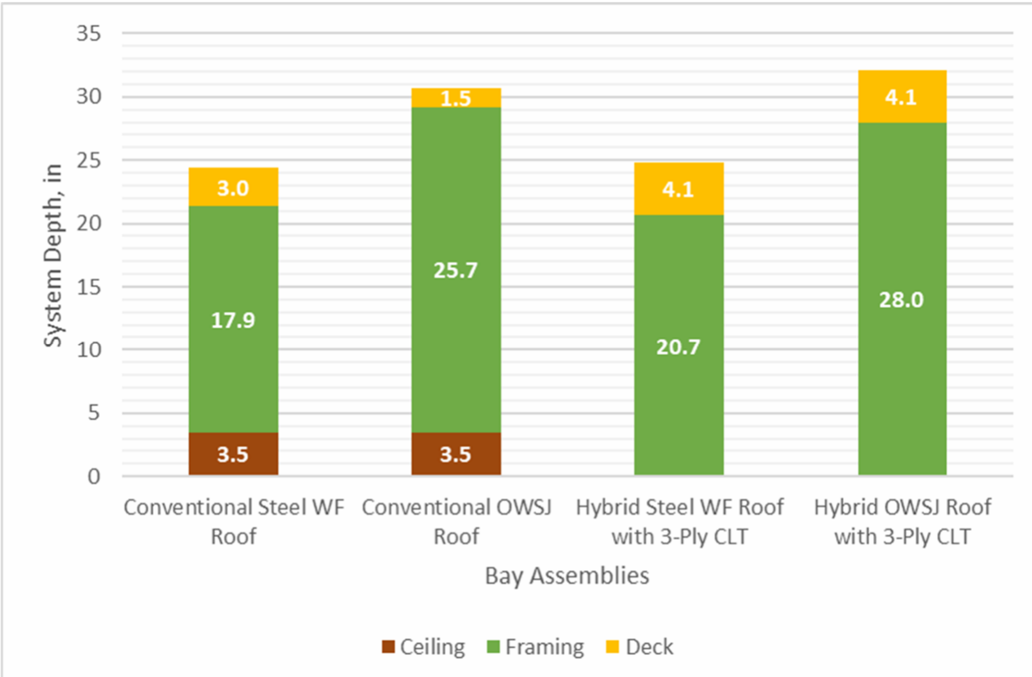

Figure 49 - System Depth Comparison for a 30x30 ft Commercial Roof Bay with 3-Ply CLT

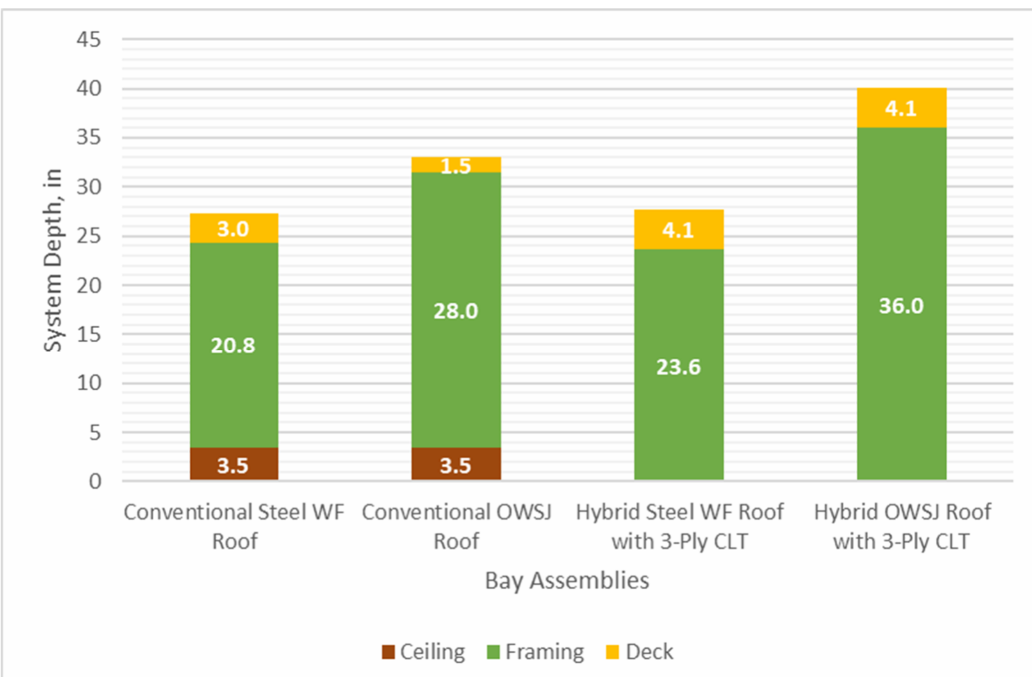

Figure 50 - System Depth Comparison for a 30x45 ft Commercial Roof Bay

Review of these graphs indicates that for wide flange beam and girder framing systems, a hybrid system results in similar depth to a conventional system. The increase in thickness of the CLT as compared to the metal deck is offset by the lack of a ceiling system. For the open web steel joist systems, the hybrid system resulted in an increase in framing depth. This is primary due to the increased spacing of the joists, which results in heavier and deeper open web steel joists.

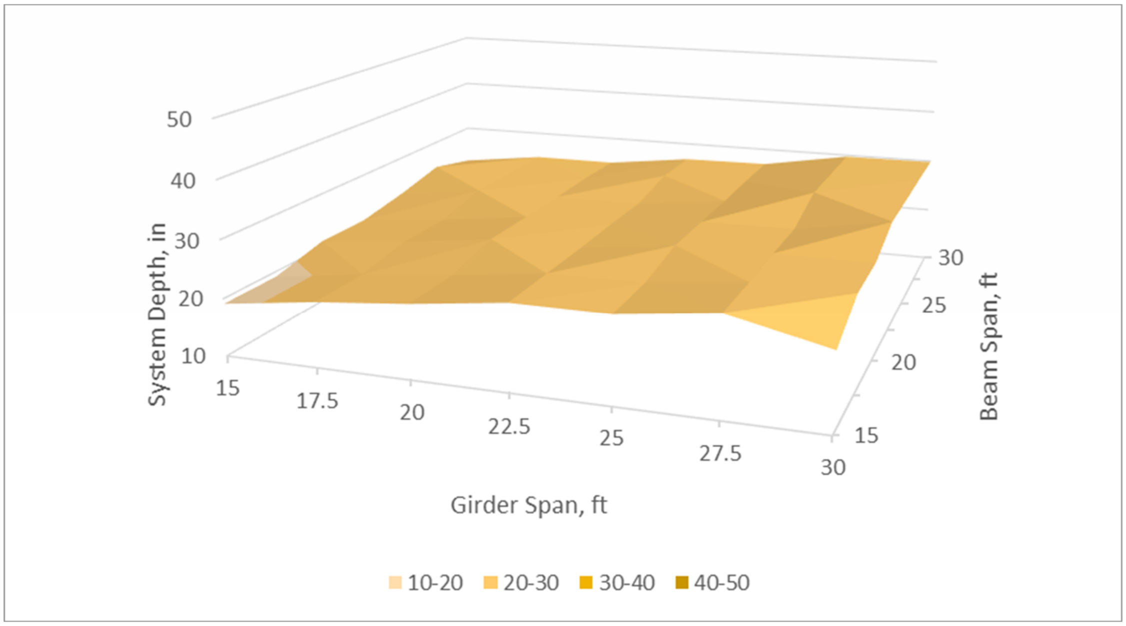

Figure 51 - System Depth, Residential Conventional Composite Steel WF Floor

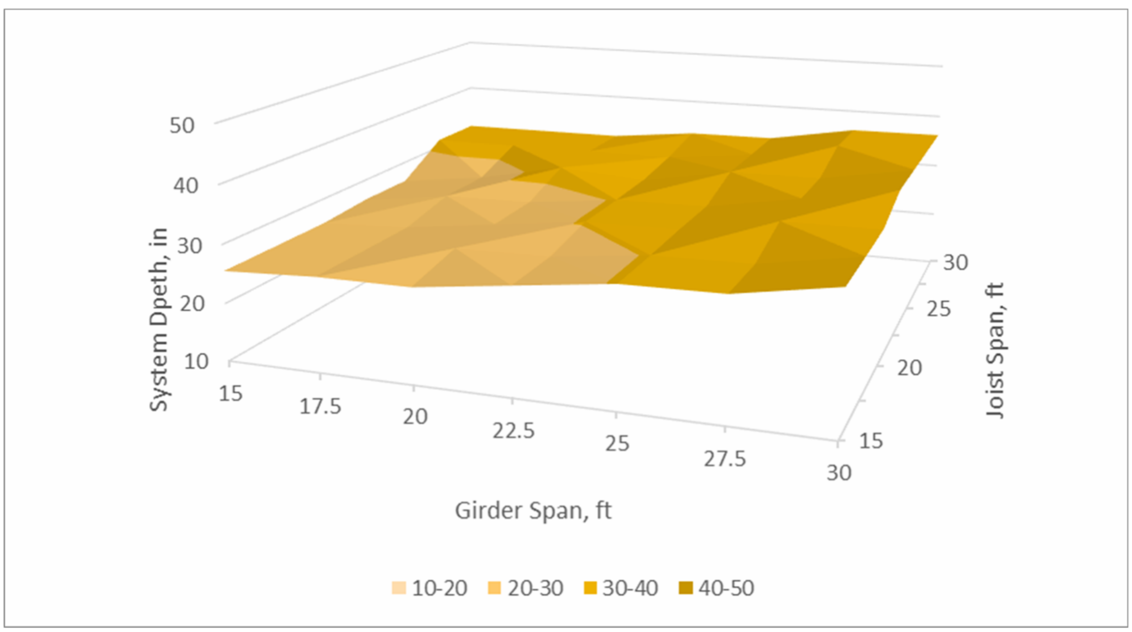

Figure 52 - System Depth, Residential Conventional OWSJ Floor

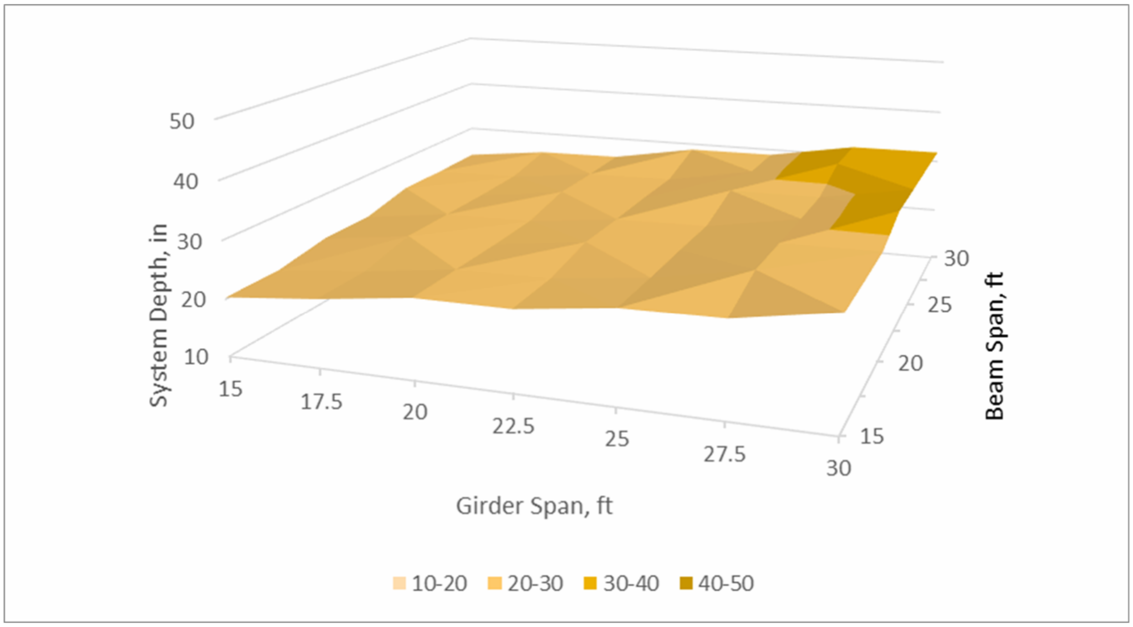

Figure 53 - System Depth, Residential Hybrid Steel WF Floor with 3-Ply CLT

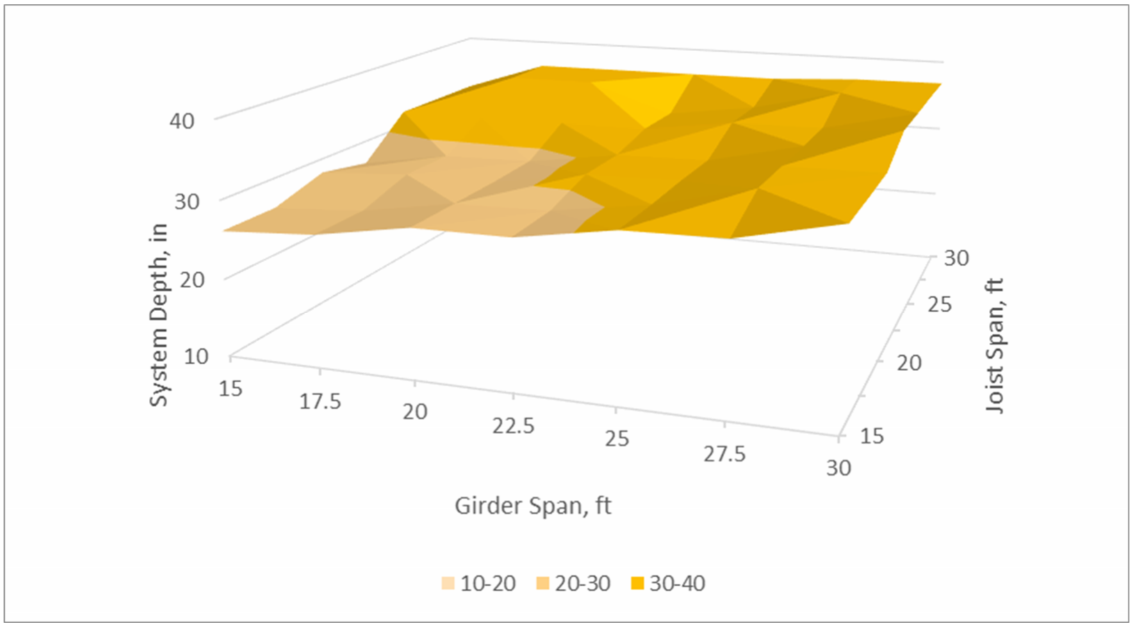

Figure 54 - System Depth, Residential Hybrid OWSJ Floor with 3-Ply CLT

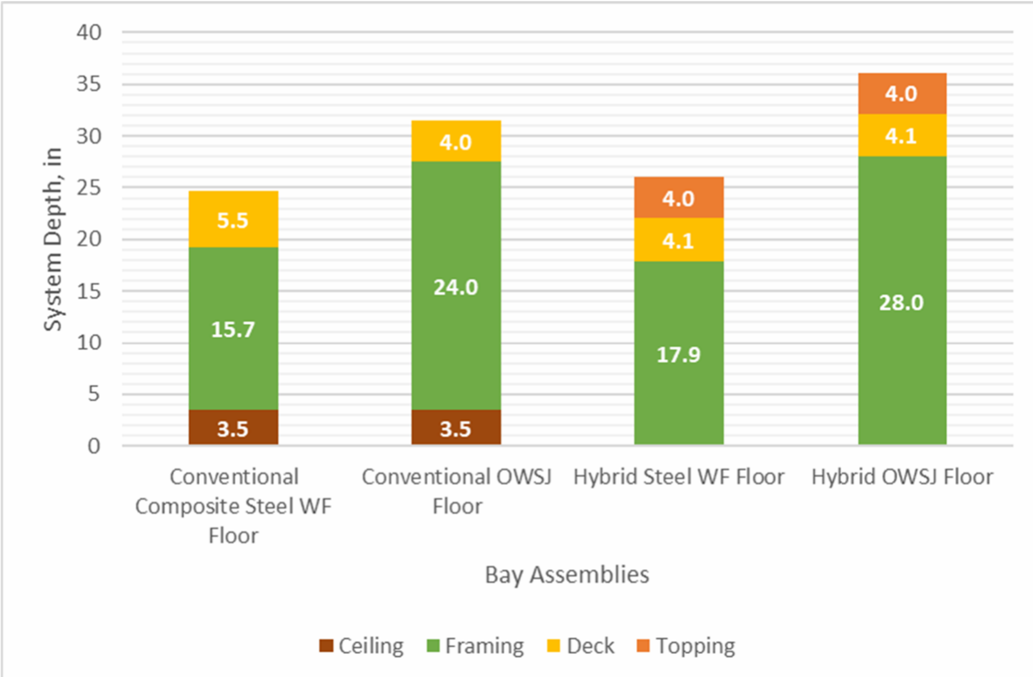

Figure 55 - System Depth Comparison for a 20x30 ft Residential Floor Bay

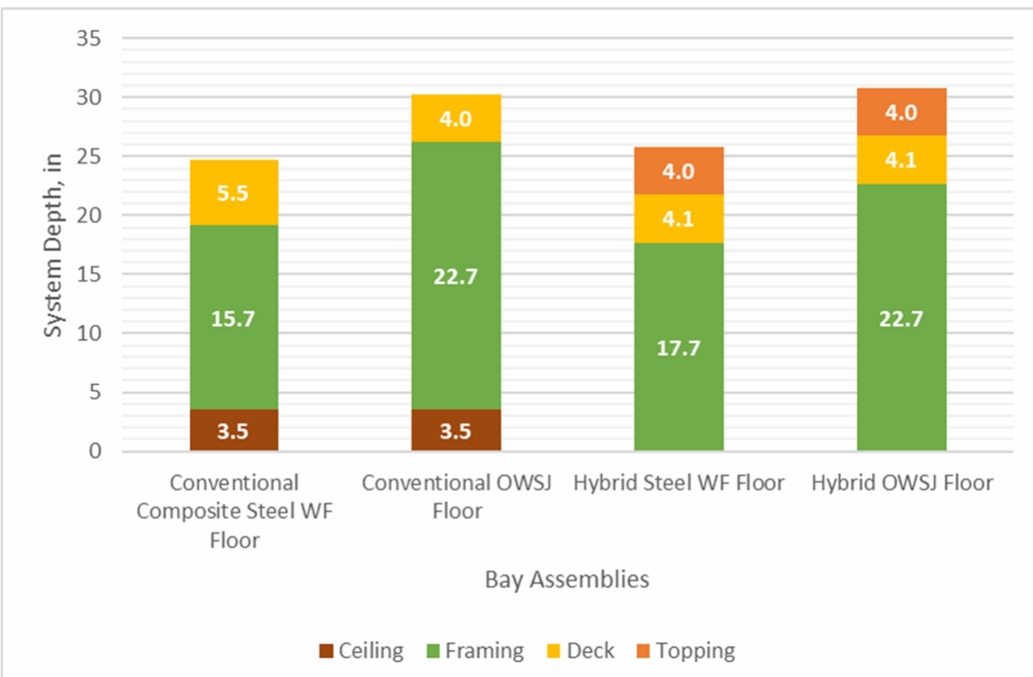

Figure 56 - System Depth Comparison for a 25x15 ft Residential Floor Bay

Review of these graphs indicates the increased depths associated with open web steel joist systems as compared to wide flange beams. The hybrid systems utilizing wide flange beams are slightly deeper than the corresponding conventional systems. For systems utilizing OWSJ, depth is generally deeper in the hybrid systems if joist depth is controlling over girder depth, and nearly identical if depth is driven by girder size.

Residential Roof Layouts – System Depth

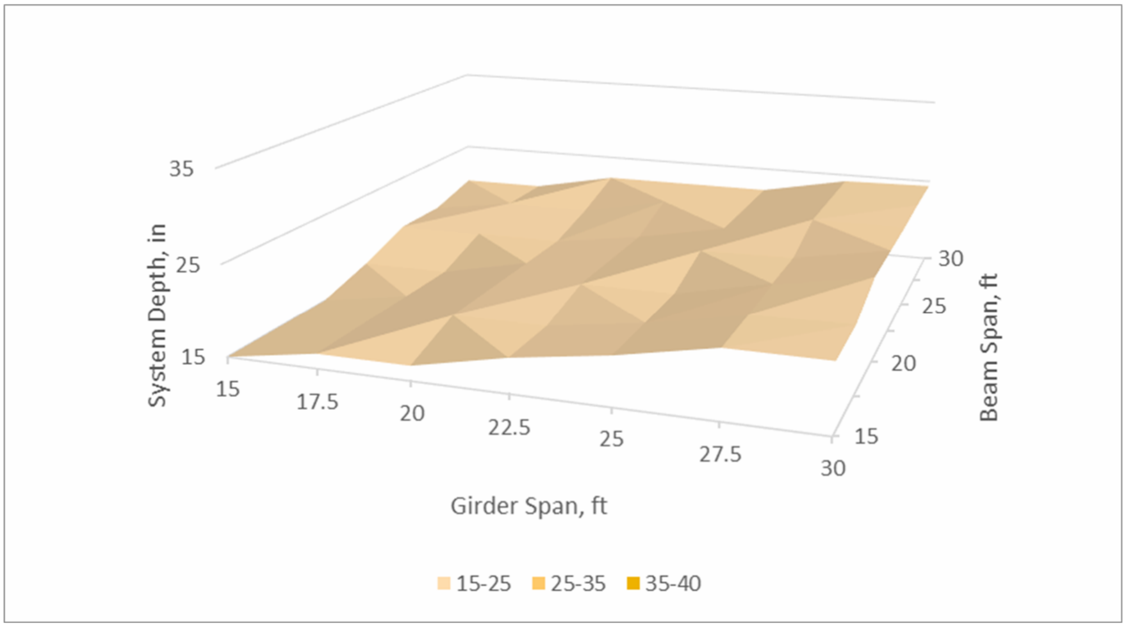

Figure 57 - System Depth, Residential Conventional Steel WF Roof

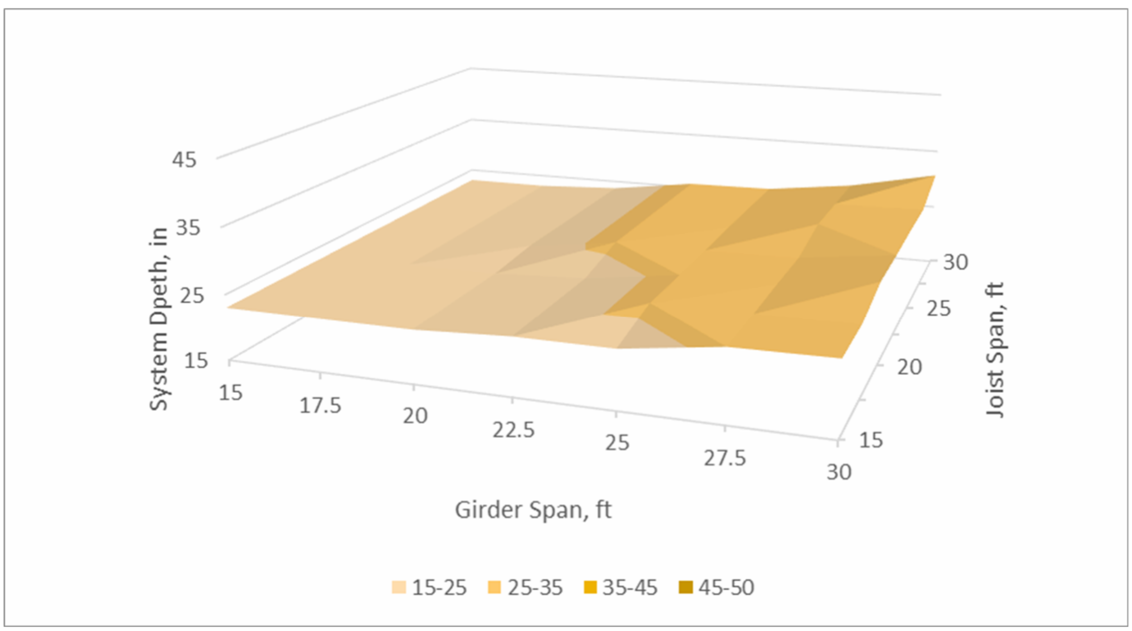

Figure 58 - System Depth, Residential Conventional OWSJ Roof

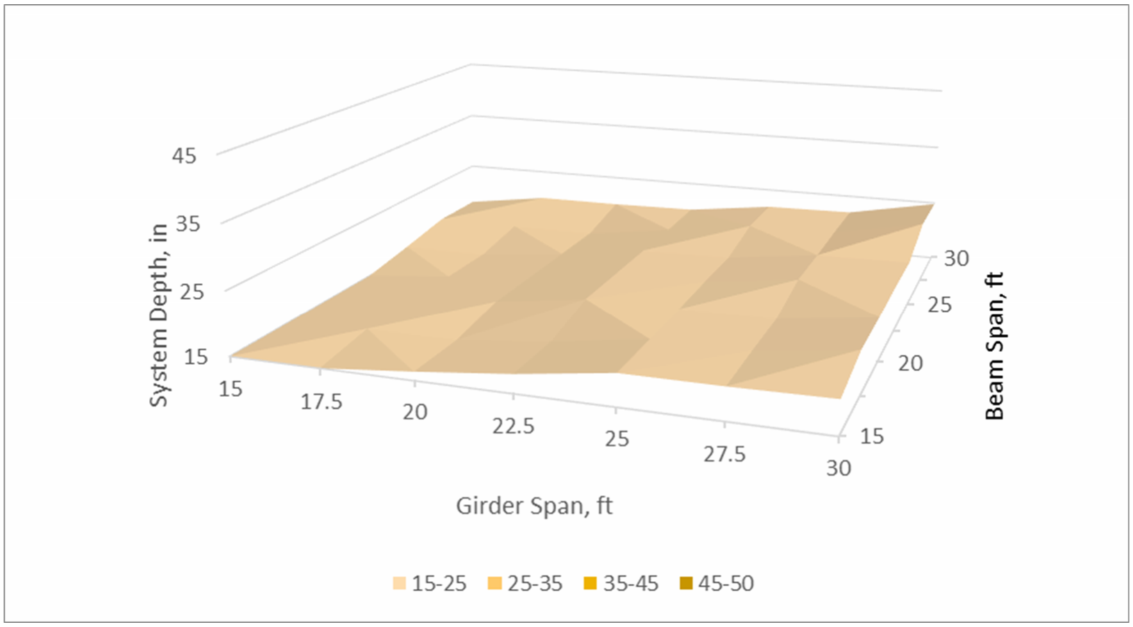

Figure 59 - System Depth, Residential Hybrid Steel WF Roof with 3-Ply CLT

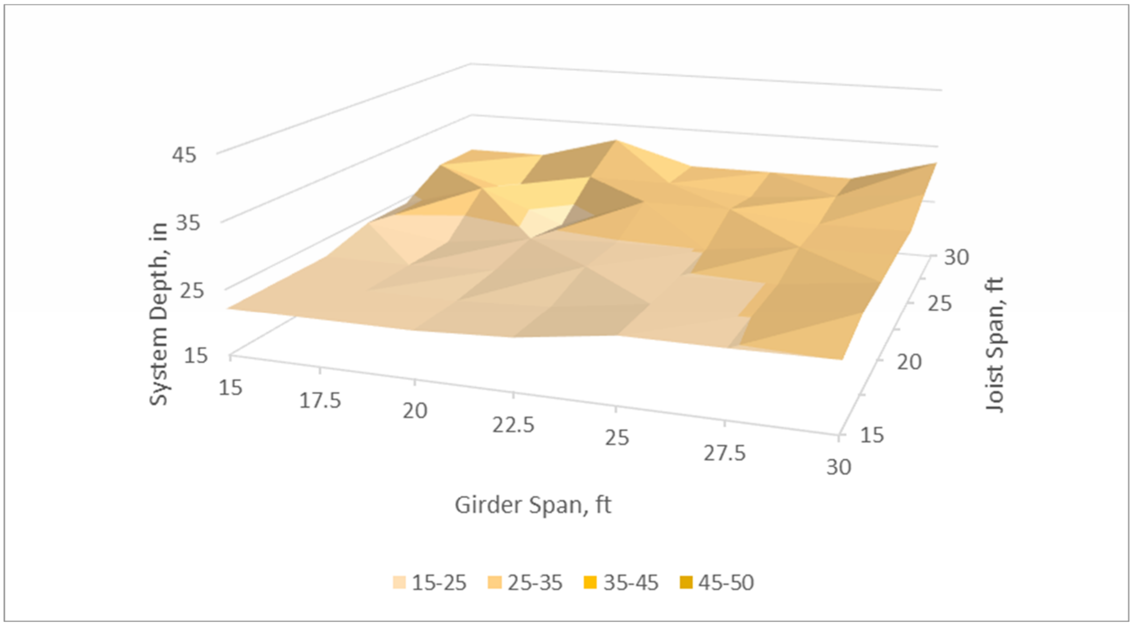

Figure 60 - System Depth, Residential Hybrid OWSJ Roof with 3-Ply CLT

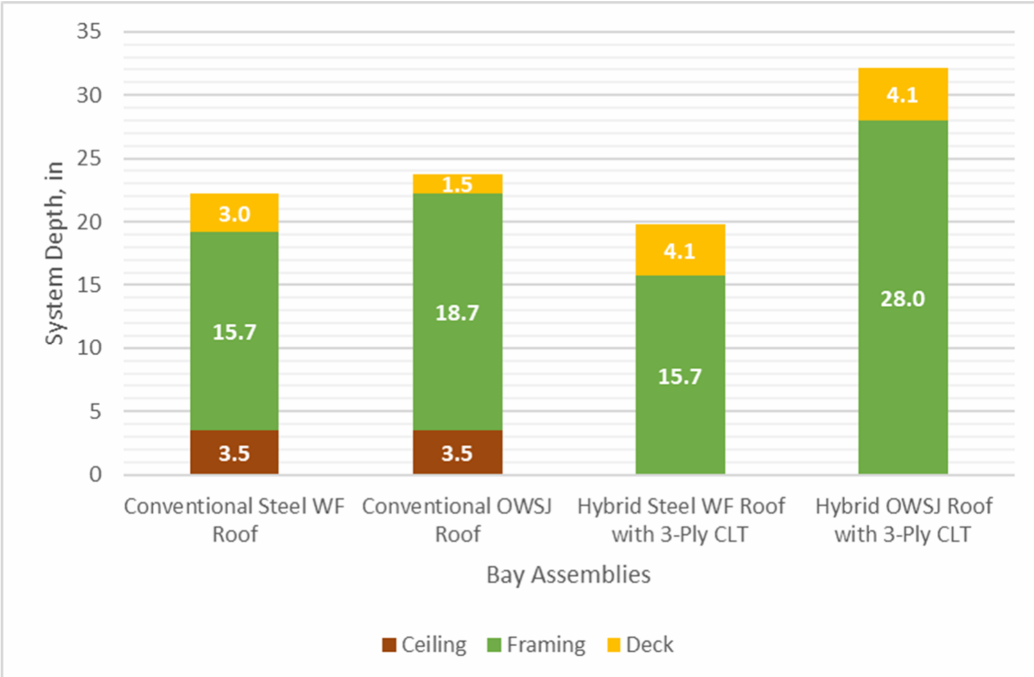

Figure 61 - System Depth Comparison for a 20x30 ft Residential Roof Bay

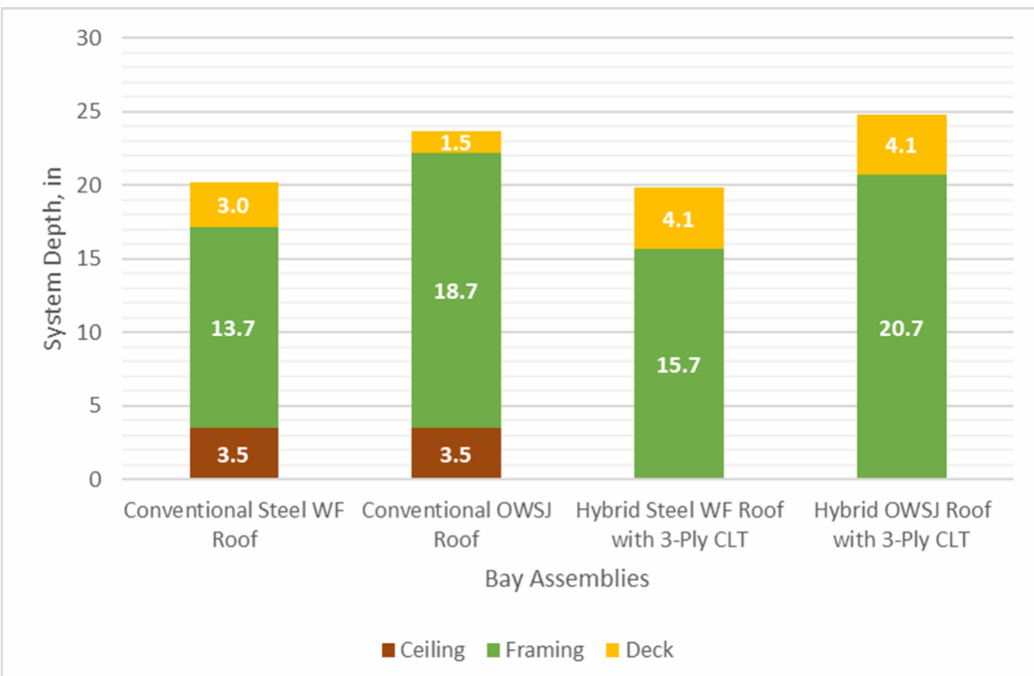

Figure 62 - System Depth Comparison for a 25x15 ft Residential Roof Bay

For residential roof systems, the hybrid system with wide flange beams is generally slightly shallower than the conventional system, mainly due to the lack of a ceiling. For OWSJ systems, the hybrid system is generally deeper due to the slight increase in dead load and larger joist spacing, which tended to increase joist depths for the hybrid system.

Predicted Cost Results

Analysis results for approximate predicted costs are presented in figures 64-85 for each framing system.

Review of the predicted cost results indicate that while predicted cost does increase for all systems as bay sizes increase, the percentage increase is significantly lower than for other metrics studied. This is due to non-variable cost items (decking, concrete fill, and CLT) contributing more significantly to cost than these items contributed to embodied carbon or system depth. For all bay sizes studied, the hybrid systems were significantly more costly than the conventional systems.

Commercial Floor Layouts – Predicted Cost

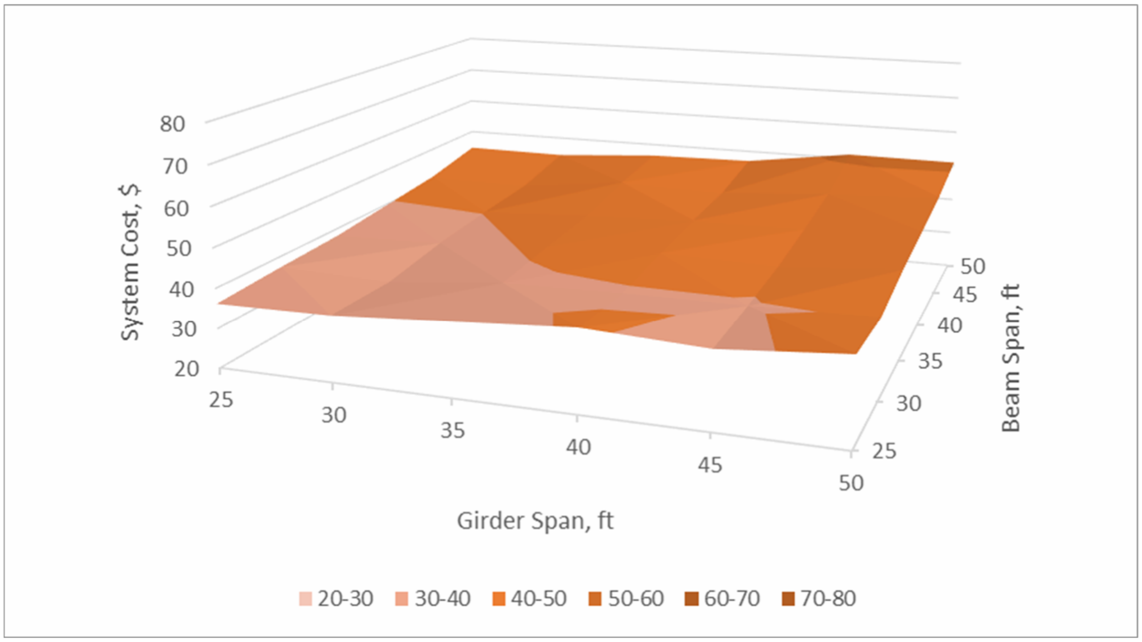

Figure 63 - Predicted Cost, Commercial Conventional Composite Steel WF Floor

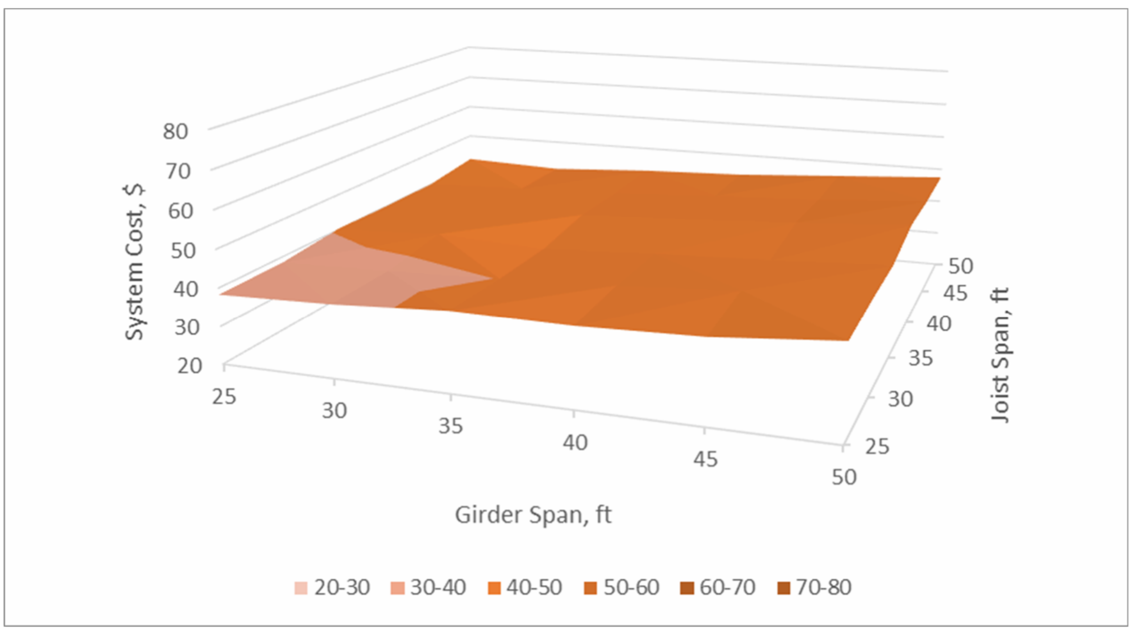

Figure 64 - Predicted Cost, Commercial Conventional OWSJ Floor

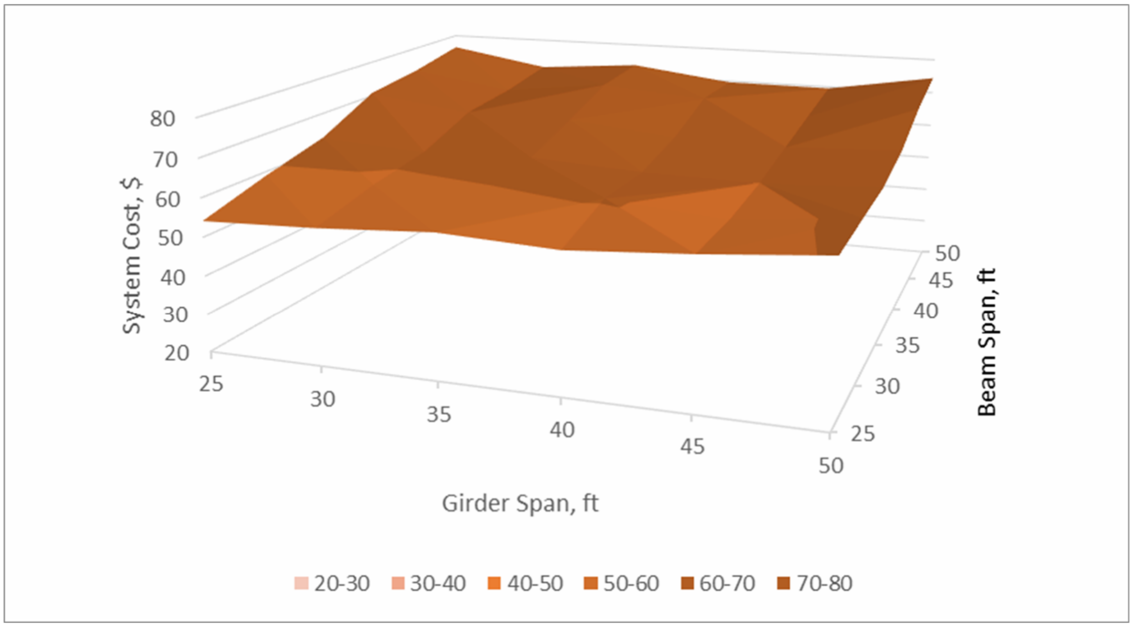

Figure 65 - Predicted Cost, Commercial Hybrid Steel WF Floor with 3-Ply CLT

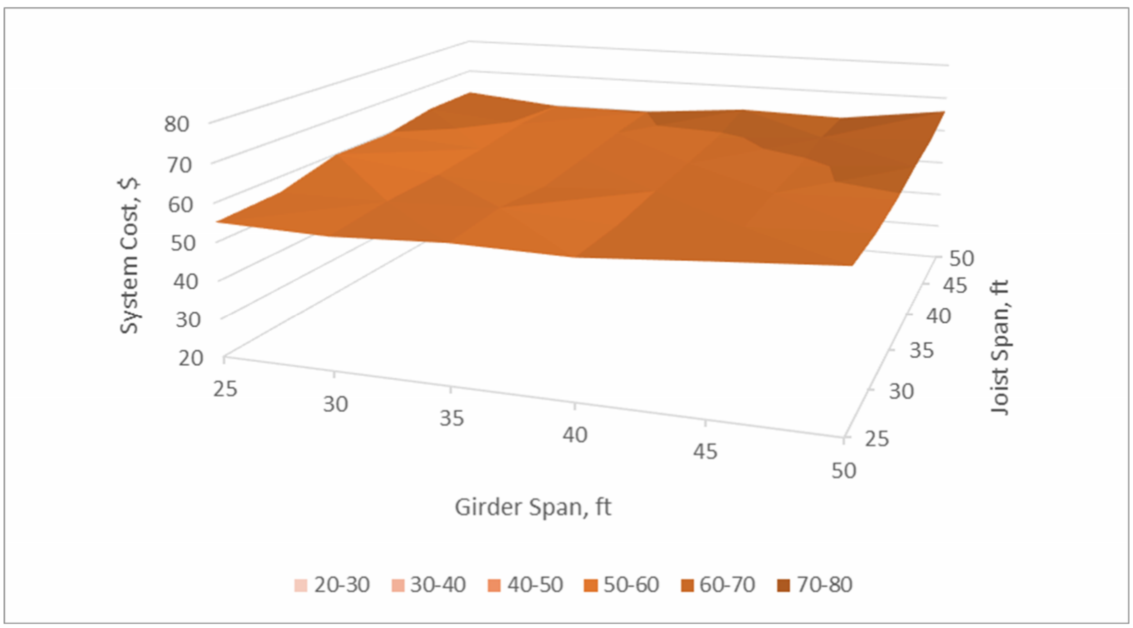

Figure 66 - Predicted Cost, Commercial Hybrid OWJS Floor with 3-Ply CLT

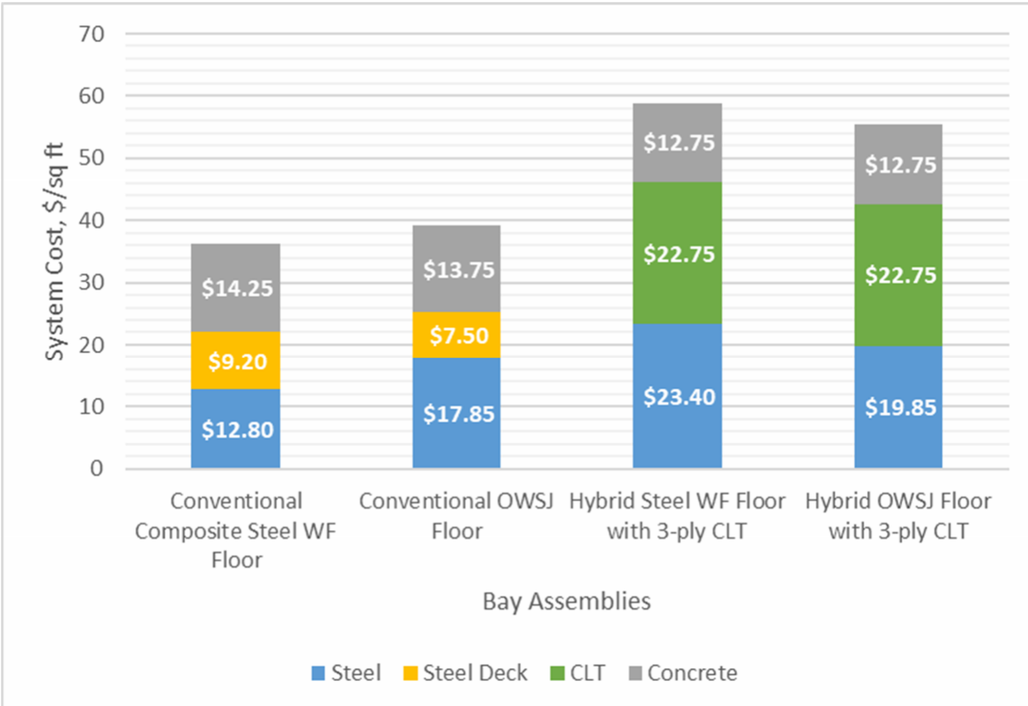

Figure 67 - Predicted Cost Comparison for a 30x30 ft Commercial Floor Bay

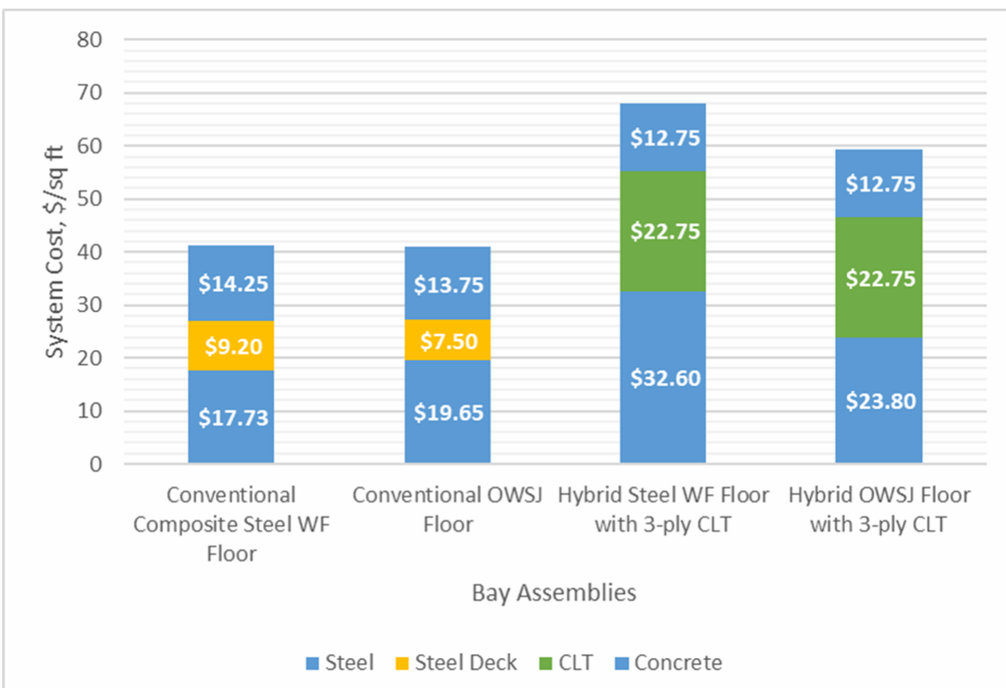

Figure 68 - Predicted Cost Comparison for a 30x45 ft Commercial Floor Bay

Review of the cost results indicates the increased cost of the CLT panels as compared to the metal deck is the most significant driver for commercial floor assemblies. For the wide flange beams systems, the loss of composite action in the hybrid system also resulted in significant cost increases. For OWSJ hybrid systems, longer spans were negatively affected by the reduced composite stiffness for vibration, which lead to significant increases in joist weight.

The hybrid systems were generally $15 - $30 per square foot more than the comparable conventional systems.

Commercial Roof Layouts – Predicted Cost

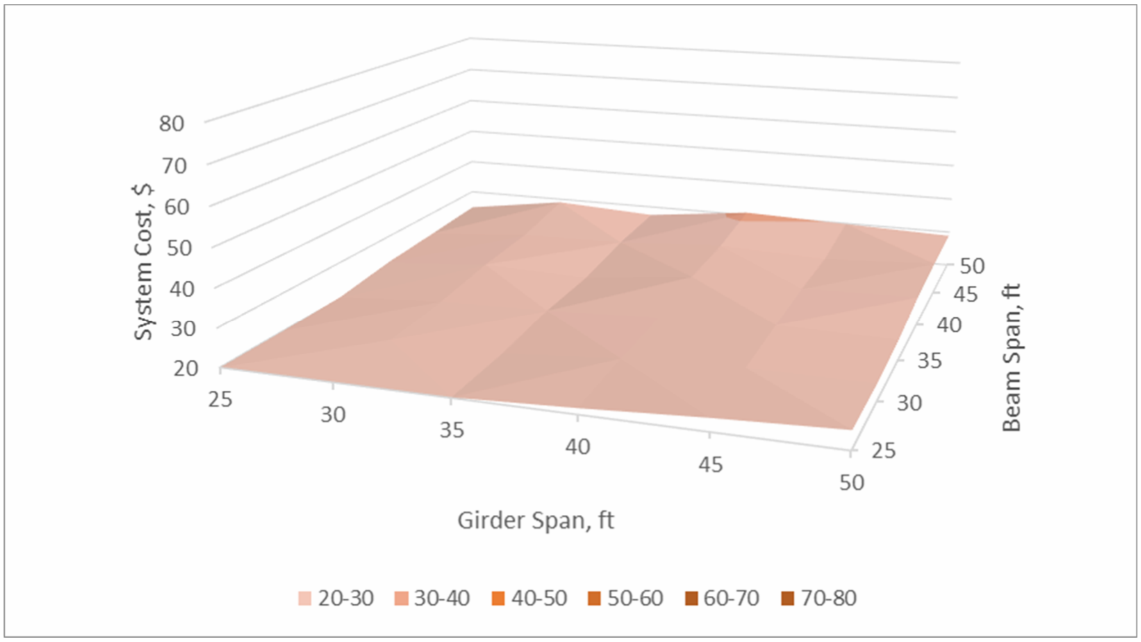

Figure 69 - Predicted Cost, Commercial Conventional Steel WF Roof

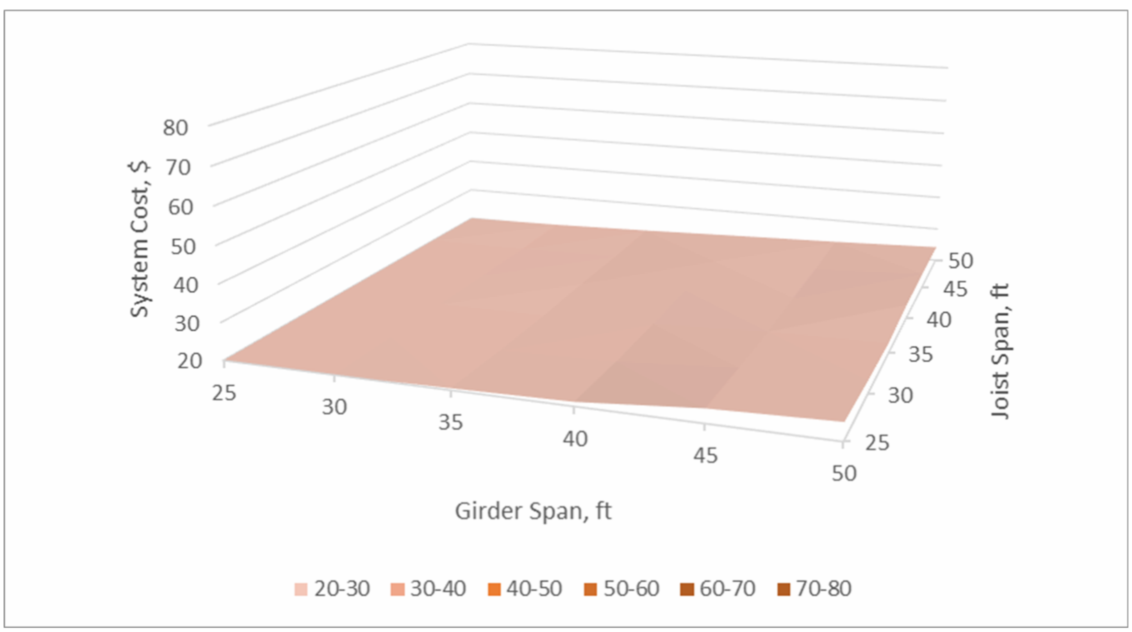

Figure 70 - Predicted Cost, Commercial Conventional OWSJ Roof

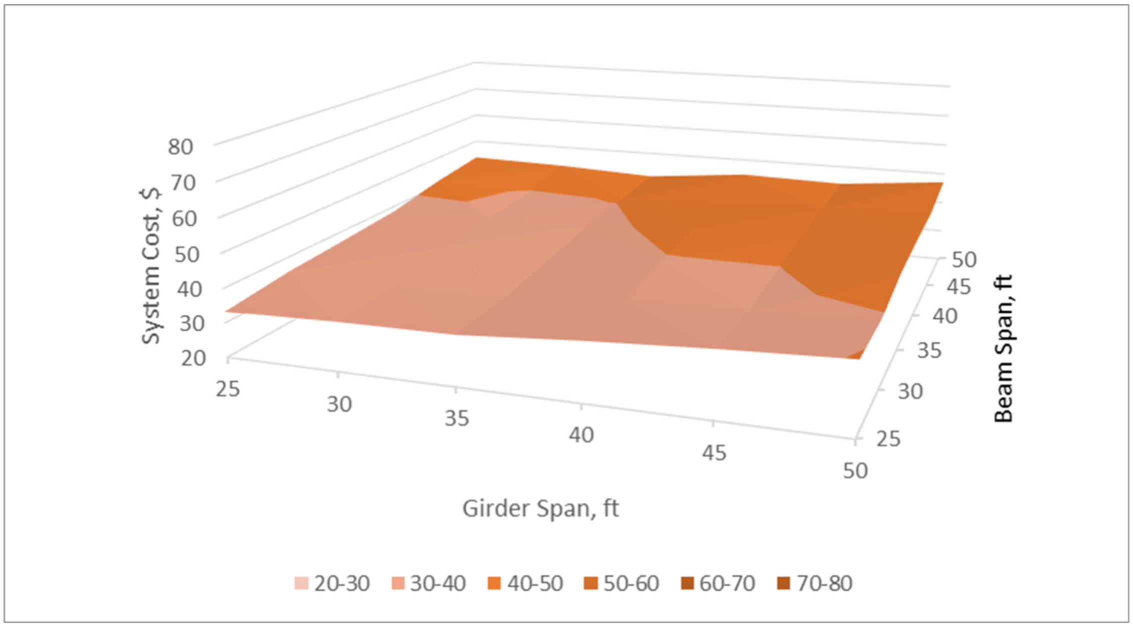

Figure 71 - Predicted Cost, Commercial Hybrid Steel WF Roof with 3-Ply CLT

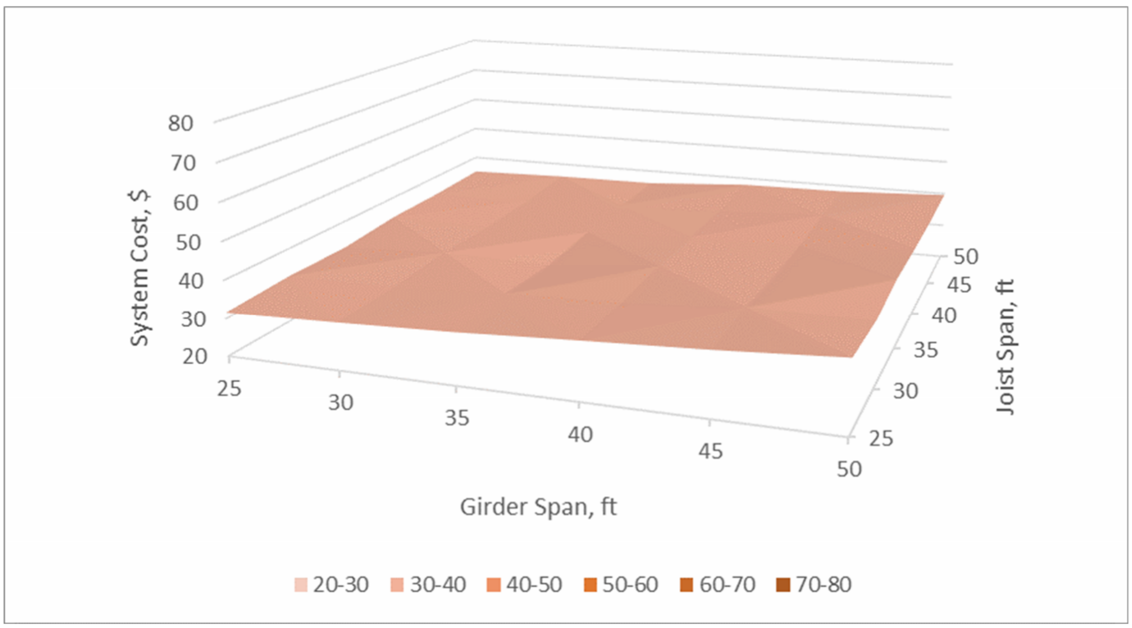

Figure 72 - Predicted Cost, Commercial Hybrid OWSJ Roof with 3-Ply CLT

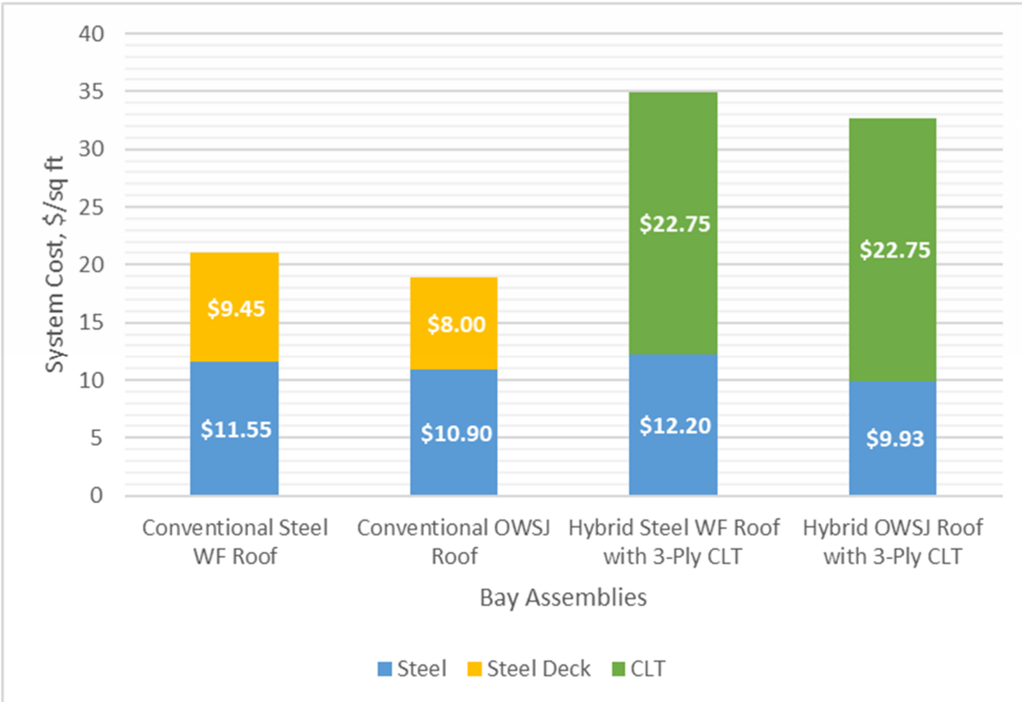

Figure 73 - Predicted Cost Comparison for a 30x30 ft Commercial Roof Bay

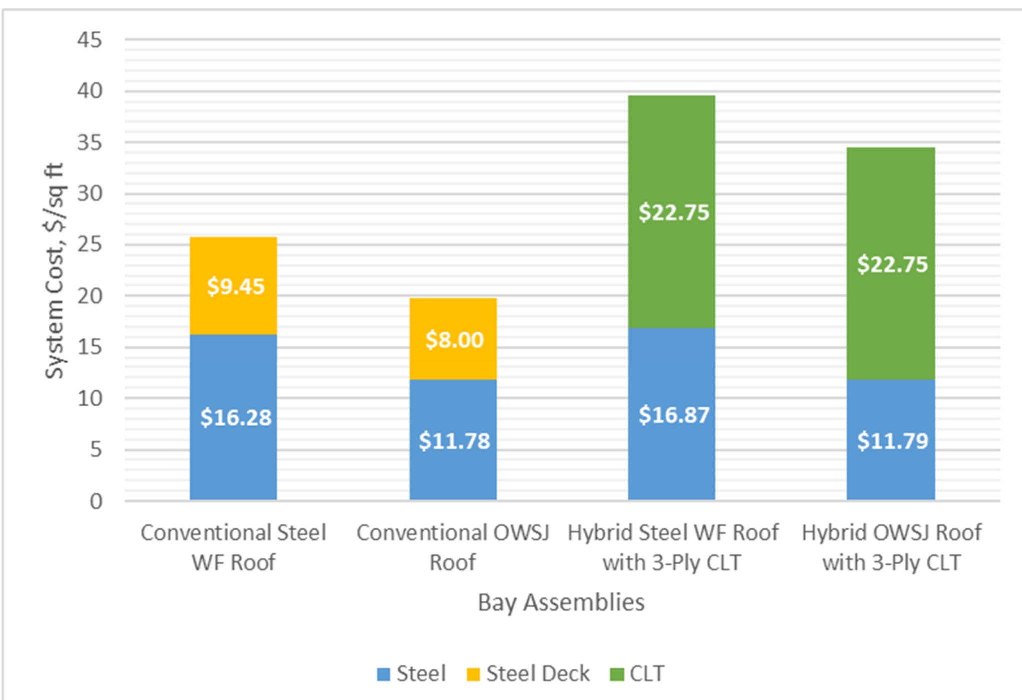

Figure 74 - Predicted Cost Comparisons for a 30x45 ft Commercial Roof Bay

Predicted cost results for commercial roof bays also indicated substantially higher costs for the hybrid systems. For the bays studied in detail, the cost of the steel framing is within +/- 10% between the hybrid and conventional system. However, the CLT is more than twice the cost of the steel decking, resulting in cost increases of $12-$16 per square foot as compared to conventional systems.

Residential Floor Layouts – Predicted Cost

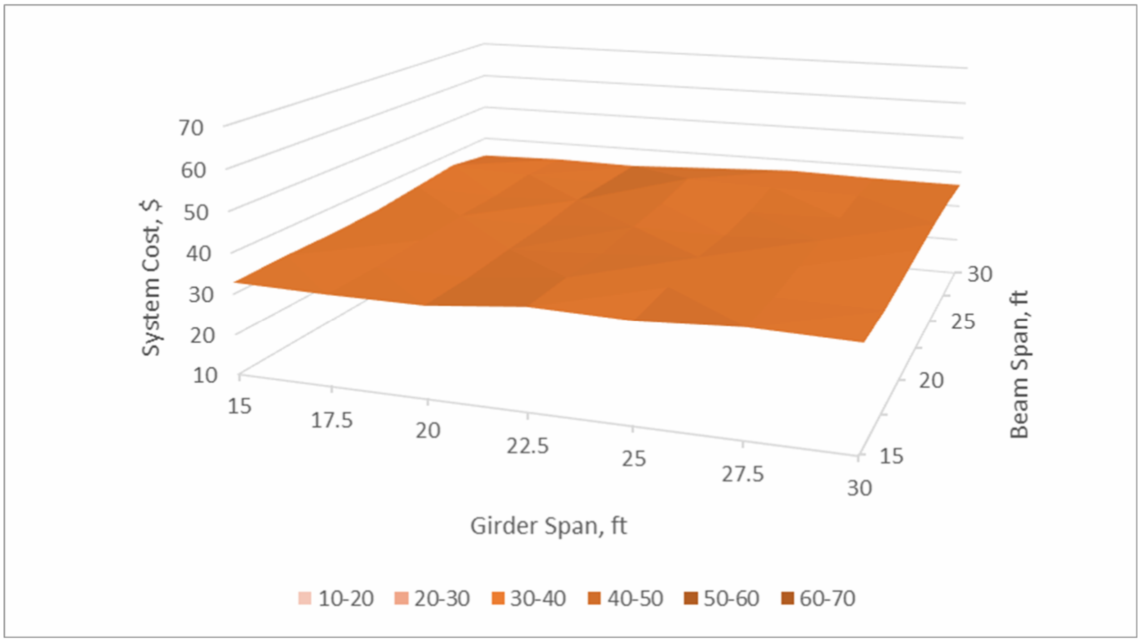

Figure 75 - Predicted Cost, Residential Conventional Composite Steel WF Floor

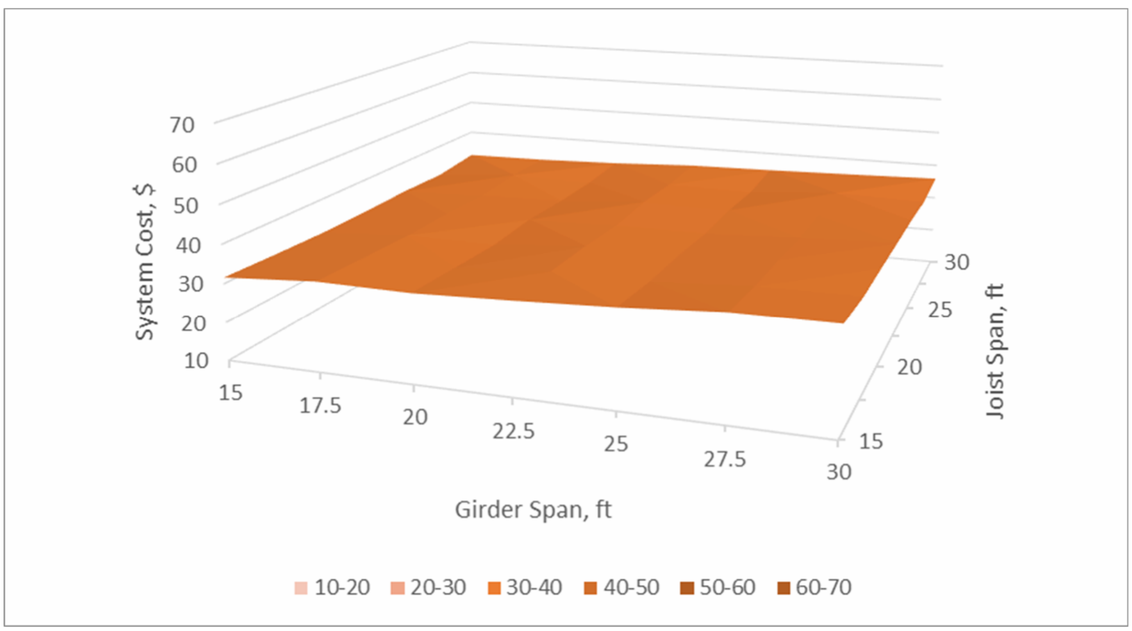

Figure 76 - Predicted Cost, Residential Conventional OWSJ Floor

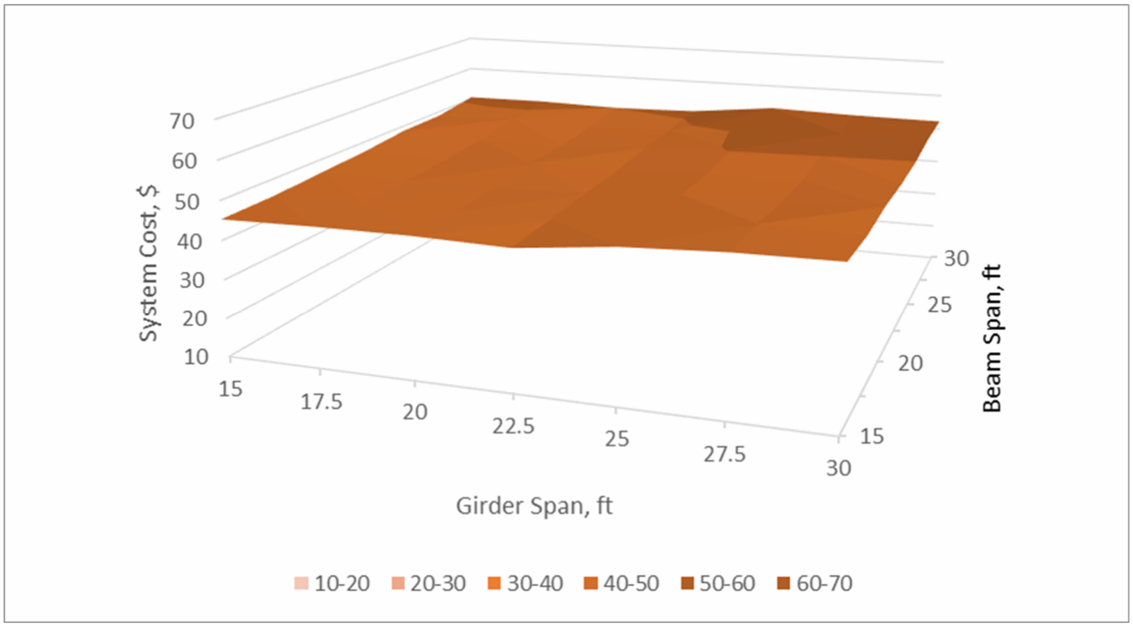

Figure 77 - Predicted Cost, Residential Hybrid Steel WF Floor with 3-Ply CLT

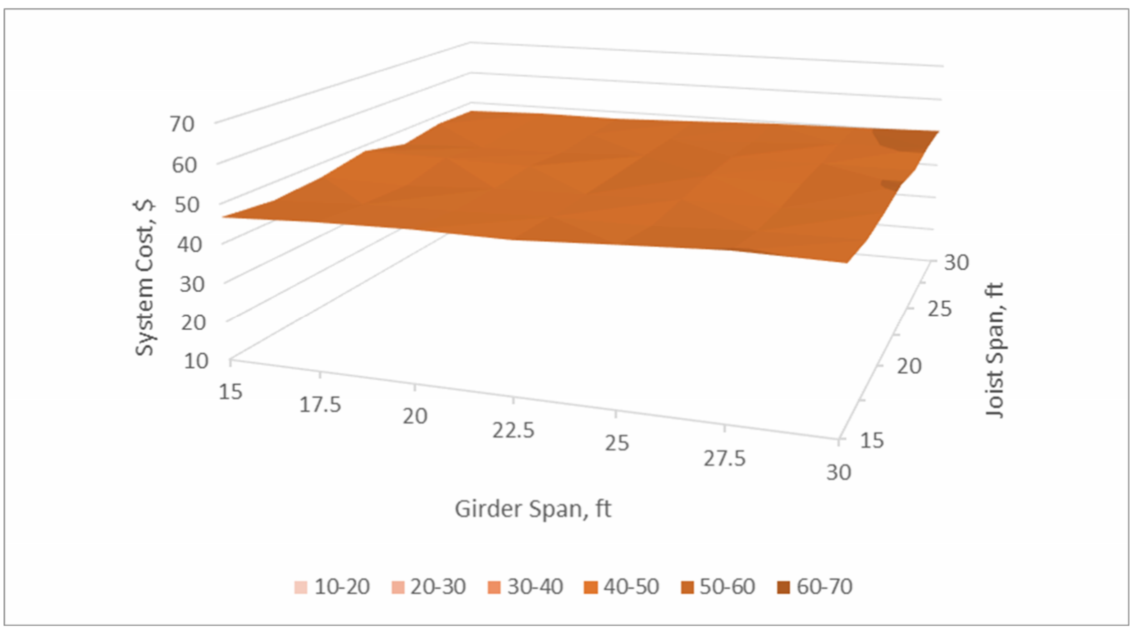

Figure 78 - Predicted Cost, Residential Hybrid OWSJ Floor with 3-Ply CLT

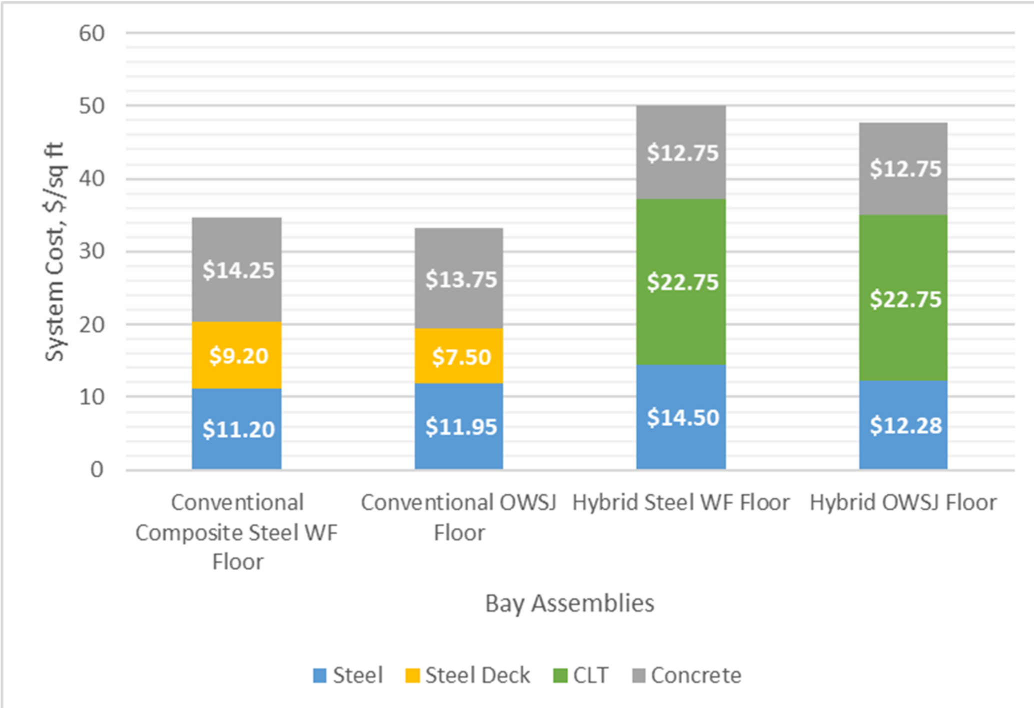

Figure 79 - Predicted Cost Comparisons for a 20x30 ft Residential Floor Bay

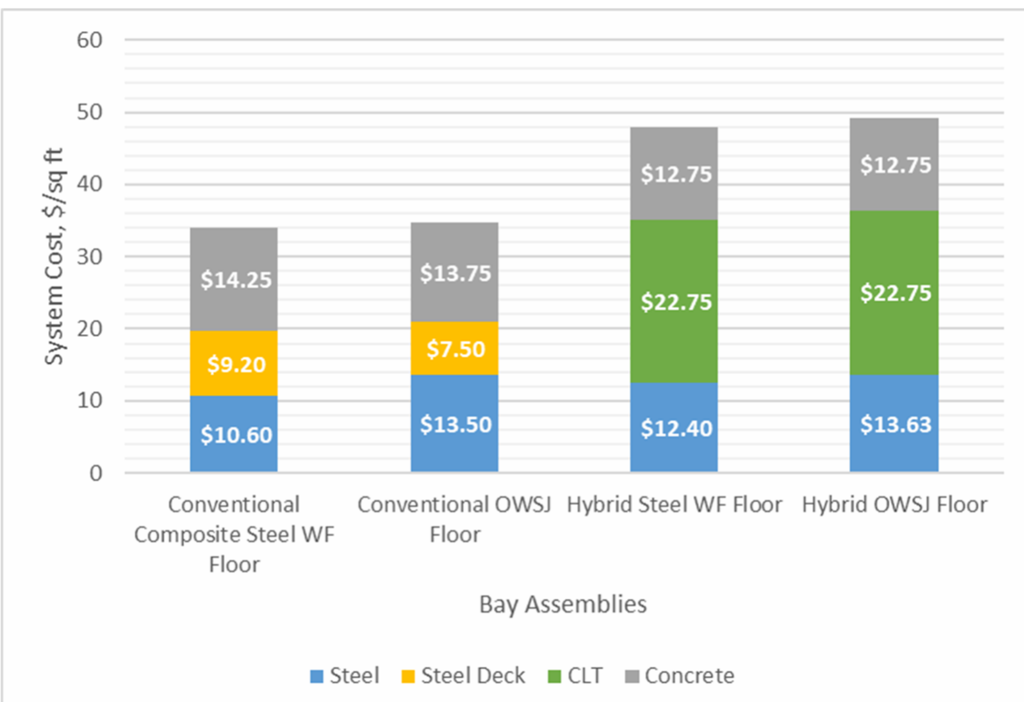

Figure 80 - Predicted Cost Comparisons for a 25x15 ft Residential Floor Bay

Residential floors bays exhibit similar trends to commercial floor bays, except the wide flange framing systems are less affected by the loss of composite action due to the shorter spans. The predicted cost of hybrid systems is approximately $15 per square foot higher than conventional systems, and this cost delta is consistent over most bay sizes studied.

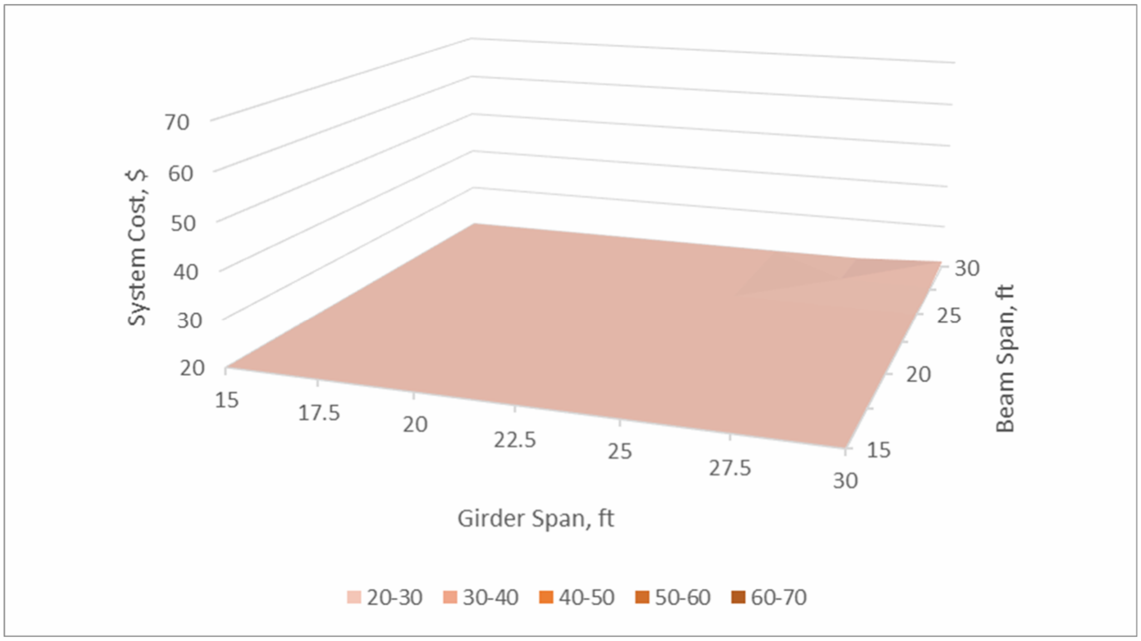

Figure 81 - Predicted Cost, Residential Conventional Steel WF Roof

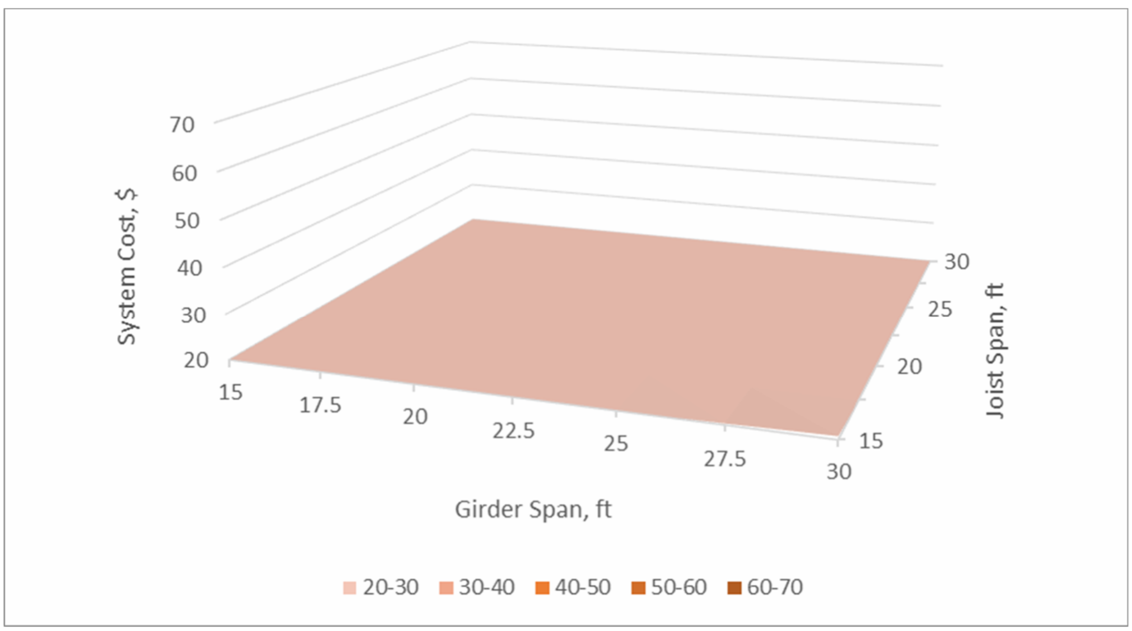

Figure 82 - Predicted Cost, Residential Conventional OWSJ Roof

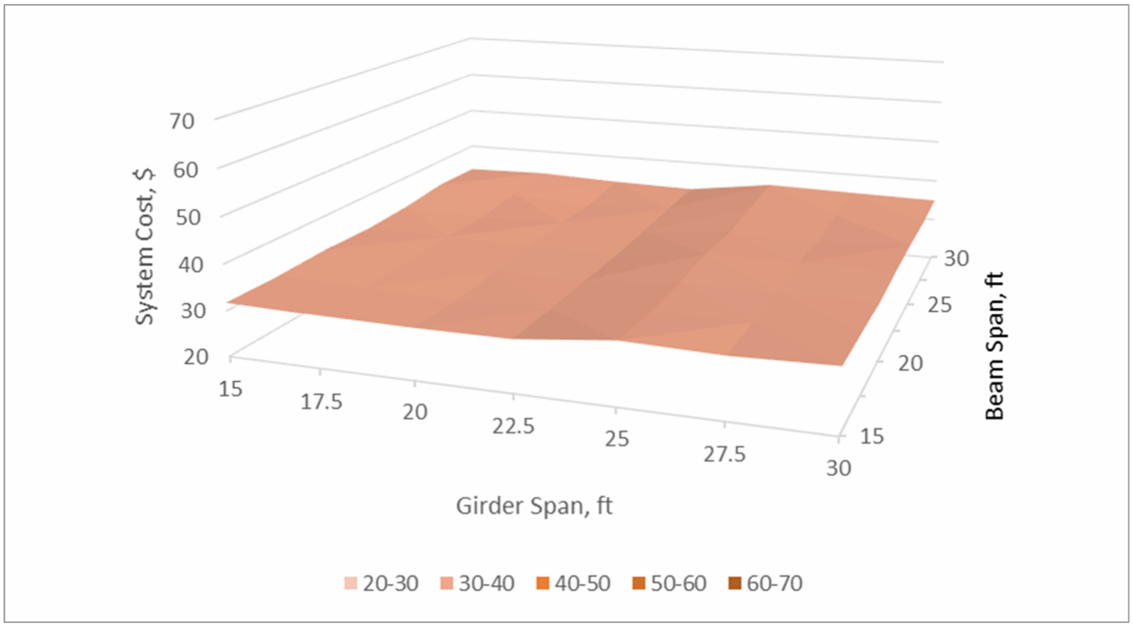

Figure 83 - Predicted Cost, Residential Hybrid Steel WF Roof with 3-Ply CLT

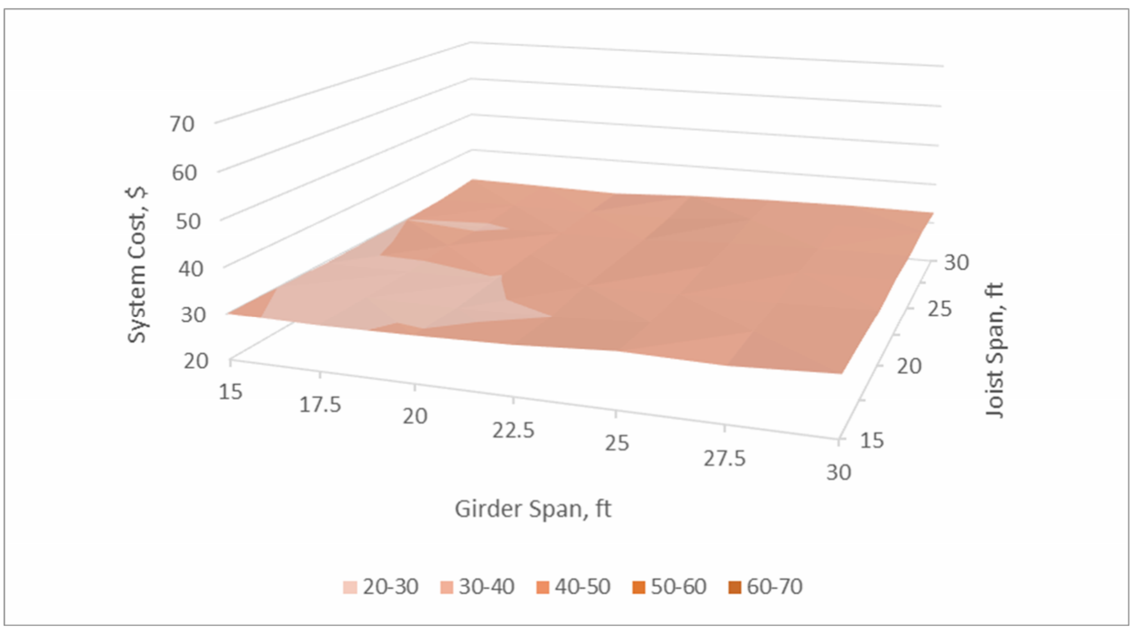

Figure 84 - Predicted Cost, Residential Hybrid OWSJ Roof with 3-Ply CLT

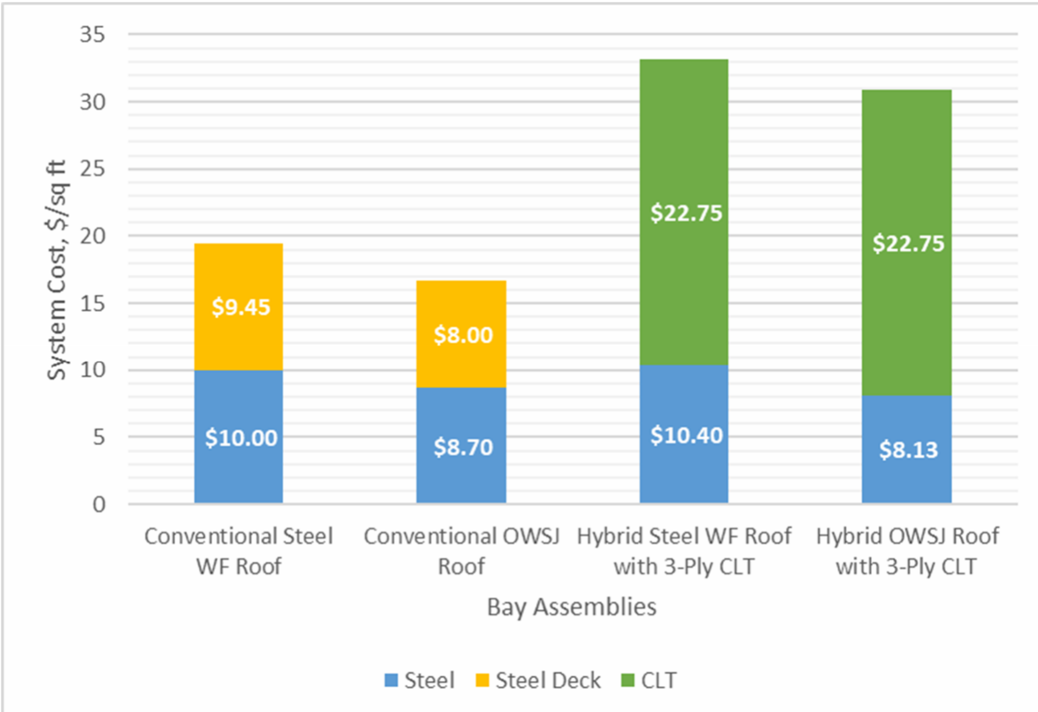

Figure 85 - Predicted Cost Comparisons for a 20x30 ft Residential Roof Bay

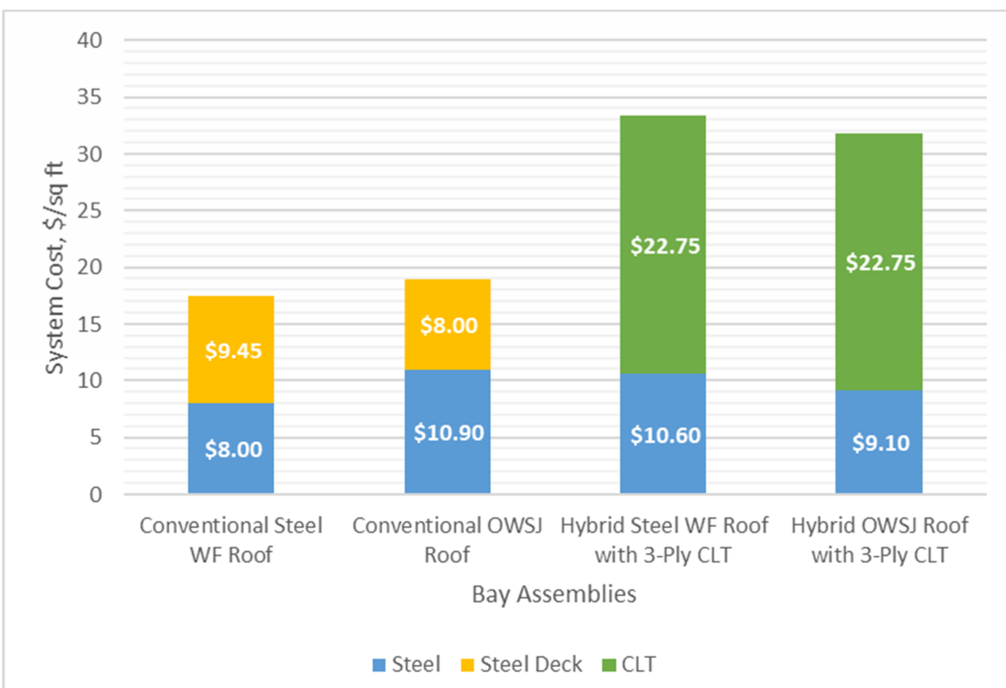

Figure 86 - Predicted Cost Comparisons for a 25x15 Residential Roof Bay

Residential roof framing exhibited similar trends to commercial roof framing in terms of predicted cost, except with slightly more variation in the framing costs.

Embodied Carbon – Reduced GWP Concrete

While the bay study results presented previously compared embodied carbon in hybrid systems to conventional systems, there are also additional strategies that can be utilized to reduce the global warming potential of the structural system. The primary applicable reduction strategy currently available is reducing the embodied carbon content of the concrete by reducing the cement content, use of alternate cements, and use of supplemental cementitious materials. In this report this is referred to as "reduced GWP concrete."

The "reduced GWP concrete" mix assumes a Type IL cement and 50% SCM content. This is assumed to reduce the embodied carbon of the concrete by 50%. It should be noted that concrete mixes utilizing this ratio of SCM's often have different behavior during finishing and curing that can make them unsuitable for some applications. Several ready-mix concrete suppliers offer products that have this range of embodied carbon reduction and offer similar finishing and curing performance to standard concrete by additional admixtures.

It should be noted that this reduction strategy is only useful for assemblies containing concrete. Roof assemblies are unaffected by this strategy.

GWP impact is computed for the two commercial floor bays studied utilizing reduced GWP concrete and results are presented below.

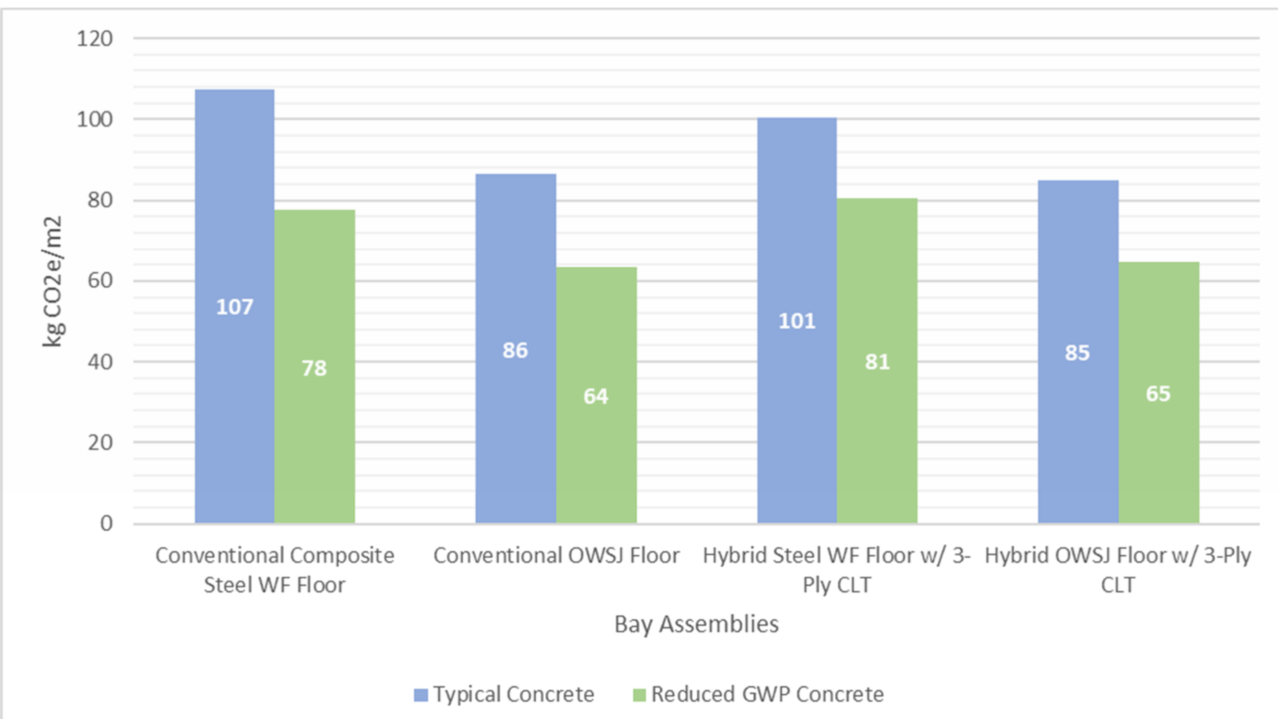

Figure 87 - Embodied Carbon Comparisons for a 30x30 ft Commercial Floor Bay with reduced GWP concrete

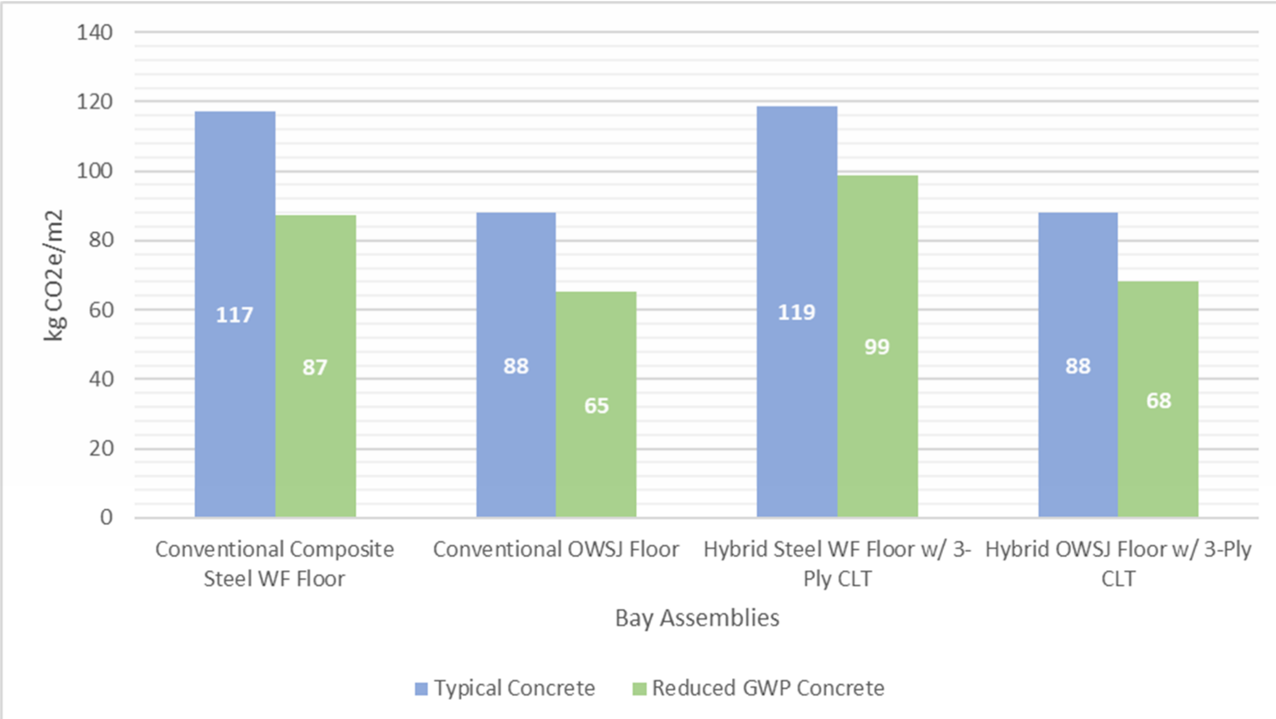

Figure 88 - Embodied Carbon Comparisons for a 30x45 ft Commercial Floor Bay with reduced GWP concrete

Review of these results indicate that alternate methods for GWP reduction that target the embodied carbon content of concrete directly (in lieu of replacement with an alternate material) can result in reductions greater than a hybrid system alone (when stored biogenic carbon is not considered). This is largely because the impact of concrete tends to dominate the total GWP of all considered systems that include concrete, whether it is on metal deck or in the form of a topping slab on CLT panels. This alternate reduction strategy does not capture the potential benefit of the stored biogenic carbon within the hybrid assemblies' CLT.

Review of the data for floor framing systems indicates that when all framing systems utilize reduced GWP concrete, hybrid systems do not always result in the lowest embodied carbon impact when stored biogenic carbon is excluded. For wide flange beam systems, the efficiency gain due to composite design in steel sizes offsets the increased GWP impact from the steel deck and thicker concrete topping for larger bay sizes. For open web steel joist systems, the GWP impact of the conventional and hybrid systems is very close, with the two selected bays within 5% and the conventional systems indicating a slight advantage.

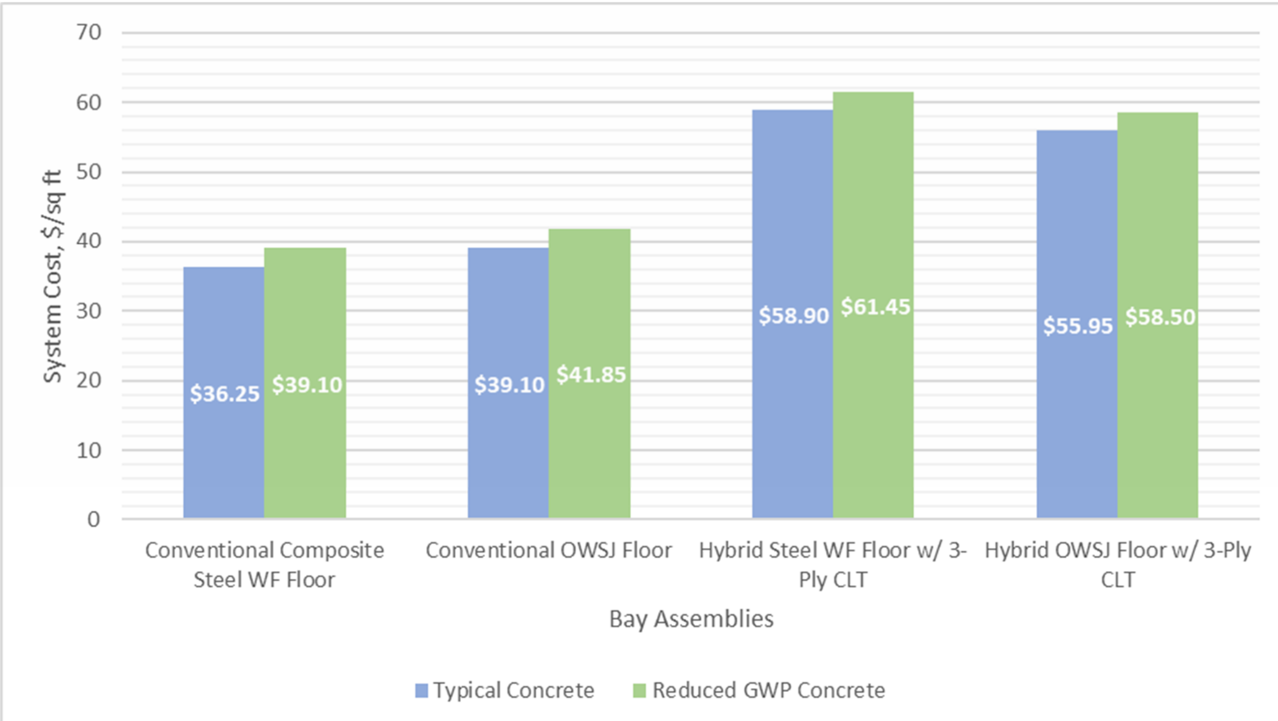

Figure 89 - Predicted Cost Comparisons for a 30x30 ft Commercial Floor Bay with reduced GWP concrete

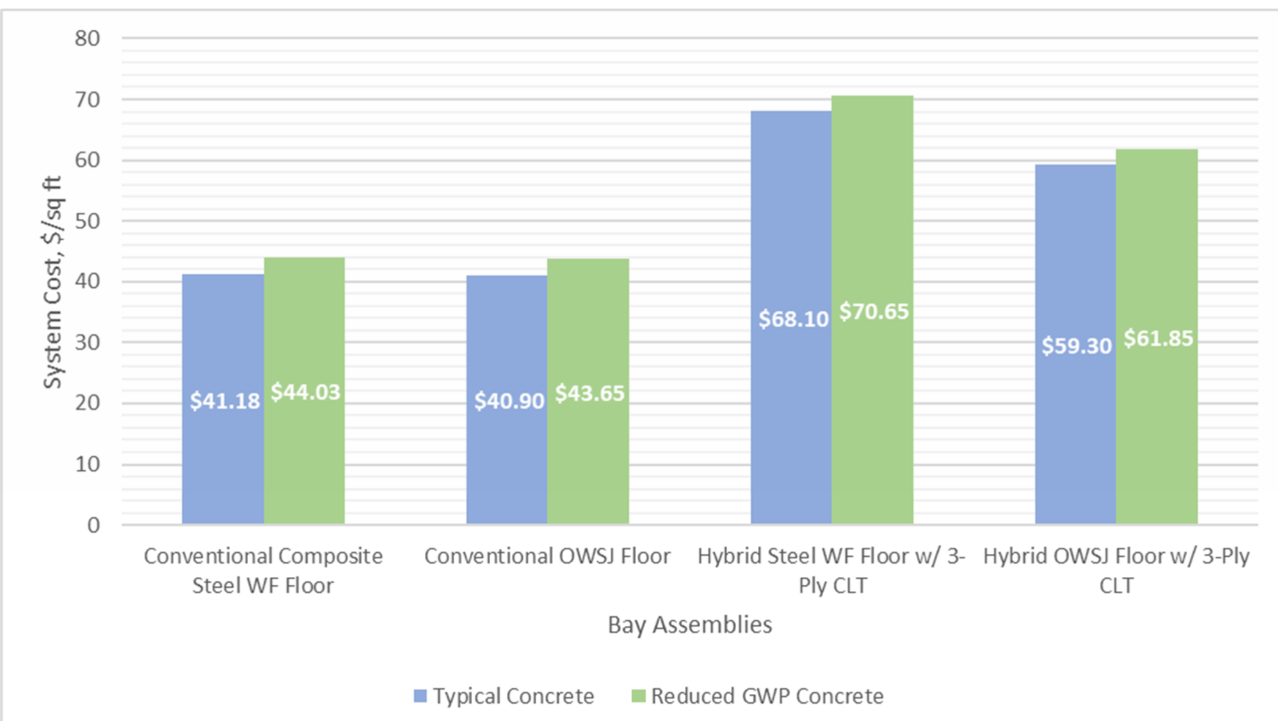

Figure 90 - Predicted Cost Comparisons for a 30x45 ft Commercial Floor Bay with reduced GWP concrete

Review of these approximate costs indicates that inclusion of a reduced GWP concrete is a cost-effective strategy to reduce embodied carbon. An approximate 7% increase in cost is paired with a 25 -27% reduction in embodied carbon impact. In comparison, the use of a hybrid system results in cost increases between 42-63% and a maximum reduction of embodied carbon of 6% excluding stored biogenic carbon. The use of a hybrid system with reduced GWP concrete results in cost increases between 49-70% and a maximum reduction of embodied carbon of 24% excluding stored biogenic carbon. When stored biogenic carbon is included, the OWSJ hybrid systems with or without reduced GWP concrete and the Hybrid WF Steel systems with reduced GWP concrete result in the stored biogenic carbon negative impact exceeding the embodied carbon impact of the system (net negative embodied carbon impact).

Conclusion

This study provides data indicating the embodied carbon, structural depth, and approximate structural cost for conventional steel framing and hybrid steel and mass timber framing systems over a range of bay sizes. This data can be utilized in combination with other project objectives and limitations to assist design teams in selection of the most appropriate framing system for a specific project.

The study has indicated that hybrid framing assemblies consisting of wide flange steel or open web steel joists can be combined with cross laminated timber (CLT) panels as an effective strategy to reduced embodied carbon impact, when considering stored biogenic carbon. If stored biogenic carbon is excluded from the carbon accounting, hybrid roof systems usually result in a reduction of embodied carbon when compared to conventional systems. Hybrid floor systems generally result in a decrease in embodied carbon impact for short spans (approximately 30' of less) but generally result in an increase in embodied carbon impact for longer spans as compared to conventional systems. This increase is due to the loss of composite action for Steel WF systems when changing to the hybrid assembly, and due to the reduced stiffness of the CLT panel as compared to the concrete slab when evaluating vibration for OWSJ systems. Embodied carbon impact of OWSJ systems is lower than for steel WF systems for all but 2 bay sizes and types studied.

Regarding structural depth, the effect of utilizing a hybrid system as compared to a conventional system varied depends on the assembly (steel WF vs OWSJ) and usage (commercial vs residential, floor vs roof). For commercial steel WF floor assemblies, the hybrid system increased structural depth due to the lack of composite action of the beams and girders. For the commercial OWSJ floor assemblies, the depth is not significantly different between the conventional and hybrid assemblies. For residential steel WF floor assemblies the hybrid assembly is slightly deeper than the conventional assembly. For residential OWSJ floor assemblies the structural depth is nearly identical if controlled by girder depth, and the hybrid assembly is deeper if controlled by OWSJ depth. For roof systems (commercial and residential), steel WF hybrid assemblies are nearly the same or slightly deeper than conventional assemblies. OWSJ hybrid roof assemblies are slightly deeper if controlled by joist depth, but nearly identical if controlled by girder depth for both residential and commercial bays. OWSJ assemblies are deeper than corresponding steel WF assemblies in all bays studied.

Review of the approximate system cost results indicate that for all bay sizes studied and uses (floors and roofs) the hybrid system is more expensive than the conventional system, due primarily to the increased cost of CLT as compared to metal deck. This cost increase ranged from $12-$31 per square foot, with the greatest difference being for commercial steel WF floor assemblies with long beam spans and shorter girder spans. For commercial floor assemblies, the cost increase is due to an increase in framing cost in addition to the cost difference between CLT and metal deck. For commercial steel WF floors this is due to the lack of composite action which resulted in a required increase in beam stiffness. For commercial OWSJ floors this is due to the reduced stiffness of the CLT panel as compared to the concrete slab for vibration design, which resulted in an increased stiffness requirement for the OWSJ.

All the assemblies studied utilize cast-in-place concrete in some capacity, and in all assemblies – conventional and hybrid, commercial and residential – concrete is a significant contributor to GWP. It is shown that a significant reduction in concrete GWP through reduction in cement content by use of SCMs and/or Type IL cement has a significant impact on system GWP for relatively low cost. It should therefore be considered as an embodied carbon reduction strategy for both conventional and hybrid systems with concrete elements.

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Appendix A: Commercial Floor Bay Study Results

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W18X40	W14X22	8.33	7.4	107	0.0	26.9	$ 36.17
30	25	W21X44	W16X26	10.00	7.6	108	0.0	29.7	$ 36.53
35	25	W24X62	W14X22	8.75	8.1	112	0.0	32.7	$ 38.43
40	25	W24X76	W16X26	10.00	8.8	116	0.0	32.9	$ 40.37
45	25	W27X84	W14X22	9.00	8.9	117	0.0	35.7	$ 40.86
50	25	W30X90	W16X26	10.00	9.4	119	0.0	38.5	$ 42.05
25	30	W21X44	W16X26	8.33	7.8	109	0.0	29.7	$ 37.21
30	30	W21X50	W16X26	10.00	7.5	107	0.0	29.8	$ 36.25
35	30	W24X68	W16X26	8.75	8.5	113	0.0	32.7	$ 39.16
40	30	W27X84	W16X26	10.00	8.6	114	0.0	35.7	$ 39.65
45	30	W30X90	W16X26	9.00	9.1	117	0.0	38.5	$ 41.12
50	30	W30X108	W16X26	10.00	9.4	119	0.0	38.8	$ 42.05
25	35	W21X44	W14X30	8.33	8.1	111	0.0	29.7	$ 38.02
30	35	W24X55	W18X35	10.00	8.3	112	0.0	32.6	$ 38.66
35	35	W24X76	W16X31	8.75	8.9	116	0.0	32.9	$ 40.59
40	35	W30X90	W18X35	10.00	9.3	118	0.0	38.5	$ 41.66
45	35	W30X108	W16X31	9.00	9.7	121	0.0	38.8	$ 43.04
50	35	W33X118	W18X35	10.00	10.1	123	0.0	41.9	$ 44.06
25	40	W21X50	W18X35	8.33	8.7	115	0.0	29.8	$ 39.80
30	40	W24X62	W18X40	10.00	8.7	115	0.0	32.7	$ 40.10
35	40	W27X84	W18X35	8.75	9.3	118	0.0	35.7	$ 41.75
40	40	W30X99	W18X40	10.00	9.7	121	0.0	38.7	$ 42.88
45	40	W30X116	W18X35	9.00	10.0	123	0.0	39.0	$ 43.82
50	40	W33X130	W18X40	10.00	10.4	125	0.0	42.1	$ 45.20
25	45	W24X55	W18X40	8.33	9.2	118	0.0	32.6	$ 41.52
30	45	W24X68	W21X44	10.00	9.1	117	0.0	32.7	$ 41.18
35	45	W30X90	W21X44	8.75	10.2	124	0.0	38.5	$ 44.54
40	45	W30X108	W21X44	10.00	10.0	123	0.0	38.8	$ 43.85
45	45	W33X118	W21X44	9.00	10.7	127	0.0	41.9	$ 45.98
50	45	W40X149	W21X44	10.00	10.9	128	0.0	47.2	$ 46.58
25	50	W24X55	W21X50	8.33	10.3	124	0.0	32.6	$ 44.75
30	50	W24X76	W24X55	10.00	10.2	124	0.0	32.9	$ 44.51
35	50	W30X99	W21X50	8.75	10.9	128	0.0	38.7	$ 46.53
40	50	W33X118	W24X55	10.00	11.0	129	0.0	41.9	$ 47.03
45	50	W33X130	W24X55	9.00	11.9	134	0.0	42.1	$ 49.58
50	50	W40X149	W24X62	10.00	12.3	137	0.0	47.2	$ 50.99

Table 4 - Results, Conventional Composite Steel WF Floor Assembly, Commercial

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W21X44	24LH07	5.00	7.0	83	0.0	33.2	$ 37.58
30	25	W24X62	24LH06	5.00	7.6	87	0.0	36.2	$ 39.09
35	25	W24X76	24LH06	5.00	8.1	90	0.0	36.4	$ 40.77
40	25	W30X90	24LH05	5.00	8.1	91	0.0	42.0	$ 40.50
45	25	W30X108	24LH03	5.00	8.4	94	0.0	42.3	$ 41.36
50	25	W33X130	24LH03	5.00	9.3	99	0.0	45.6	$ 44.00
25	30	W24X55	28LH08	5.00	7.3	85	0.0	36.1	$ 38.45
30	30	W24X68	28LH07	5.00	7.5	86	0.0	36.2	$ 39.10
35	30	W27X84	28LH06	5.00	7.9	89	0.0	39.2	$ 40.05
40	30	W30X99	24LH06	5.00	8.4	92	0.0	42.2	$ 41.55
45	30	W33X118	24LH06	5.00	9.0	95	0.0	45.4	$ 43.45
50	30	W36X135	20LH06	5.00	9.4	98	0.0	48.1	$ 44.50
25	35	W24X55	32LH09	5.00	7.6	86	0.0	39.5	$ 39.61
30	35	W24X76	28LH09	5.00	8.2	89	0.0	36.4	$ 41.41
35	35	W30X90	32LH08	5.00	7.8	88	0.0	42.0	$ 40.01
40	35	W30X116	32LH07	5.00	8.4	92	0.0	42.5	$ 41.59
45	35	W33X130	32LH07	5.00	8.8	94	0.0	45.6	$ 42.79
50	35	W40X149	32LH07	5.00	9.3	97	0.0	50.7	$ 44.42
25	40	W24X62	36LH10	5.00	7.6	85	0.0	43.5	$ 39.55
30	40	W27X84	32LH10	5.00	8.2	89	0.0	39.5	$ 41.20
35	40	W30X99	32LH09	5.00	8.5	91	0.0	42.2	$ 42.33
40	40	W33X118	28LH09	5.00	9.0	94	0.0	45.4	$ 43.75
45	40	W36X135	28LH09	5.00	9.4	96	0.0	48.1	$ 45.03
50	40	W40X167	28LH09	5.00	10.2	101	0.0	51.1	$ 47.43
25	45	W24X68	40LH11	5.00	7.8	86	0.0	47.5	$ 40.08
30	45	W30X90	40LH10	5.00	8.1	88	0.0	47.5	$ 40.90
35	45	W30X108	36LH09	5.00	8.5	90	0.0	43.5	$ 42.10
40	45	W33X130	32LH09	5.00	9.0	93	0.0	45.6	$ 43.57
45	45	W40X149	32LH09	5.00	9.4	96	0.0	50.7	$ 44.83
50	45	W36X182	32LH09	5.00	10.1	100	0.0	48.8	$ 47.03
25	50	W24X76	40LH12	5.00	8.4	88	0.0	47.5	$ 42.06
30	50	W30X90	44LH11	5.00	8.1	88	0.0	51.5	$ 40.95
35	50	W30X116	40LH11	5.00	8.6	91	0.0	47.5	$ 42.51
40	50	W36X135	40LH11	5.00	9.0	93	0.0	48.1	$ 43.65
45	50	W40X167	40LH11	5.00	9.6	97	0.0	51.1	$ 45.57
50	50	W40X199	40LH11	5.00	10.3	101	0.0	51.2	$ 47.49

Table 5 - Results, Conventional OWSJ Floor Assembly, Commercial

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W21X50	W18X35	8.33	6.2	91	-96	28.7	$ 54.10
30	25	W24X76	W18X35	10.00	6.5	93	-96	31.8	$ 55.12
35	25	W30X90	W16X31	8.75	7.1	97	-96	37.4	$ 56.93
40	25	W30X90	W16X31	10.00	6.7	94	-96	37.4	$ 55.60
45	25	W30X108	W16X31	11.25	7.1	96	-96	37.7	$ 56.73
50	25	W33X130	W16X31	10.00	8.3	104	-96	41.0	$ 60.40
25	30	W24X55	W21X50	8.33	7.8	101	-96	31.5	$ 59.00
30	30	W27X84	W21X50	10.00	7.8	101	-96	34.6	$ 58.90
35	30	W30X90	W21X44	8.75	8.0	102	-96	37.4	$ 59.59
40	30	W33X118	W21X44	10.00	8.3	104	-96	40.8	$ 60.50
45	30	W33X118	W18X40	11.25	7.5	99	-96	40.8	$ 57.97
50	30	W36X135	W18X40	10.00	8.5	105	-96	43.5	$ 61.00
25	35	W24X55	W24X62	8.33	9.0	108	-96	31.6	$ 62.53
30	35	W24X76	W24X62	10.00	8.4	104	-96	31.8	$ 60.61
35	35	W30X90	W24X55	8.75	8.9	107	-96	37.4	$ 62.07
40	35	W30X116	W21X50	10.00	8.3	104	-96	37.9	$ 60.44
45	35	W33X130	W21X50	11.25	8.2	103	-96	41.0	$ 59.98
50	35	W40X149	W21X44	10.00	8.7	106	-96	46.1	$ 61.47
25	40	W24X62	W27X84	8.33	11.6	123	-96	34.6	$ 70.39
30	40	W27X84	W27X84	10.00	10.5	117	-96	34.6	$ 67.00
35	40	W30X108	W24X68	8.75	10.5	116	-96	37.7	$ 66.91
40	40	W33X130	W24X62	10.00	9.5	110	-96	41.0	$ 63.85
45	40	W40X149	W24X62	11.25	9.2	109	-96	46.1	$ 63.21
50	40	W40X167	W24X55	10.00	9.7	112	-96	46.5	$ 64.53
25	45	W24X68	W30X90	8.33	12.3	127	-96	37.4	$ 72.43
30	45	W27X84	W30X90	10.00	10.9	119	-96	37.4	$ 68.10
35	45	W30X116	W27X84	8.75	12.2	127	-96	37.9	$ 72.03
40	45	W36X135	W27X84	10.00	11.4	122	-96	43.5	$ 69.70
45	45	W36X160	W24X76	11.25	10.3	116	-96	43.9	$ 66.43
50	45	W40X183	W24X76	10.00	11.7	124	-96	46.9	$ 70.50
25	50	W24X76	W30X99	8.33	13.4	134	-96	37.6	$ 75.70
30	50	W30X90	W30X99	10.00	11.7	124	-96	37.6	$ 70.60
35	50	W33X118	W30X90	8.75	12.6	129	-96	40.8	$ 73.44
40	50	W40X149	W27X84	10.00	11.4	122	-96	46.1	$ 69.64
45	50	W40X167	W30X90	11.25	11.3	122	-96	46.5	$ 69.52
50	50	W40X199	W30X90	10.00	13.0	131	-96	46.6	$ 74.44

Table 6 - Results, Hybrid Steel WF Floor Assembly with 3-Ply CLT, Commercial

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W21X44	24LH15	8.33	6.3	83	-96	33.6	$ 55.60
30	25	W24X55	24LH15	10.00	6.0	83	-96	36.5	$ 54.45
35	25	W24X76	24LH12	8.75	6.1	85	-96	36.8	$ 54.65
40	25	W30X90	24LH12	10.00	6.3	87	-96	42.4	$ 55.08
45	25	W30X108	24LH12	11.25	6.7	90	-96	42.7	$ 56.26
50	25	W33X130	24LH11	10.00	7.7	95	-96	46.0	$ 59.23
25	30	W21X50	28LH16	8.33	6.7	85	-96	35.9	$ 56.88
30	30	W24X62	28LH16	10.00	6.3	84	-96	36.6	$ 55.35
35	30	W27X84	28LH14	8.75	6.8	87	-96	39.6	$ 56.90
40	30	W30X99	28LH13	10.00	6.3	86	-96	42.6	$ 55.15
45	30	W33X118	24LH14	11.25	7.0	90	-96	45.8	$ 57.41
50	30	W36X135	28LH13	10.00	7.5	93	-96	48.5	$ 58.75
25	35	W24X55	32LH17	8.33	7.5	88	-96	39.9	$ 59.32
30	35	W24X76	32LH17	10.00	7.1	87	-96	39.9	$ 57.94
35	35	W30X90	32LH14	8.75	6.3	85	-96	42.4	$ 55.47
40	35	W30X116	32LH15	10.00	6.8	88	-96	42.9	$ 56.82
45	35	W33X130	28LH16	11.25	7.4	91	-96	46.0	$ 58.78
50	35	W40X149	32LH15	10.00	7.8	94	-96	51.1	$ 59.65
25	40	W24X62	36LH17	8.33	7.4	87	-96	43.9	$ 59.26
30	40	W27X84	36LH17	10.00	7.0	87	-96	43.9	$ 57.73
35	40	W30X108	36LH15	8.75	6.8	87	-96	43.9	$ 56.97
40	40	W33X118	32LH16	10.00	7.2	89	-96	45.8	$ 58.00
45	40	W40X149	36LH16	11.25	7.6	92	-96	51.1	$ 59.39
50	40	W40X167	32LH16	10.00	8.4	96	-96	51.5	$ 61.68
25	45	W24X68	40LH18	8.33	8.2	91	-96	47.9	$ 61.87
30	45	W27X84	40LH18	10.00	7.5	88	-96	47.9	$ 59.30
35	45	W30X116	40LH16	8.75	7.4	89	-96	47.9	$ 58.83
40	45	W33X130	44LH17	10.00	7.6	91	-96	51.9	$ 59.44
45	45	W40X149	40LH18	11.25	8.3	94	-96	53.6	$ 61.61
50	45	W36X182	44LH18	10.00	9.7	102	-96	51.9	$ 66.16
25	50	W24X76	44LH18	8.33	8.4	91	-96	51.9	$ 62.29
30	50	W30X90	44LH18	10.00	7.5	88	-96	51.9	$ 59.43
35	50	W33X118	44LH17	8.75	7.7	90	-96	51.9	$ 60.04
40	50	W40X149	40LH18	10.00	8.6	95	-96	53.6	$ 62.64
45	50	W40X167	48LH18	11.25	8.4	95	-96	55.9	$ 61.99
50	50	W40X199	44LH18	10.00	9.7	101	-96	54.1	$ 65.97

Table 7 - Results, Hybrid OWSJ Floor Assembly with 3-Ply CLT, Commercial

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W21X50	W18X35	12.50	4.8	92	-160	31.4	$ 56.90
30	25	W24X62	W18X35	15.00	4.8	92	-160	34.3	$ 56.94
35	25	W24X76	W16X31	11.67	5.7	97	-160	34.5	$ 59.59
40	25	W30X90	W18X35	13.33	6.2	101	-160	40.1	$ 61.18
45	25	W30X108	W18X35	15.00	6.7	103	-160	40.4	$ 62.46
50	25	W33X130	W18X40	16.67	7.6	109	-160	43.7	$ 65.30
25	30	W24X55	W21X44	12.50	5.4	95	-160	34.2	$ 58.56
30	30	W24X76	W21X44	15.00	5.5	96	-160	34.5	$ 58.90
35	30	W27X84	W21X44	11.67	6.6	103	-160	37.3	$ 62.21
40	30	W30X99	W21X44	13.33	6.6	103	-160	40.3	$ 62.30
45	30	W33X118	W21X44	15.00	6.9	104	-160	43.5	$ 63.10
50	30	W36X135	W21X50	16.67	7.5	108	-160	46.2	$ 65.00
25	35	W24X62	W24X55	12.50	6.2	100	-160	34.3	$ 61.01
30	35	W27X84	W24X55	15.00	6.1	100	-160	37.3	$ 60.70
35	35	W30X90	W24X55	11.67	7.3	107	-160	40.1	$ 64.36
40	35	W30X108	W24X55	13.33	7.2	106	-160	40.4	$ 64.13
45	35	W33X130	W24X55	15.00	7.4	107	-160	43.7	$ 64.64
50	35	W40X149	W24X62	16.67	8.0	111	-160	48.8	$ 66.43
25	40	W24X68	W24X68	12.50	7.1	106	-160	34.3	$ 63.92
30	40	W27X84	W24X76	15.00	7.2	106	-160	37.3	$ 64.00
35	40	W30X99	W24X62	11.67	7.8	110	-160	40.3	$ 65.87
40	40	W33X118	W24X68	13.33	8.1	111	-160	43.5	$ 66.65
45	40	W36X135	W24X76	15.00	8.4	114	-160	46.2	$ 67.83
50	40	W36X160	W27X84	16.67	9.0	117	-160	46.6	$ 69.62
25	45	W24X76	W27X84	12.50	8.4	114	-160	37.3	$ 67.73
30	45	W30X90	W27X84	15.00	7.6	109	-160	40.1	$ 65.30
35	45	W30X108	W27X84	11.67	9.6	121	-160	40.4	$ 71.30
40	45	W33X130	W27X84	13.33	9.2	118	-160	43.7	$ 70.07
45	45	W40X149	W27X84	15.00	8.9	117	-160	48.8	$ 69.23
50	45	W40X167	W30X90	16.67	9.1	118	-160	49.2	$ 69.83
25	50	W27X84	W30X90	12.50	8.9	116	-160	40.1	$ 69.14
30	50	W30X99	W30X99	15.00	8.6	115	-160	40.3	$ 68.24
35	50	W30X116	W30X90	11.67	10.0	123	-160	40.6	$ 72.60
40	50	W36X135	W30X90	13.33	9.5	120	-160	46.2	$ 70.85
45	50	W36X160	W30X99	15.00	9.8	122	-160	46.6	$ 71.90
50	50	W40X183	W30X108	16.67	10.1	124	-160	49.6	$ 72.92

Table 8 - Results, Hybrid Steel WF Floor Assembly with 5-Ply CLT, Commercial

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W21X50	24LH13	12.50	4.6	86	-160	36.4	$ 56.82
30	25	W24X62	24LH14	15.00	4.8	88	-160	39.3	$ 57.52
35	25	W24X76	24LH13	11.67	5.8	93	-160	39.5	$ 60.53
40	25	W30X90	24LH13	13.33	6.0	95	-160	45.1	$ 61.10
45	25	W30X108	24LH14	15.00	6.7	99	-160	45.4	$ 63.04
50	25	W33X130	18LH17	16.67	8.2	107	-160	48.7	$ 67.85
25	30	W24X55	28LH15	12.50	4.9	87	-160	39.2	$ 57.88
30	30	W24X76	28LH16	15.00	5.3	90	-160	39.5	$ 59.20
35	30	W27X84	28LH14	11.67	5.8	92	-160	42.3	$ 60.65
40	30	W30X99	24LH16	13.33	6.5	96	-160	45.3	$ 62.64
45	30	W33X118	28LH16	15.00	6.7	98	-160	48.5	$ 63.40
50	30	W40X149	20LH19	16.67	9.1	110	-160	56.3	$ 70.86
25	35	W24X62	32LH16	12.50	5.1	88	-160	42.6	$ 58.73
30	35	W27X84	28LH18	15.00	6.1	93	-160	44.8	$ 61.83
35	35	W30X90	28LH16	11.67	6.2	94	-160	45.1	$ 61.91
40	35	W30X108	28LH17	13.33	6.8	97	-160	45.4	$ 63.70
45	35	W33X130	28LH18	15.00	7.4	101	-160	51.2	$ 65.78
50	35	W40X149	32LH16	16.67	6.8	99	-160	53.8	$ 63.46
25	40	W24X68	36LH17	12.50	5.6	90	-160	46.6	$ 60.34
30	40	W27X84	32LH19	15.00	6.2	93	-160	44.8	$ 62.23
35	40	W30X99	32LH17	11.67	6.7	95	-160	45.3	$ 63.58
40	40	W33X118	40LH18	13.33	7.2	98	-160	51.0	$ 65.00
45	40	W36X135	32LH19	15.00	7.5	101	-160	53.7	$ 66.06
50	40	W40X167	36LH17	16.67	7.1	100	-160	54.2	$ 64.58
25	45	W24X76	44LH18	12.50	6.2	92	-160	54.6	$ 62.39
30	45	W27X84	44LH17	15.00	5.0	87	-160	54.6	$ 58.28
35	45	W30X108	40LH18	11.67	7.2	97	-160	50.6	$ 65.30
40	45	W33X130	36LH19	13.33	7.7	100	-160	51.2	$ 66.77
45	45	W36X160	40LH18	15.00	7.3	100	-160	54.1	$ 65.30
50	45	W40X183	44LH18	16.67	7.5	102	-160	57.1	$ 65.82
25	50	W27X84	48LH19	12.50	6.6	94	-160	58.6	$ 63.66
30	50	W30X99	44LH20	15.00	7.4	98	-160	54.6	$ 66.21
35	50	W30X116	48LH19	11.67	7.6	99	-160	58.6	$ 66.73
40	50	W36X135	36LH20	13.33	8.8	104	-160	53.7	$ 70.34
45	50	W36X160	44LH20	15.00	8.7	105	-160	54.6	$ 69.87
50	50	W40X199	48LH19	16.67	7.7	102	-160	58.6	$ 66.53

Table 9 - Results, Hybrid OWSJ Floor Assembly with 5-Ply CLT, Commercial

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W21X50	W18X35	12.50	4.8	102	-224	34.2	$ 64.90
30	25	W24X68	W18X35	15.00	5.1	103	-224	37.1	$ 65.66
35	25	W27X84	W18X40	17.50	5.6	107	-224	40.1	$ 67.44
40	25	W30X90	W21X44	20.00	5.8	108	-224	42.9	$ 67.90
45	25	W30X116	W18X35	15.00	7.0	114	-224	43.4	$ 71.42
50	25	W33X130	W18X40	16.67	7.6	118	-224	46.5	$ 73.30
25	30	W24X55	W21X44	12.50	5.4	105	-224	37.0	$ 66.56
30	30	W24X76	W21X50	15.00	5.9	108	-224	37.3	$ 68.10
35	30	W30X90	W24X55	17.50	6.1	110	-224	42.9	$ 68.93
40	30	W30X108	W24X55	20.00	6.4	111	-224	43.2	$ 69.55
45	30	W33X118	W21X50	15.00	7.3	116	-224	46.3	$ 72.30
50	30	W36X135	W21X50	16.67	7.5	118	-224	49.0	$ 73.00
25	35	W24X68	W24X55	12.50	6.3	111	-224	37.1	$ 69.53
30	35	W27X84	W24X62	15.00	6.5	112	-224	40.1	$ 70.10
35	35	W30X99	W24X68	17.50	6.7	113	-224	43.1	$ 70.64
40	35	W33X118	W24X76	20.00	7.2	116	-224	46.3	$ 72.01
45	35	W33X130	W24X62	15.00	7.8	120	-224	46.5	$ 74.04
50	35	W40X149	W24X62	16.67	8.0	120	-224	51.6	$ 74.43
25	40	W24X76	W24X68	12.50	7.3	117	-224	37.3	$ 72.52
30	40	W30X90	W24X76	15.00	7.3	117	-224	42.9	$ 72.45
35	40	W30X116	W27X84	17.50	7.7	119	-224	43.4	$ 73.60
40	40	W33X130	W27X84	20.00	7.5	117	-224	46.5	$ 72.85
45	40	W40X149	W24X76	15.00	8.8	125	-224	51.6	$ 76.88
50	40	W40X167	W27X84	16.67	9.2	128	-224	52.0	$ 78.15
25	45	W27X84	W27X84	12.50	8.6	124	-224	40.1	$ 76.26
30	45	W30X99	W30X90	15.00	8.2	122	-224	43.1	$ 75.10
35	45	W33X118	W30X90	17.50	7.8	119	-224	46.3	$ 73.80
40	45	W33X141	W30X99	20.00	8.1	121	-224	46.7	$ 74.75
45	45	W40X149	W30X90	15.00	9.3	128	-224	51.6	$ 78.43
50	45	W40X183	W30X90	16.67	9.5	129	-224	52.4	$ 78.90
25	50	W27X84	W30X90	12.50	8.9	126	-224	42.9	$ 77.14
30	50	W30X108	W30X108	15.00	9.4	129	-224	43.2	$ 78.58
35	50	W33X130	W30X116	17.50	9.2	128	-224	46.5	$ 78.19
40	50	W40X149	W33X118	20.00	8.9	126	-224	51.6	$ 77.14
45	50	W40X167	W30X108	15.00	10.5	136	-224	52.0	$ 82.12
50	50	W40X199	W30X116	16.67	10.9	138	-224	52.1	$ 83.32

Table 10 - Results, Hybrid Steel WF Floor Assembly with 7-Ply CLT, Commercial

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W21X50	24LH13	12.50	4.6	95	-224	39.2	$ 64.82
30	25	W24X68	24LH15	15.00	5.3	100	-224	42.1	$ 66.89
35	25	W27X84	18LH17	17.50	6.2	105	-224	45.1	$ 69.87
40	25	W30X90	18LH17	20.00	6.1	105	-224	47.9	$ 69.43
45	25	W30X116	24LH15	15.00	7.2	111	-224	48.4	$ 72.65
50	25	W33X130	18LH17	16.67	8.2	116	-224	51.5	$ 75.85
25	30	W24X55	28LH15	12.50	4.9	96	-224	42.0	$ 65.88
30	30	W24X76	24LH17	15.00	5.8	101	-224	42.3	$ 68.72
35	30	W27X84	20LH19	17.50	6.7	106	-224	47.6	$ 71.71
40	30	W30X99	20LH19	20.00	6.8	107	-224	50.6	$ 71.61
45	30	W33X118	24LH17	15.00	7.2	110	-224	51.3	$ 72.92
50	30	W40X149	20LH19	16.67	9.1	119	-224	59.1	$ 78.86
25	35	W24X68	28LH17	12.50	5.9	101	-224	42.1	$ 69.07
30	35	W27X84	20LH20	15.00	8.2	111	-224	47.6	$ 76.55
35	35	W30X90	32LH16	17.50	5.0	98	-224	47.9	$ 66.01
40	35	W30X116	32LH17	20.00	5.8	103	-224	48.4	$ 68.41
45	35	W36X135	28LH16	15.00	6.7	107	-224	54.0	$ 71.17
50	35	W40X167	28LH17	16.67	7.7	113	-224	57.0	$ 74.37
25	40	W24X68	40LH17	12.50	5.8	100	-224	53.4	$ 68.86
30	40	W30X90	36LH19	15.00	6.5	104	-224	50.4	$ 71.12
35	40	W30X108	24LH21	17.50	7.7	110	-224	50.7	$ 74.94
40	40	W33X118	40LH18	20.00	5.8	102	-224	53.8	$ 68.45
45	40	W33X141	36LH19	15.00	7.8	111	-224	54.2	$ 74.94
50	40	W36X182	40LH17	16.67	7.6	113	-224	54.7	$ 74.10
25	45	W24X76	36LH19	12.50	6.8	104	-224	49.4	$ 72.21
30	45	W30X90	40LH17	15.00	5.4	99	-224	53.4	$ 67.55
35	45	W30X116	40LH18	17.50	5.8	101	-224	53.4	$ 68.63
40	45	W33X130	40LH19	20.00	6.1	103	-224	54.0	$ 69.57
45	45	W40X167	40LH18	15.00	7.4	110	-224	59.5	$ 73.77
50	45	W40X199	36LH19	16.67	8.3	115	-224	59.6	$ 76.25
25	50	W27X84	48LH19	12.50	6.6	103	-224	61.4	$ 71.66
30	50	W30X108	44LH20	15.00	7.6	108	-224	57.4	$ 74.75
35	50	W33X118	48LH19	17.50	5.9	102	-224	61.4	$ 69.09
40	50	W33X141	40LH20	20.00	6.9	106	-224	54.2	$ 72.12
45	50	W40X167	44LH20	15.00	8.8	115	-224	59.5	$ 78.29
50	50	W40X211	48LH19	16.67	7.9	113	-224	61.4	$ 75.25

Table 11 - Results, Hybrid OWSJ Floor Assembly with 7-Ply CLT, Commercial

Appendix B: Commercial Roof Bay Study Results

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W16X26	W14X22	12.50	6.4	47	0.0	22.2	$ 17.60
30	25	W18X35	W12X19	10.00	6.9	50	0.0	24.2	$ 19.10
35	25	W21X44	W14X22	11.67	7.2	52	0.0	27.2	$ 20.14
40	25	W24X55	W12X19	10.00	7.7	55	0.0	30.1	$ 21.50
45	25	W24X68	W14X22	11.25	8.2	58	0.0	30.2	$ 23.23
50	25	W27X84	W14X22	12.50	8.7	61	0.0	33.2	$ 24.56
25	30	W16X26	W16X26	12.50	6.5	48	0.0	22.2	$ 18.04
30	30	W18X40	W16X26	10.00	7.5	54	0.0	24.4	$ 21.00
35	30	W21X50	W16X26	11.67	7.5	53	0.0	27.3	$ 20.89
40	30	W24X62	W16X26	10.00	8.2	58	0.0	30.2	$ 23.20
45	30	W27X84	W16X26	11.25	8.7	61	0.0	33.2	$ 24.53
50	30	W30X90	W16X26	12.50	8.6	61	0.0	36.0	$ 24.44
25	35	W16X31	W18X35	12.50	7.2	52	0.0	24.2	$ 20.26
30	35	W21X44	W16X31	10.00	7.9	56	0.0	27.2	$ 22.27
35	35	W24X55	W18X35	11.67	8.1	57	0.0	30.1	$ 22.91
40	35	W24X68	W16X31	10.00	8.6	60	0.0	30.2	$ 24.33
45	35	W27X84	W18X35	11.25	9.1	63	0.0	33.2	$ 25.73
50	35	W30X90	W18X35	12.50	8.9	62	0.0	36.0	$ 25.31
25	40	W18X35	W21X44	12.50	8.0	56	0.0	27.2	$ 22.39
30	40	W21X44	W18X40	10.00	8.7	61	0.0	27.2	$ 24.50
35	40	W24X55	W18X40	11.67	8.4	59	0.0	30.1	$ 23.61
40	40	W24X76	W18X40	10.00	9.5	65	0.0	30.4	$ 26.90
45	40	W30X90	W18X40	11.25	9.4	65	0.0	36.0	$ 26.62
50	40	W27X102	W21X44	12.50	9.6	66	0.0	33.6	$ 27.41
25	45	W18X35	W21X50	12.50	8.3	59	0.0	27.3	$ 23.53
30	45	W21X50	W21X44	10.00	9.1	63	0.0	27.3	$ 25.73
35	45	W24X62	W21X50	11.67	9.2	64	0.0	30.2	$ 26.19
40	45	W27X84	W21X44	10.00	9.8	68	0.0	33.2	$ 28.00
45	45	W30X90	W21X44	11.25	9.5	65	0.0	36.0	$ 26.93
50	45	W30X108	W21X50	12.50	10.0	68	0.0	36.3	$ 28.40
25	50	W18X40	W24X55	12.50	8.8	61	0.0	30.1	$ 24.80
30	50	W24X55	W24X55	10.00	10.2	70	0.0	30.1	$ 29.00
35	50	W24X68	W24X55	11.67	9.6	66	0.0	30.2	$ 27.42
40	50	W27X84	W24X55	10.00	10.7	73	0.0	33.2	$ 30.74
45	50	W30X99	W24X55	11.25	10.4	71	0.0	36.2	$ 29.81
50	50	W30X108	W24X55	12.50	10.1	69	0.0	36.3	$ 28.88

Table 12 - Results, Conventional Steel WF Roof Assembly, Commercial

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W16X31	18LH02	5.00	5.4	34	0.0	25.9	$ 18.22
30	25	W18X40	18LH02	5.00	5.7	36	0.0	27.9	$ 19.30
35	25	W21X50	18LH02	5.00	6.1	38	0.0	30.8	$ 20.50
40	25	W24X55	18LH02	5.00	6.3	39	0.0	33.6	$ 21.10
45	25	W24X76	18LH02	5.00	7.2	44	0.0	33.9	$ 23.62
50	25	W27X84	18LH02	5.00	7.5	46	0.0	36.7	$ 24.58
25	30	W16X31	18LH02	5.00	5.2	33	0.0	25.9	$ 17.60
30	30	W21X44	18LH02	5.00	5.6	35	0.0	30.7	$ 18.90
35	30	W24X55	18LH02	5.00	6.0	37	0.0	33.6	$ 20.00
40	30	W24X62	18LH02	5.00	6.2	39	0.0	33.7	$ 20.70
45	30	W27X84	18LH02	5.00	6.9	43	0.0	36.7	$ 22.90
50	30	W30X90	18LH02	5.00	7.1	44	0.0	39.5	$ 23.50
25	35	W18X35	20LH03	5.00	5.3	33	0.0	27.7	$ 18.15
30	35	W21X44	20LH03	5.00	5.6	35	0.0	30.7	$ 18.92
35	35	W24X55	20LH03	5.00	5.9	37	0.0	33.6	$ 19.86
40	35	W24X68	20LH03	5.00	6.3	39	0.0	33.7	$ 20.98
45	35	W27X84	20LH03	5.00	6.7	41	0.0	36.7	$ 22.35
50	35	W30X90	20LH03	5.00	6.9	43	0.0	39.5	$ 22.86
25	40	W18X35	24LH04	5.00	5.4	33	0.0	29.0	$ 18.43
30	40	W21X50	24LH04	5.00	5.8	35	0.0	30.8	$ 19.55
35	40	W24X62	24LH04	5.00	6.1	37	0.0	33.7	$ 20.45
40	40	W24X76	24LH04	5.00	6.4	39	0.0	33.9	$ 21.50
45	40	W30X90	24LH04	5.00	6.8	41	0.0	39.5	$ 22.55
50	40	W30X108	24LH04	5.00	7.2	44	0.0	39.8	$ 23.90
25	45	W18X40	28LH05	5.00	5.6	34	0.0	33.0	$ 19.12
30	45	W21X50	28LH05	5.00	5.9	35	0.0	33.0	$ 19.78
35	45	W24X62	28LH05	5.00	6.1	37	0.0	33.7	$ 20.58
40	45	W27X84	28LH05	5.00	6.6	40	0.0	36.7	$ 22.05
45	45	W30X90	28LH05	5.00	6.7	41	0.0	39.5	$ 22.45
50	45	W30X116	28LH05	5.00	7.3	44	0.0	40.0	$ 24.18
25	50	W21X44	32LH06	5.00	5.8	35	0.0	37.0	$ 19.74
30	50	W24X55	32LH06	5.00	6.0	36	0.0	37.0	$ 20.40
35	50	W24X68	32LH06	5.00	6.3	38	0.0	37.0	$ 21.18
40	50	W27X84	32LH06	5.00	6.6	40	0.0	37.0	$ 22.14
45	50	W30X99	32LH06	5.00	6.9	41	0.0	39.7	$ 23.04
50	50	W33X118	32LH06	5.00	7.3	44	0.0	42.9	$ 24.18

Table 13 - Results, Conventional OWSJ Roof Assembly, Commercial

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W16X31	W12X19	8.33	3.5	35	-96	20.0	$ 33.31
30	25	W18X40	W14X22	10.00	3.8	37	-96	22.0	$ 34.15
35	25	W21X50	W14X22	11.67	3.9	37	-96	24.9	$ 34.41
40	25	W24X62	W14X22	10.00	4.7	42	-96	27.8	$ 36.79
45	25	W27X84	W14X22	11.25	5.3	46	-96	30.8	$ 38.70
50	25	W30X90	W14X22	10.00	5.8	49	-96	33.6	$ 40.15
25	30	W18X35	W16X26	8.33	4.3	40	-96	21.8	$ 35.61
30	30	W21X44	W16X26	10.00	4.1	38	-96	24.8	$ 34.95
35	30	W24X55	W16X26	11.67	4.1	38	-96	27.7	$ 34.94
40	30	W24X68	W16X26	10.00	4.9	43	-96	27.8	$ 37.35
45	30	W27X84	W16X26	11.25	5.1	45	-96	30.8	$ 38.08
50	30	W30X90	W16X26	10.00	5.6	48	-96	33.6	$ 39.55
25	35	W18X35	W16X31	8.33	4.7	42	-96	21.8	$ 36.91
30	35	W21X50	W18X35	10.00	4.9	44	-96	24.9	$ 37.54
35	35	W24X62	W18X35	11.67	4.8	43	-96	27.8	$ 37.06
40	35	W24X76	W18X35	10.00	5.7	48	-96	28.0	$ 39.76
45	35	W30X90	W18X35	11.25	5.7	48	-96	33.6	$ 39.80
50	35	W30X108	W18X35	10.00	6.6	53	-96	33.9	$ 42.51
25	40	W18X40	W18X35	8.33	5.2	45	-96	22.0	$ 38.35
30	40	W24X55	W18X40	10.00	5.4	46	-96	27.7	$ 38.88
35	40	W24X68	W21X44	11.67	5.5	47	-96	27.8	$ 39.16
40	40	W27X84	W18X40	10.00	6.1	51	-96	30.8	$ 41.05
45	40	W30X90	W21X44	11.25	6.2	51	-96	33.6	$ 41.23
50	40	W30X116	W18X40	10.00	6.9	55	-96	34.1	$ 43.45
25	45	W21X44	W21X44	8.33	6.3	51	-96	24.8	$ 41.52
30	45	W24X55	W21X44	10.00	5.6	48	-96	27.7	$ 39.62
35	45	W24X68	W21X50	11.67	5.8	49	-96	27.8	$ 40.14
40	45	W27X84	W21X44	10.00	6.3	52	-96	30.8	$ 41.55
45	45	W30X99	W21X50	11.25	6.6	54	-96	33.8	$ 42.68
50	45	W33X118	W21X44	10.00	7.0	56	-96	37.0	$ 43.82
25	50	W21X50	W21X50	8.33	7.0	56	-96	24.9	$ 43.75
30	50	W24X62	W24X55	10.00	6.7	54	-96	27.8	$ 42.97
35	50	W24X76	W24X55	11.67	6.2	51	-96	28.0	$ 41.45
40	50	W30X90	W24X55	10.00	7.3	58	-96	33.6	$ 44.65
45	50	W30X108	W24X55	11.25	7.0	56	-96	33.9	$ 43.90
50	50	W33X130	W24X55	10.00	8.1	62	-96	37.2	$ 47.05

Table 14 - Results, Hybrid Steel WF Roof Assembly with 3-Ply CLT, Commercial

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W16X31	24LH05	8.33	2.8	28	-96	28.1	$ 31.54
30	25	W18X40	18LH06	10.00	3.1	30	-96	27.0	$ 32.43
35	25	W21X50	20LH07	11.67	3.5	32	-96	29.9	$ 33.49
40	25	W24X62	18LH06	10.00	4.0	35	-96	32.8	$ 35.07
45	25	W24X76	24LH06	11.25	4.5	38	-96	33.0	$ 36.49
50	25	W30X90	18LH06	10.00	5.1	42	-96	38.6	$ 38.43
25	30	W18X35	24LH06	8.33	3.1	29	-96	28.1	$ 32.49
30	30	W21X44	28LH07	10.00	3.2	30	-96	32.1	$ 32.68
35	30	W24X55	24LH09	11.67	3.6	32	-96	32.7	$ 34.10
40	30	W24X68	28LH07	10.00	4.0	35	-96	32.8	$ 35.08
45	30	W27X84	24LH09	11.25	4.7	38	-96	35.8	$ 37.22
50	30	W30X90	28LH07	10.00	4.7	39	-96	38.6	$ 37.28
25	35	W18X35	32LH08	8.33	3.0	28	-96	36.1	$ 32.38
30	35	W21X50	28LH09	10.00	3.5	31	-96	32.1	$ 33.86
35	35	W24X55	32LH10	11.67	3.4	31	-96	36.1	$ 33.31
40	35	W24X76	28LH09	10.00	4.3	36	-96	33.0	$ 36.09
45	35	W30X90	32LH10	11.25	4.4	37	-96	38.6	$ 36.53
50	35	W30X108	28LH09	10.00	5.2	41	-96	38.9	$ 38.83
25	40	W18X40	28LH09	8.33	3.5	30	-96	32.1	$ 33.94
30	40	W21X50	40LH11	10.00	3.5	31	-96	44.1	$ 33.65
35	40	W24X68	36LH12	11.67	3.8	33	-96	40.1	$ 34.81
40	40	W27X84	40LH11	10.00	4.3	36	-96	44.1	$ 36.20
45	40	W30X90	36LH12	11.25	4.5	37	-96	40.1	$ 36.72
50	40	W30X116	40LH11	10.00	5.1	40	-96	44.1	$ 38.60
25	45	W21X44	40LH11	8.33	3.6	31	-96	44.1	$ 34.26
30	45	W24X55	36LH12	10.00	3.7	32	-96	40.1	$ 34.54
35	45	W24X68	32LH13	11.67	4.1	34	-96	36.1	$ 35.64
40	45	W27X84	36LH12	10.00	4.4	36	-96	40.1	$ 36.48
45	45	W30X99	32LH13	11.25	4.9	38	-96	38.8	$ 38.02
50	45	W33X118	36LH12	10.00	5.1	40	-96	42.0	$ 38.74
25	50	W21X44	36LH12	8.33	3.9	32	-96	40.1	$ 35.14
30	50	W24X55	36LH13	10.00	4.1	33	-96	40.1	$ 35.80
35	50	W24X76	44LH14	11.67	4.2	34	-96	48.1	$ 35.95
40	50	W30X90	36LH13	10.00	4.8	37	-96	40.1	$ 37.90
45	50	W30X108	44LH14	11.25	4.9	38	-96	48.1	$ 38.19
50	50	W33X118	36LH13	10.00	5.4	41	-96	42.0	$ 39.58

Table 15 - Results, Hybrid OWSJ Roof Assembly with 3-Ply CLT, Commercial

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W18X35	W14X22	12.50	3.2	42	-160	24.6	$ 39.23
30	25	W21X44	W16X26	15.00	3.5	44	-160	27.6	$ 40.23
35	25	W24X55	W14X22	11.67	4.1	48	-160	30.5	$ 42.01
40	25	W24X68	W16X26	13.33	4.7	51	-160	30.6	$ 43.76
45	25	W27X84	W16X26	15.00	5.1	54	-160	33.6	$ 45.03
50	25	W30X90	W16X26	16.67	5.2	54	-160	36.4	$ 45.23
25	30	W18X35	W16X31	12.50	3.6	45	-160	24.6	$ 40.69
30	30	W21X44	W18X35	15.00	3.8	46	-160	27.6	$ 41.15
35	30	W24X55	W16X31	11.67	4.5	50	-160	30.5	$ 43.22
40	30	W24X76	W16X31	13.33	4.9	53	-160	30.8	$ 44.33
45	30	W27X84	W18X35	15.00	5.1	54	-160	33.6	$ 45.15
50	30	W30X99	W18X35	16.67	5.4	56	-160	36.6	$ 45.95
25	35	W18X40	W18X40	12.50	4.3	49	-160	24.8	$ 42.78
30	35	W21X50	W21X44	15.00	4.4	50	-160	27.7	$ 42.84
35	35	W24X62	W18X35	11.67	4.8	52	-160	30.6	$ 44.06
40	35	W27X84	W18X40	13.33	5.4	56	-160	33.6	$ 45.95
45	35	W30X90	W21X44	15.00	5.5	56	-160	36.4	$ 46.26
50	35	W30X116	W21X44	16.67	6.0	59	-160	36.9	$ 47.61
25	40	W21X44	W21X44	12.50	4.6	51	-160	27.6	$ 43.61
30	40	W24X55	W21X50	15.00	4.7	52	-160	30.5	$ 43.88
35	40	W24X68	W21X44	11.67	5.5	56	-160	30.6	$ 46.16
40	40	W27X84	W21X50	13.33	5.9	58	-160	33.6	$ 47.30
45	40	W30X99	W21X50	15.00	5.8	58	-160	36.6	$ 47.18
50	40	W33X118	W24X55	16.67	6.3	61	-160	39.8	$ 48.50
25	45	W21X44	W24X55	12.50	5.4	56	-160	30.5	$ 45.88
30	45	W24X62	W24X62	15.00	5.5	56	-160	30.6	$ 46.28
35	45	W24X76	W24X55	11.67	6.4	62	-160	30.8	$ 48.96
40	45	W30X90	W24X55	13.33	6.1	60	-160	36.4	$ 48.13
45	45	W30X108	W24X62	15.00	6.5	63	-160	36.7	$ 49.35
50	45	W33X118	W24X62	16.67	6.3	61	-160	39.8	$ 48.78
25	50	W21X50	W24X68	12.50	6.4	62	-160	30.6	$ 49.07
30	50	W24X62	W24X76	15.00	6.3	61	-160	30.8	$ 48.67
35	50	W27X84	W24X62	11.67	7.0	65	-160	33.6	$ 50.73
40	50	W30X90	W24X68	13.33	6.9	65	-160	36.4	$ 50.45
45	50	W30X116	W24X76	15.00	7.4	68	-160	36.9	$ 51.91
50	50	W33X130	W27X84	16.67	7.6	69	-160	40.0	$ 52.67

Table 16 - Results, Hybrid Steel WF Roof Assembly with 5-Ply CLT, Commercial

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W18X35	24LH08	12.50	2.8	38	-160	30.9	$ 38.63
30	25	W21X44	24LH09	15.00	3.2	40	-160	32.6	$ 39.58
35	25	W24X55	24LH07	11.67	3.7	43	-160	35.5	$ 41.09
40	25	W24X68	24LH09	13.33	4.3	46	-160	35.6	$ 43.03
45	25	W27X84	24LH09	15.00	4.8	49	-160	38.6	$ 44.38
50	25	W30X90	24LH09	16.67	4.9	50	-160	41.4	$ 44.65
25	30	W18X35	28LH09	12.50	2.8	37	-160	34.9	$ 38.71
30	30	W21X44	28LH11	15.00	3.1	39	-160	34.9	$ 39.57
35	30	W24X55	24LH09	11.67	3.6	42	-160	35.5	$ 41.10
40	30	W24X76	28LH10	13.33	4.3	46	-160	35.8	$ 42.96
45	30	W27X84	28LH11	15.00	4.5	47	-160	38.6	$ 43.57
50	30	W30X99	28LH12	16.67	4.9	50	-160	41.6	$ 44.92
25	35	W18X40	28LH12	12.50	3.3	39	-160	34.9	$ 40.20
30	35	W21X50	28LH13	15.00	3.4	40	-160	34.9	$ 40.54
35	35	W24X62	32LH11	11.67	3.8	43	-160	38.9	$ 41.75
40	35	W27X84	28LH12	13.33	4.4	46	-160	38.6	$ 43.53
45	35	W30X90	28LH13	15.00	4.6	47	-160	41.4	$ 43.96
50	35	W30X108	32LH13	16.67	4.9	49	-160	41.7	$ 44.86
25	40	W21X44	32LH13	12.50	3.5	40	-160	38.9	$ 40.85
30	40	W24X55	32LH15	15.00	3.7	41	-160	38.9	$ 41.46
35	40	W24X68	36LH12	11.67	3.8	43	-160	42.9	$ 41.81
40	40	W27X84	32LH13	13.33	4.4	45	-160	38.9	$ 43.36
45	40	W30X99	32LH15	15.00	4.8	48	-160	41.6	$ 44.76
50	40	W33X118	36LH15	16.67	5.1	50	-160	44.8	$ 45.62
25	45	W21X44	40LH14	12.50	3.8	41	-160	46.9	$ 41.78
30	45	W24X55	44LH15	15.00	3.6	41	-160	50.9	$ 41.22
35	45	W24X76	32LH15	11.67	4.7	46	-160	38.9	$ 44.57
40	45	W30X90	36LH15	13.33	4.7	47	-160	42.9	$ 44.53
45	45	W30X108	44LH15	15.00	4.8	48	-160	50.9	$ 44.75
50	45	W33X118	40LH16	16.67	5.1	50	-160	46.9	$ 45.81
25	50	W21X50	40LH15	12.50	3.9	41	-160	46.9	$ 42.11
30	50	W24X62	44LH16	15.00	4.0	42	-160	50.9	$ 42.57
35	50	W27X84	40LH15	11.67	4.8	46	-160	46.9	$ 44.82
40	50	W30X90	40LH16	13.33	5.0	47	-160	46.9	$ 45.39
45	50	W30X116	44LH16	15.00	5.1	49	-160	50.9	$ 45.81
50	50	W33X130	44LH17	16.67	5.4	51	-160	50.9	$ 46.72

Table 17 - Results, Hybrid OWSJ Roof Assembly with 5-Ply CLT, Commercial

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W18X35	W16X26	12.50	3.5	54	-224	27.3	$ 48.19
30	25	W21X44	W16X26	15.00	3.5	54	-224	30.3	$ 48.23
35	25	W24X55	W16X26	17.50	3.7	55	-224	33.2	$ 48.81
40	25	W24X68	W16X31	20.00	4.3	58	-224	33.3	$ 50.56
45	25	W27X84	W16X26	15.00	5.1	63	-224	36.3	$ 53.03
50	25	W30X90	W16X26	16.67	5.2	64	-224	39.1	$ 53.23
25	30	W18X40	W16X31	12.50	3.8	56	-224	27.5	$ 49.19
30	30	W21X50	W18X35	15.00	4.0	57	-224	30.4	$ 49.75
35	30	W24X62	W18X35	17.50	4.1	57	-224	33.3	$ 49.95
40	30	W27X84	W18X40	20.00	4.8	62	-224	36.3	$ 52.15
45	30	W30X90	W18X35	15.00	5.3	65	-224	39.1	$ 53.75
50	30	W30X108	W18X35	16.67	5.7	67	-224	39.4	$ 54.85
25	35	W21X44	W18X40	12.50	4.5	60	-224	30.3	$ 51.12
30	35	W24X55	W21X44	15.00	4.5	60	-224	33.2	$ 51.26
35	35	W24X68	W21X44	17.50	4.5	60	-224	33.3	$ 51.12
40	35	W27X84	W21X50	20.00	4.9	62	-224	36.3	$ 52.45
45	35	W30X90	W21X44	15.00	5.5	66	-224	39.1	$ 54.26
50	35	W33X118	W21X44	16.67	6.0	69	-224	42.5	$ 55.78
25	40	W21X44	W21X50	12.50	5.1	63	-224	30.4	$ 53.05
30	40	W24X55	W24X55	15.00	5.0	63	-224	33.2	$ 52.88
35	40	W24X76	W24X55	17.50	5.0	63	-224	33.5	$ 52.88
40	40	W30X90	W24X62	20.00	5.4	65	-224	39.1	$ 53.80
45	40	W30X108	W24X55	15.00	6.4	71	-224	39.4	$ 56.85
50	40	W33X118	W24X55	16.67	6.3	70	-224	42.5	$ 56.50
25	45	W21X50	W24X55	12.50	5.5	66	-224	33.2	$ 54.28
30	45	W24X62	W24X62	15.00	5.5	66	-224	33.3	$ 54.28
35	45	W27X84	W24X68	17.50	5.8	67	-224	36.3	$ 55.01
40	45	W30X90	W24X76	20.00	5.8	68	-224	39.1	$ 55.15
45	45	W30X116	W24X62	15.00	6.7	73	-224	39.6	$ 57.88
50	45	W33X130	W24X68	16.67	7.0	75	-224	42.7	$ 58.66
25	50	W24X55	W24X68	12.50	6.5	72	-224	33.3	$ 57.37
30	50	W24X68	W27X84	15.00	7.0	75	-224	36.3	$ 58.63
35	50	W27X84	W27X84	17.50	6.5	72	-224	36.3	$ 57.19
40	50	W30X99	W27X84	20.00	6.2	70	-224	39.3	$ 56.29
45	50	W33X118	W27X84	15.00	8.0	80	-224	42.5	$ 61.63
50	50	W36X135	W27X84	16.67	7.7	79	-224	45.2	$ 60.97

Table 18 - Results, Hybrid Steel WF Roof Assembly with 7-Ply CLT, Commercial

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
25	25	W18X35	24LH09	12.50	3.1	48	-224	33.6	$ 47.41
30	25	W21X44	24LH09	15.00	3.2	49	-224	35.3	$ 47.58
35	25	W24X55	24LH11	17.50	3.6	52	-224	38.2	$ 48.99
40	25	W24X68	24LH12	20.00	4.1	55	-224	38.3	$ 50.30
45	25	W27X84	24LH09	15.00	4.8	59	-224	41.3	$ 52.38
50	25	W30X90	24LH10	16.67	5.0	60	-224	44.1	$ 53.04
25	30	W18X40	28LH10	12.50	3.2	49	-224	37.6	$ 47.73
30	30	W21X50	24LH12	15.00	3.5	50	-224	35.4	$ 48.60
35	30	W24X62	28LH13	17.50	3.8	52	-224	38.3	$ 49.52
40	30	W27X84	24LH14	20.00	4.6	57	-224	41.3	$ 51.84
45	30	W30X90	24LH12	15.00	4.8	58	-224	44.1	$ 52.60
50	30	W30X108	28LH12	16.67	5.2	61	-224	44.4	$ 53.82
25	35	W18X40	28LH12	12.50	3.3	49	-224	37.6	$ 48.20
30	35	W24X55	32LH13	15.00	3.6	51	-224	41.6	$ 48.96
35	35	W24X68	32LH15	17.50	3.9	53	-224	41.6	$ 50.08
40	35	W27X84	28LH16	20.00	4.5	56	-224	41.3	$ 51.78
45	35	W30X90	32LH13	15.00	4.6	57	-224	44.1	$ 51.96
50	35	W33X118	32LH14	16.67	5.4	61	-224	47.5	$ 54.30
25	40	W21X44	36LH13	12.50	3.5	49	-224	45.6	$ 48.85
30	40	W24X55	36LH15	15.00	3.8	51	-224	45.6	$ 49.68
35	40	W24X76	32LH16	17.50	4.3	54	-224	41.6	$ 51.25
40	40	W30X90	32LH17	20.00	4.7	56	-224	44.1	$ 52.46
45	40	W30X108	36LH15	15.00	5.1	59	-224	45.6	$ 53.65
50	40	W33X118	32LH16	16.67	5.5	61	-224	47.5	$ 54.79
25	45	W21X50	36LH15	12.50	4.0	51	-224	45.6	$ 50.44
30	45	W24X62	40LH16	15.00	4.2	53	-224	49.6	$ 50.98
35	45	W27X84	44LH17	17.50	4.6	55	-224	53.6	$ 52.08
40	45	W30X90	40LH18	20.00	4.8	56	-224	49.6	$ 52.85
45	45	W30X116	40LH16	15.00	5.4	60	-224	49.6	$ 54.58
50	45	W33X130	44LH16	16.67	5.4	61	-224	53.6	$ 54.61
25	50	W24X55	40LH16	12.50	4.5	53	-224	49.6	$ 51.97
30	50	W24X68	44LH17	15.00	4.5	54	-224	53.6	$ 52.01
35	50	W27X84	40LH18	17.50	4.9	56	-224	49.6	$ 53.19
40	50	W30X99	48LH18	20.00	4.8	57	-224	57.6	$ 52.95
45	50	W33X118	44LH17	15.00	5.5	60	-224	53.6	$ 55.01
50	50	W36X135	40LH18	16.67	6.1	63	-224	52.7	$ 56.77

Table 19 - Results, Hybrid OWSJ Roof Assembly with 7-Ply CLT, Commercial

Appendix C: Residential Floor Bay Study Results

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W10X17	W8X15	7.50	6.3	101	0.0	19.1	$ 32.85
17.5	15	W12X19	W8X15	8.75	6.1	100	0.0	21.2	$ 32.39
20	15	W14X22	W8X15	10.00	6.1	100	0.0	22.7	$ 32.35
22.5	15	W16X26	W8X15	7.50	6.9	104	0.0	24.7	$ 34.65
25	15	W16X26	W8X15	8.33	6.7	103	0.0	24.7	$ 34.05
27.5	15	W18X35	W8X15	9.17	7.2	106	0.0	26.7	$ 35.36
30	15	W14X34	W8X15	10.00	6.9	104	0.0	23.0	$ 34.75
15	17.5	W10X17	W10X17	7.50	6.3	101	0.0	19.1	$ 33.16
17.5	17.5	W12X19	W10X17	8.75	6.1	100	0.0	21.2	$ 32.54
20	17.5	W14X22	W10X17	10.00	6.1	100	0.0	22.7	$ 32.32
22.5	17.5	W16X26	W10X17	7.50	6.9	104	0.0	24.7	$ 34.71
25	17.5	W16X31	W10X17	8.33	7.0	105	0.0	24.9	$ 34.88
27.5	17.5	W18X35	W10X17	9.17	7.0	105	0.0	26.7	$ 35.01
30	17.5	W18X35	W10X17	10.00	6.9	104	0.0	26.7	$ 34.55
15	20	W12X19	W10X17	7.50	6.3	101	0.0	21.2	$ 33.10
17.5	20	W14X22	W12X19	8.75	6.4	102	0.0	22.7	$ 33.26
20	20	W16X26	W12X19	10.00	6.3	101	0.0	24.7	$ 33.05
22.5	20	W16X26	W10X17	7.50	6.7	103	0.0	24.7	$ 34.15
25	20	W18X35	W12X19	8.33	7.2	106	0.0	26.7	$ 35.54
27.5	20	W18X40	W12X19	9.17	7.2	106	0.0	26.9	$ 35.67
30	20	W18X40	W12X19	10.00	7.0	105	0.0	26.9	$ 35.15
15	22.5	W12X19	W12X19	7.50	6.5	102	0.0	21.2	$ 33.58
17.5	22.5	W14X22	W14X22	8.75	6.6	103	0.0	22.7	$ 33.93
20	22.5	W16X26	W14X22	10.00	6.5	102	0.0	24.7	$ 33.52
22.5	22.5	W16X31	W12X19	7.50	7.1	105	0.0	24.9	$ 35.18
25	22.5	W18X35	W12X19	8.33	7.0	105	0.0	26.7	$ 34.96
27.5	22.5	W18X40	W14X22	9.17	7.3	107	0.0	26.9	$ 35.98
30	22.5	W21X44	W14X22	10.00	7.3	107	0.0	29.7	$ 35.92
15	25	W14X22	W14X22	7.50	7.0	105	0.0	22.7	$ 34.89
17.5	25	W16X26	W14X22	8.75	6.7	103	0.0	24.7	$ 34.11
20	25	W14X30	W16X26	10.00	7.0	105	0.0	24.7	$ 34.85
22.5	25	W16X31	W14X22	7.50	7.3	107	0.0	24.9	$ 35.97
25	25	W18X35	W14X22	8.33	7.2	106	0.0	26.7	$ 35.57
27.5	25	W21X44	W14X22	9.17	7.3	107	0.0	29.7	$ 35.93
30	25	W21X44	W16X26	10.00	7.6	108	0.0	29.7	$ 36.53
15	27.5	W14X22	W16X26	7.50	7.5	107	0.0	24.7	$ 36.25
17.5	27.5	W16X26	W16X26	8.75	7.1	105	0.0	24.7	$ 35.20
20	27.5	W16X31	W16X26	10.00	6.9	104	0.0	24.9	$ 34.63
22.5	27.5	W18X35	W16X26	7.50	8.0	110	0.0	26.7	$ 37.67
25	27.5	W18X40	W16X26	8.33	7.8	109	0.0	26.9	$ 37.17
27.5	27.5	W21X44	W16X26	9.17	7.6	108	0.0	29.7	$ 36.76
30	27.5	W21X50	W16X26	10.00	7.6	108	0.0	29.8	$ 36.70
15	30	W14X22	W14X22	7.50	6.8	104	0.0	22.7	$ 34.45
17.5	30	W16X26	W16X26	8.75	7.1	105	0.0	24.7	$ 34.96
20	30	W14X34	W16X26	10.00	6.9	104	0.0	24.7	$ 34.65
22.5	30	W18X35	W14X22	7.50	7.2	106	0.0	26.7	$ 35.75
25	30	W18X40	W16X26	8.33	7.7	109	0.0	26.9	$ 36.81
27.5	30	W21X44	W16X26	9.17	7.5	108	0.0	29.7	$ 36.36
30	30	W21X50	W16X26	10.00	7.5	107	0.0	29.8	$ 36.25

Table 20 - Results, Conventional Composite Steel WF Floor Assembly, Residential

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W12X19	18LH02	5.00	5.1	75	0.0	25.5	$ 31.55
17.5	15	W14X22	18LH02	4.38	5.6	77	0.0	26.2	$ 33.08
20	15	W14X22	18LH03	5.00	5.5	77	0.0	26.2	$ 32.80
22.5	15	W16X26	18LH02	4.50	5.8	78	0.0	28.2	$ 33.67
25	15	W18X35	18LH02	5.00	6.2	81	0.0	30.2	$ 34.75
27.5	15	W18X40	18LH02	4.58	6.7	84	0.0	30.4	$ 36.34
30	15	W21X44	18LH02	5.00	6.8	85	0.0	33.2	$ 36.55
15	17.5	W12X19	18LH02	5.00	5.0	74	0.0	25.5	$ 31.01
17.5	17.5	W14X22	18LH02	4.38	5.4	76	0.0	26.2	$ 32.45
20	17.5	W16X26	18LH02	5.00	5.4	76	0.0	28.2	$ 32.21
22.5	17.5	W16X31	18LH02	4.50	5.9	79	0.0	28.4	$ 33.79
25	17.5	W18X35	18LH02	5.00	5.9	79	0.0	30.2	$ 33.75
27.5	17.5	W18X40	18LH02	4.58	6.3	82	0.0	30.4	$ 35.20
30	17.5	W21X44	18LH02	5.00	6.4	82	0.0	33.2	$ 35.29
15	20	W12X19	18LH02	5.00	4.8	73	0.0	25.5	$ 30.60
17.5	20	W14X22	18LH02	4.38	5.3	75	0.0	26.2	$ 31.98
20	20	W16X26	18LH02	5.00	5.2	75	0.0	28.2	$ 31.65
22.5	20	W18X35	18LH02	4.50	5.8	78	0.0	30.2	$ 33.72
25	20	W18X40	18LH02	5.00	5.9	79	0.0	30.4	$ 33.75
27.5	20	W21X44	18LH02	4.58	6.3	81	0.0	33.2	$ 34.94
30	20	W21X50	18LH02	5.00	6.4	82	0.0	33.3	$ 35.25
15	22.5	W14X22	18LH02	5.00	4.8	73	0.0	26.2	$ 30.68
17.5	22.5	W16X26	18LH02	4.38	5.3	75	0.0	28.2	$ 32.15
20	22.5	W16X31	18LH03	5.00	5.4	76	0.0	28.4	$ 32.53
22.5	22.5	W18X35	18LH02	4.50	5.6	77	0.0	30.2	$ 33.14
25	22.5	W18X40	18LH02	5.00	5.6	78	0.0	30.4	$ 33.08
27.5	22.5	W21X44	18LH02	4.58	6.0	80	0.0	33.2	$ 34.21
30	22.5	W24X55	18LH02	5.00	6.3	82	0.0	36.1	$ 35.08
15	25	W14X22	18LH03	5.00	5.0	73	0.0	26.2	$ 31.04
17.5	25	W16X26	18LH02	4.38	5.2	75	0.0	28.2	$ 31.80
20	25	W16X31	24LH03	5.00	5.3	75	0.0	31.5	$ 32.12
22.5	25	W18X40	18LH03	4.50	5.9	78	0.0	30.4	$ 33.99
25	25	W21X44	18LH03	5.00	5.8	78	0.0	33.2	$ 33.68
27.5	25	W21X50	18LH02	4.58	6.1	80	0.0	33.3	$ 34.34
30	25	W24X55	18LH03	5.00	6.3	81	0.0	36.1	$ 35.00
15	27.5	W14X22	24LH03	5.00	4.9	73	0.0	31.5	$ 30.80
17.5	27.5	W14X30	24LH03	4.38	5.5	76	0.0	31.5	$ 32.69
20	27.5	W18X35	24LH03	5.00	5.3	76	0.0	31.5	$ 32.22
22.5	27.5	W18X40	24LH03	4.50	5.8	78	0.0	31.5	$ 33.56
25	27.5	W21X44	24LH03	5.00	5.7	77	0.0	33.2	$ 33.20
27.5	27.5	W24X55	24LH03	4.58	6.3	81	0.0	36.1	$ 35.05
30	27.5	W24X55	24LH03	5.00	6.1	80	0.0	36.1	$ 34.40
15	30	W16X26	24LH05	5.00	5.3	75	0.0	31.5	$ 32.30
17.5	30	W16X31	24LH03	4.38	5.4	75	0.0	31.5	$ 32.52
20	30	W18X35	24LH05	5.00	5.6	77	0.0	31.5	$ 33.20
22.5	30	W21X44	20LH04	4.50	6.0	79	0.0	33.2	$ 34.32
25	30	W21X50	24LH05	5.00	6.1	80	0.0	33.3	$ 34.70
27.5	30	W24X55	24LH04	4.58	6.3	81	0.0	36.1	$ 35.26
30	30	W24X62	24LH05	5.00	6.5	82	0.0	36.2	$ 35.90

Table 21 - Results, Conventional OWSJ Floor Assembly, Residential

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W12X19	W8X15	7.50	3.3	74	-96	20.3	$ 45.30
17.5	15	W14X22	W10X17	8.75	3.4	74	-96	21.8	$ 45.73
20	15	W16X26	W10X17	10.00	3.4	75	-96	23.8	$ 45.80
22.5	15	W16X26	W10X17	11.25	3.2	73	-96	23.8	$ 45.23
25	15	W18X35	W8X15	8.33	4.1	79	-96	25.8	$ 47.90
27.5	15	W18X40	W10X17	9.17	4.5	81	-96	26.0	$ 49.06
30	15	W21X44	W10X17	10.00	4.6	82	-96	28.8	$ 49.40
15	17.5	W12X19	W10X17	7.50	3.4	74	-96	20.3	$ 45.56
17.5	17.5	W14X22	W12X19	8.75	3.4	74	-96	21.8	$ 45.79
20	17.5	W16X26	W12X19	10.00	3.4	74	-96	23.8	$ 45.66
22.5	17.5	W16X31	W12X19	11.25	3.5	75	-96	24.0	$ 45.88
25	17.5	W18X35	W10X17	8.33	4.0	78	-96	25.8	$ 47.62
27.5	17.5	W21X44	W12X19	9.17	4.6	81	-96	28.8	$ 49.26
30	17.5	W21X44	W12X19	10.00	4.4	80	-96	28.8	$ 48.74
15	20	W14X22	W12X19	7.50	3.6	76	-96	21.8	$ 46.40
17.5	20	W16X26	W12X19	8.75	3.5	75	-96	23.8	$ 45.91
20	20	W16X26	W14X22	10.00	3.5	75	-96	23.8	$ 46.00
22.5	20	W18X35	W14X22	11.25	3.7	76	-96	25.8	$ 46.62
25	20	W18X40	W12X19	8.33	4.3	80	-96	26.0	$ 48.34
27.5	20	W21X44	W12X19	9.17	4.3	80	-96	28.8	$ 48.32
30	20	W21X50	W14X22	10.00	4.7	82	-96	28.9	$ 49.60
15	22.5	W14X22	W14X22	7.50	3.9	77	-96	21.8	$ 47.23
17.5	22.5	W16X26	W14X22	8.75	3.7	76	-96	23.8	$ 46.51
20	22.5	W16X31	W16X26	10.00	4.0	78	-96	24.0	$ 47.43
22.5	22.5	W18X35	W16X26	11.25	3.9	77	-96	25.8	$ 47.10
25	22.5	W18X40	W14X22	8.33	4.4	80	-96	26.0	$ 48.75
27.5	22.5	W21X44	W14X22	9.17	4.4	80	-96	28.8	$ 48.57
30	22.5	W24X55	W14X22	10.00	4.6	82	-96	31.7	$ 49.43
15	25	W14X22	W16X26	7.50	4.3	80	-96	23.8	$ 48.54
17.5	25	W16X26	W16X26	8.75	4.0	78	-96	23.8	$ 47.53
20	25	W18X35	W16X26	10.00	4.0	78	-96	25.8	$ 47.50
22.5	25	W18X40	W16X31	11.25	4.4	80	-96	26.0	$ 48.57
25	25	W21X44	W16X26	8.33	4.9	83	-96	28.8	$ 50.14
27.5	25	W21X50	W16X26	9.17	4.8	83	-96	28.9	$ 50.01
30	25	W24X55	W16X26	10.00	4.8	83	-96	31.7	$ 49.90
15	27.5	W16X26	W16X26	7.50	4.4	80	-96	23.8	$ 48.74
17.5	27.5	W14X30	W16X31	8.75	4.6	82	-96	24.0	$ 49.40
20	27.5	W18X35	W16X31	10.00	4.4	80	-96	25.8	$ 48.62
22.5	27.5	W18X40	W18X35	11.25	4.6	81	-96	26.0	$ 49.20
25	27.5	W21X50	W16X26	8.33	4.9	83	-96	28.9	$ 50.31
27.5	27.5	W24X55	W16X31	9.17	5.4	86	-96	31.7	$ 51.65
30	27.5	W24X62	W16X31	10.00	5.4	86	-96	31.8	$ 51.56
15	30	W16X26	W16X31	7.50	5.0	84	-96	24.0	$ 50.50
17.5	30	W16X31	W18X35	8.75	5.0	84	-96	25.8	$ 50.60
20	30	W18X40	W18X35	10.00	4.8	83	-96	26.0	$ 50.00
22.5	30	W21X44	W18X40	11.25	5.0	84	-96	28.8	$ 50.57
25	30	W21X50	W18X35	8.33	5.9	89	-96	28.9	$ 53.10
27.5	30	W24X55	W18X35	9.17	5.7	88	-96	31.7	$ 52.45
30	30	W24X62	W18X35	10.00	5.6	87	-96	31.8	$ 52.20

Table 22 - Results, Hybrid Steel WF Floor Assembly with 3-Ply CLT, Residential

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W12X19	18LH07	7.50	3.5	71	-96	26.1	$ 46.67
17.5	15	W14X22	18LH09	8.75	3.9	73	-96	26.8	$ 47.70
20	15	W16X26	18LH10	10.00	4.0	74	-96	28.8	$ 48.18
22.5	15	W16X26	18LH11	11.25	4.0	73	-96	28.8	$ 47.92
25	15	W18X35	18LH07	8.33	4.4	76	-96	30.8	$ 49.13
27.5	15	W18X40	18LH08	9.17	4.7	78	-96	31.0	$ 50.24
30	15	W21X44	18LH07	10.00	4.6	79	-96	33.8	$ 49.83
15	17.5	W12X19	18LH06	7.50	3.1	69	-96	26.1	$ 45.26
17.5	17.5	W14X22	18LH08	8.75	3.4	70	-96	26.8	$ 46.33
20	17.5	W16X26	18LH09	10.00	3.6	72	-96	28.8	$ 46.78
22.5	17.5	W16X31	18LH10	11.25	3.8	73	-96	29.0	$ 47.46
25	17.5	W18X35	18LH06	8.33	3.8	73	-96	30.8	$ 47.35
27.5	17.5	W21X44	18LH06	9.17	4.2	76	-96	33.8	$ 48.36
30	17.5	W21X44	18LH07	10.00	4.2	76	-96	33.8	$ 48.57
15	20	W16x26	18LH10	7.50	3.4	70	-96	28.1	$ 46.17
17.5	20	W16X26	20LH07	8.75	3.2	70	-96	28.8	$ 45.71
20	20	W16X26	18LH10	10.00	3.6	71	-96	28.8	$ 46.88
22.5	20	W18X35	18LH10	11.25	3.8	73	-96	30.8	$ 47.39
25	20	W18X40	18LH07	8.33	4.0	74	-96	31.0	$ 48.13
27.5	20	W21X44	20LH07	9.17	4.1	75	-96	33.8	$ 48.13
30	20	W21X50	20LH08	10.00	4.4	77	-96	33.9	$ 49.18
15	22.5	W14X22	18LH10	7.50	4.0	72	-96	26.8	$ 48.40
17.5	22.5	W16X26	18LH11	8.75	4.0	73	-96	28.8	$ 48.25
20	22.5	W16X31	20LH11	10.00	3.9	73	-96	29.0	$ 47.76
22.5	22.5	W18X35	20LH11	11.25	3.8	72	-96	30.8	$ 47.39
25	22.5	W18X40	20LH09	8.33	4.3	75	-96	31.0	$ 49.02
27.5	22.5	W21X44	20LH09	9.17	4.2	75	-96	33.8	$ 48.81
30	22.5	W24X55	18LH10	10.00	4.7	78	-96	36.7	$ 50.31
15	25	W14X22	24LH07	7.50	3.1	69	-96	32.1	$ 45.51
17.5	25	W16X26	24LH09	8.75	3.4	70	-96	32.1	$ 46.42
20	25	W18X35	24LH09	10.00	3.5	71	-96	32.1	$ 46.53
22.5	25	W18X40	24LH11	11.25	3.8	73	-96	32.1	$ 47.52
25	25	W21X44	24LH09	8.33	4.3	75	-96	33.8	$ 48.97
27.5	25	W21X50	24LH09	9.17	4.3	75	-96	33.9	$ 48.95
30	25	W24X55	24LH09	10.00	4.3	76	-96	36.7	$ 48.93
15	27.5	W16X26	24LH09	7.50	3.7	71	-96	32.1	$ 47.44
17.5	27.5	W14X30	28LH10	8.75	3.7	71	-96	36.1	$ 47.32
20	27.5	W18X35	28LH11	10.00	3.8	72	-96	36.1	$ 47.44
22.5	27.5	W18X40	24LH12	11.25	3.9	73	-96	32.1	$ 47.66
25	27.5	W21X44	24LH09	8.33	4.1	74	-96	33.8	$ 48.49
27.5	27.5	W24X55	24LH10	9.17	4.5	76	-96	36.7	$ 49.65
30	27.5	W24X62	24LH11	10.00	4.8	78	-96	36.8	$ 50.39
15	30	W16X26	24LH09	7.50	3.7	71	-96	32.1	$ 47.20
17.5	30	W16X31	28LH11	8.75	3.9	72	-96	36.1	$ 47.89
20	30	W18X35	28LH12	10.00	3.9	72	-96	36.1	$ 47.78
22.5	30	W21X44	28LH13	11.25	4.1	74	-96	36.1	$ 48.57
25	30	W21X50	28LH10	8.33	4.4	75	-96	36.1	$ 49.47
27.5	30	W24X55	28LH11	9.17	4.6	76	-96	36.7	$ 49.86
30	30	W24X62	24LH12	10.00	4.8	77	-96	36.8	$ 50.48

Table 23 - Results, Hybrid OWSJ Floor Assembly with 3-Ply CLT, Residential

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W12X19	W12X19	15.00	2.5	79	-160	23.1	$ 50.10
17.5	15	W14X22	W10X17	8.75	3.4	84	-160	24.6	$ 52.73
20	15	W16X26	W10X17	10.00	3.4	84	-160	26.6	$ 52.80
22.5	15	W16X31	W10X17	11.25	3.6	85	-160	26.8	$ 53.23
25	15	W18X35	W10X17	12.50	3.7	86	-160	28.6	$ 53.58
27.5	15	W18X40	W12X19	13.75	4.0	88	-160	28.8	$ 54.65
30	15	W21X44	W12X19	15.00	4.2	89	-160	31.6	$ 55.10
15	17.5	W12X19	W14X22	15.00	2.6	79	-160	24.6	$ 50.16
17.5	17.5	W14X22	W12X19	8.75	3.4	84	-160	24.6	$ 52.79
20	17.5	W16X26	W12X19	10.00	3.4	84	-160	26.6	$ 52.66
22.5	17.5	W16X31	W12X19	11.25	3.5	84	-160	26.8	$ 52.88
25	17.5	W18X35	W12X19	12.50	3.5	84	-160	28.6	$ 53.06
27.5	17.5	W21X44	W14X22	13.75	4.1	88	-160	31.6	$ 54.84
30	17.5	W21X50	W14X22	15.00	4.3	89	-160	31.7	$ 55.47
15	20	W14X22	W16X26	15.00	2.8	80	-160	26.6	$ 51.00
17.5	20	W16X26	W12X19	8.75	3.5	84	-160	26.6	$ 52.91
20	20	W14X30	W14X22	10.00	3.7	86	-160	24.7	$ 53.60
22.5	20	W18X35	W14X22	11.25	3.7	86	-160	28.6	$ 53.62
25	20	W18X40	W14X22	12.50	3.8	86	-160	28.8	$ 53.78
27.5	20	W21X44	W14X22	13.75	3.8	86	-160	31.6	$ 53.90
30	20	W21X50	W16X26	15.00	4.2	89	-160	31.7	$ 55.20
15	22.5	W14X22	W16X31	15.00	3.0	82	-160	26.8	$ 51.63
17.5	22.5	W16X26	W14X22	8.75	3.7	85	-160	26.6	$ 53.51
20	22.5	W16X31	W16X26	10.00	4.0	87	-160	26.8	$ 54.43
22.5	22.5	W18X40	W16X26	11.25	4.1	88	-160	28.8	$ 54.77
25	22.5	W21X44	W16X26	12.50	4.0	88	-160	31.6	$ 54.61
27.5	22.5	W21X50	W16X26	13.75	4.1	88	-160	31.7	$ 54.84
30	22.5	W24X55	W16X31	15.00	4.5	90	-160	34.5	$ 56.03
15	25	W14X22	W18X35	15.00	3.2	83	-160	28.6	$ 52.14
17.5	25	W14X30	W16X26	8.75	4.2	88	-160	26.6	$ 55.01
20	25	W18X35	W16X26	10.00	4.0	87	-160	28.6	$ 54.50
22.5	25	W18X40	W16X31	11.25	4.4	89	-160	28.8	$ 55.57
25	25	W21X44	W16X31	12.50	4.2	89	-160	31.6	$ 55.22
27.5	25	W24X55	W18X35	13.75	4.7	92	-160	34.5	$ 56.74
30	25	W24X55	W18X35	15.00	4.5	91	-160	34.5	$ 56.10
15	27.5	W16X26	W18X40	15.00	3.6	85	-160	28.8	$ 53.34
17.5	27.5	W16X31	W16X31	8.75	4.7	91	-160	26.8	$ 56.51
20	27.5	W18X35	W16X31	10.00	4.4	90	-160	28.6	$ 55.62
22.5	27.5	W21X44	W18X35	11.25	4.7	92	-160	31.6	$ 56.63
25	27.5	W21X50	W18X35	12.50	4.6	91	-160	31.7	$ 56.35
27.5	27.5	W24X55	W18X40	13.75	4.9	93	-160	34.5	$ 57.23
30	27.5	W24X62	W18X40	15.00	4.9	93	-160	34.6	$ 57.26
15	30	W16X26	W21X44	15.00	3.8	86	-160	31.6	$ 53.90
17.5	30	W14X34	W18X35	8.75	5.1	94	-160	28.6	$ 57.90
20	30	W18X40	W18X35	10.00	4.8	92	-160	28.8	$ 57.00
22.5	30	W21X44	W18X40	11.25	5.0	93	-160	31.6	$ 57.57
25	30	W24X55	W18X40	12.50	5.0	93	-160	34.5	$ 57.60
27.5	30	W24X62	W21X44	13.75	5.3	95	-160	34.6	$ 58.30
30	30	W24X68	W21X44	15.00	5.2	94	-160	34.6	$ 58.10

Table 24 - Results, Hybrid Steel WF Floor Assembly with 5-Ply CLT, Residential

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W12X19	18LH11	15.00	2.9	78	-160	28.9	$ 51.72
17.5	15	W14X22	18LH06	8.75	3.2	79	-160	29.6	$ 52.47
20	15	W16X26	18LH08	10.00	3.6	82	-160	31.6	$ 53.88
22.5	15	W16X31	18LH09	11.25	3.9	83	-160	31.8	$ 54.77
25	15	W18X35	18LH09	12.50	4.0	84	-160	33.6	$ 54.96
27.5	15	W18X40	18LH10	13.75	4.3	86	-160	33.8	$ 55.94
30	15	W21X44	18LH11	15.00	4.6	88	-160	36.6	$ 56.72
15	17.5	W12X19	18LH11	15.00	2.8	77	-160	28.9	$ 51.17
17.5	17.5	W14X22	18LH06	8.75	3.0	78	-160	29.6	$ 51.84
20	17.5	W16X26	18LH08	10.00	3.4	80	-160	31.6	$ 53.13
22.5	17.5	W16X31	18LH09	11.25	3.6	82	-160	31.8	$ 53.88
25	17.5	W18X35	18LH09	12.50	3.7	82	-160	33.6	$ 53.96
27.5	17.5	W21X44	18LH10	13.75	4.2	85	-160	36.6	$ 55.48
30	17.5	W21X50	18LH11	15.00	4.5	87	-160	36.7	$ 56.49
15	20	W14X22	18LH12	15.00	3.4	79	-160	30.9	$ 53.17
17.5	20	W16X26	20LH07	8.75	3.2	79	-160	31.6	$ 52.71
20	20	W14X30	20LH08	10.00	3.4	80	-160	30.9	$ 53.18
22.5	20	W18X35	20LH09	11.25	3.6	82	-160	33.6	$ 53.82
25	20	W18X40	18LH11	12.50	4.0	84	-160	33.8	$ 55.00
27.5	20	W21X44	20LH11	13.75	4.0	84	-160	36.6	$ 55.01
30	20	W21X50	18LH12	15.00	4.4	86	-160	36.7	$ 56.07
15	22.5	W14X22	20LH13	15.00	3.2	79	-160	30.9	$ 52.80
17.5	22.5	W16X26	20LH09	8.75	3.6	80	-160	31.6	$ 53.77
20	22.5	W16X31	18LH11	10.00	3.9	82	-160	31.8	$ 54.76
22.5	22.5	W18X40	20LH11	11.25	4.0	83	-160	33.8	$ 55.06
25	22.5	W21X44	20LH12	12.50	4.2	84	-160	36.6	$ 55.65
27.5	22.5	W21X50	18LH13	13.75	4.6	87	-160	36.7	$ 56.97
30	22.5	W24X55	20LH13	15.00	4.7	87	-160	39.5	$ 57.20
15	25	W14X22	24LH13	15.00	3.0	77	-160	34.9	$ 52.07
17.5	25	W14X30	24LH09	8.75	3.6	80	-160	34.9	$ 53.90
20	25	W18X35	24LH09	10.00	3.5	80	-160	34.9	$ 53.53
22.5	25	W18X40	24LH11	11.25	3.8	82	-160	34.9	$ 54.52
25	25	W21X44	24LH12	12.50	3.9	83	-160	36.6	$ 54.80
27.5	25	W24X55	24LH13	13.75	4.5	86	-160	39.5	$ 56.66
30	25	W24X55	24LH13	15.00	4.3	85	-160	39.5	$ 56.03
15	27.5	W16X26	28LH14	15.00	3.3	79	-160	38.9	$ 52.92
17.5	27.5	W16X31	24LH10	8.75	3.8	81	-160	34.9	$ 54.42
20	27.5	W18X35	28LH11	10.00	3.8	81	-160	38.9	$ 54.44
22.5	27.5	W21X44	28LH12	11.25	4.0	83	-160	38.9	$ 55.10
25	27.5	W21X50	28LH13	12.50	4.2	84	-160	38.9	$ 55.75
27.5	27.5	W24X55	24LH14	13.75	4.5	86	-160	39.5	$ 56.77
30	27.5	W24X62	28LH14	15.00	4.6	86	-160	39.6	$ 56.85
15	30	W16X26	28LH15	15.00	3.4	79	-160	38.9	$ 53.33
17.5	30	W16X31	28LH11	8.75	3.9	81	-160	38.9	$ 54.89
20	30	W18X40	28LH12	10.00	4.0	83	-160	38.9	$ 55.28
22.5	30	W21X44	28LH13	11.25	4.1	83	-160	38.9	$ 55.57
25	30	W24X55	24LH14	12.50	4.6	86	-160	39.5	$ 57.10
27.5	30	W24X55	28LH14	13.75	4.4	85	-160	39.5	$ 56.27
30	30	W24X68	28LH15	15.00	4.8	87	-160	39.6	$ 57.53

Table 25 - Results, Hybrid OWSJ Floor Assembly with 5-Ply CLT, Residential

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W12X19	W12X19	15.00	2.5	88	-224	25.8	$ 58.10
17.5	15	W14X22	W12X19	17.50	2.6	88	-224	27.3	$ 58.16
20	15	W16X26	W14X22	20.00	2.8	90	-224	29.3	$ 59.00
22.5	15	W16X31	W10X17	11.25	3.6	94	-224	29.5	$ 61.23
25	15	W18X35	W10X17	12.50	3.7	95	-224	31.3	$ 61.58
27.5	15	W18X40	W12X19	13.75	4.0	97	-224	31.5	$ 62.65
30	15	W21X44	W12X19	15.00	4.2	98	-224	34.3	$ 63.10
15	17.5	W12X19	W14X22	15.00	2.6	88	-224	27.3	$ 58.16
17.5	17.5	W14X22	W14X22	17.50	2.5	88	-224	27.3	$ 58.04
20	17.5	W16X26	W16X26	20.00	2.8	90	-224	29.3	$ 58.86
22.5	17.5	W18X35	W12X19	11.25	3.7	95	-224	31.3	$ 61.57
25	17.5	W18X40	W12X19	12.50	3.8	96	-224	31.5	$ 61.92
27.5	17.5	W21X44	W14X22	13.75	4.1	97	-224	34.3	$ 62.84
30	17.5	W21X50	W14X22	15.00	4.3	99	-224	34.4	$ 63.47
15	20	W14X22	W16X26	15.00	2.8	90	-224	29.3	$ 59.00
17.5	20	W16X26	W16X26	17.50	2.8	90	-224	29.3	$ 58.86
20	20	W16X31	W16X31	20.00	3.1	91	-224	29.5	$ 59.80
22.5	20	W18X35	W14X22	11.25	3.7	95	-224	31.3	$ 61.62
25	20	W18X40	W14X22	12.50	3.8	95	-224	31.5	$ 61.78
27.5	20	W21X44	W16X26	13.75	4.1	97	-224	34.3	$ 62.77
30	20	W24X55	W16X26	15.00	4.5	100	-224	37.2	$ 63.95
15	22.5	W14X22	W16X31	15.00	3.0	91	-224	29.5	$ 59.63
17.5	22.5	W16X26	W16X31	17.50	2.9	90	-224	29.5	$ 59.28
20	22.5	W18X35	W18X35	20.00	3.3	93	-224	31.3	$ 60.42
22.5	22.5	W18X40	W16X26	11.25	4.1	97	-224	31.5	$ 62.77
25	22.5	W21X44	W16X26	12.50	4.0	97	-224	34.3	$ 62.61
27.5	22.5	W21X50	W16X26	13.75	4.1	97	-224	34.4	$ 62.84
30	22.5	W24X55	W16X31	15.00	4.5	100	-224	37.2	$ 64.03
15	25	W16X26	W18X35	15.00	3.4	93	-224	31.3	$ 60.62
17.5	25	W14X30	W18X40	17.50	3.5	94	-224	31.5	$ 60.96
20	25	W18X35	W18X40	20.00	3.4	93	-224	31.5	$ 60.70
22.5	25	W21X44	W16X31	11.25	4.5	100	-224	34.3	$ 64.05
25	25	W21X50	W16X31	12.50	4.5	100	-224	34.4	$ 63.94
27.5	25	W24X55	W18X35	13.75	4.7	101	-224	37.2	$ 64.74
30	25	W24X62	W18X35	15.00	4.8	102	-224	37.3	$ 64.94
15	27.5	W16X26	W18X40	15.00	3.6	94	-224	31.5	$ 61.34
17.5	27.5	W16X31	W21X44	17.50	3.6	95	-224	34.3	$ 61.42
20	27.5	W18X40	W21X44	20.00	3.7	95	-224	34.3	$ 61.46
22.5	27.5	W21X44	W18X35	11.25	4.7	101	-224	34.3	$ 64.63
25	27.5	W21X50	W18X35	12.50	4.6	100	-224	34.4	$ 64.35
27.5	27.5	W24X55	W18X40	13.75	4.9	102	-224	37.2	$ 65.23
30	27.5	W24X68	W18X40	15.00	5.1	104	-224	37.3	$ 65.92
15	30	W16X26	W21X44	15.00	3.8	96	-224	34.3	$ 61.90
17.5	30	W18X35	W21X50	17.50	4.0	97	-224	34.4	$ 62.57
20	30	W18X40	W24X55	20.00	4.1	97	-224	37.2	$ 62.75
22.5	30	W21X44	W18X40	11.25	5.0	103	-224	34.3	$ 65.57
25	30	W24X55	W21X44	12.50	5.4	105	-224	37.2	$ 66.56
27.5	30	W24X62	W21X44	13.75	5.3	104	-224	37.3	$ 66.30
30	30	W24X68	W21X44	15.00	5.2	104	-224	37.3	$ 66.10

Table 26 - Results, Hybrid Steel WF Floor Assembly with 7-Ply CLT, Residential

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W12X19	18LH11	15.00	2.9	87	-224	31.6	$ 59.72
17.5	15	W14x22	18LH06	8.75	3.2	89	-224	32.3	$ 60.47
20	15	W16X26	18LH08	10.00	3.6	91	-224	34.3	$ 61.88
22.5	15	W16X31	18LH09	11.25	3.9	93	-224	34.5	$ 62.77
25	15	W18X35	18LH10	12.50	4.2	94	-224	36.3	$ 63.48
27.5	15	W18X40	18LH10	13.75	4.3	96	-224	36.5	$ 63.94
30	15	W21X44	18LH11	15.00	4.6	97	-224	39.3	$ 64.72
15	17.5	W12X19	18LH11	15.00	2.8	86	-224	31.6	$ 59.17
17.5	17.5	W14X22	18LH06	8.75	3.0	87	-224	32.3	$ 59.84
20	17.5	W16X26	18LH08	10.00	3.4	90	-224	34.3	$ 61.13
22.5	17.5	W18X35	18LH09	11.25	3.9	92	-224	36.3	$ 62.57
25	17.5	W18X40	18LH10	12.50	4.1	94	-224	36.5	$ 63.34
27.5	17.5	W21X44	18LH10	13.75	4.2	95	-224	39.3	$ 63.48
30	17.5	W21X50	18LH11	15.00	4.5	97	-224	39.4	$ 64.49
15	20	W14X22	20LH12	15.00	3.4	89	-224	33.6	$ 61.17
17.5	20	W16x26	20LH07	8.75	3.2	89	-224	34.3	$ 60.71
20	20	W16X31	18LH09	10.00	3.7	91	-224	34.5	$ 61.98
22.5	20	W18X35	18LH10	11.25	3.8	92	-224	36.3	$ 62.39
25	20	W18X40	18LH11	12.50	4.0	93	-224	36.5	$ 63.00
27.5	20	W21X44	20LH11	13.75	4.0	93	-224	39.3	$ 63.01
30	20	W24X55	20LH12	15.00	4.6	97	-224	42.2	$ 64.82
15	22.5	W14X22	20LH13	15.00	3.2	88	-224	33.6	$ 60.80
17.5	22.5	W16X26	20LH15	17.50	3.4	89	-224	34.3	$ 61.40
20	22.5	W18X35	18LH11	10.00	4.1	92	-224	36.3	$ 63.29
22.5	22.5	W18X40	20LH11	11.25	4.0	93	-224	36.5	$ 63.06
25	22.5	W21X44	20LH12	12.50	4.2	94	-224	39.3	$ 63.65
27.5	22.5	W21X50	20LH13	13.75	4.7	96	-224	39.4	$ 65.20
30	22.5	W24X55	20LH13	15.00	4.7	97	-224	42.2	$ 65.20
15	25	W16X26	24LH13	15.00	3.2	88	-224	37.6	$ 60.55
17.5	25	W14X30	24LH15	17.50	3.4	89	-224	37.6	$ 61.16
20	25	W18X35	24LH10	10.00	3.7	91	-224	37.6	$ 62.18
22.5	25	W18X40	24LH11	11.25	3.8	92	-224	37.6	$ 62.52
25	25	W21X50	24LH12	12.50	4.2	94	-224	39.4	$ 63.52
27.5	25	W24X55	24LH13	13.75	4.5	96	-224	42.2	$ 64.66
30	25	W24X62	24LH13	15.00	4.6	96	-224	42.3	$ 64.87
15	27.5	W16X26	28LH14	15.00	3.3	88	-224	41.6	$ 60.92
17.5	27.5	W16X31	24LH16	17.50	3.5	89	-224	37.6	$ 61.68
20	27.5	W18X40	24LH12	10.00	4.2	93	-224	37.6	$ 63.64
22.5	27.5	W21X44	28LH12	11.25	4.0	92	-224	41.6	$ 63.10
25	27.5	W21X50	28LH13	12.50	4.2	94	-224	41.6	$ 63.75
27.5	27.5	W24X55	24LH14	13.75	4.5	95	-224	42.2	$ 64.77
30	27.5	W24X68	28LH14	15.00	4.8	97	-224	42.3	$ 65.50
15	30	W16X26	24LH16	15.00	3.7	90	-224	37.6	$ 62.20
17.5	30	W18x35	24LH12	8.75	4.3	93	-224	37.6	$ 64.03
20	30	W18X40	28LH12	10.00	4.0	92	-224	41.6	$ 63.28
22.5	30	W21X44	24LH13	11.25	4.3	93	-224	39.3	$ 64.14
25	30	W24X55	28LH14	12.50	4.6	95	-224	42.2	$ 65.10
27.5	30	W24X62	28LH15	13.75	4.8	97	-224	42.3	$ 65.68
30	30	W24X68	24LH16	15.00	5.1	98	-224	42.3	$ 66.40

Table 27 - Results, Hybrid OWSJ Floor Assembly with 7-Ply CLT, Residential

Appendix D: Residential Roof Bay Study Results

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W8X15	W8X15	7.50	6.6	48	0.0	14.6	$ 18.45
17.5	15	W10X17	W8X15	8.75	6.4	47	0.0	16.6	$ 17.99
20	15	W10X17	W8X15	10.00	6.2	46	0.0	16.6	$ 17.35
22.5	15	W12X19	W8X15	11.25	6.2	46	0.0	18.7	$ 17.25
25	15	W14X22	W8X15	12.50	6.2	46	0.0	20.2	$ 17.45
27.5	15	W16X26	W8X15	9.17	6.9	50	0.0	22.2	$ 19.56
30	15	W16X26	W8X15	10.00	6.8	50	0.0	22.2	$ 19.15
15	17.5	W8X15	W8X15	7.50	6.4	47	0.0	14.6	$ 18.02
17.5	17.5	W10X17	W8X15	8.75	6.2	46	0.0	16.6	$ 17.51
20	17.5	W12X19	W8X15	10.00	6.1	46	0.0	18.7	$ 17.21
22.5	17.5	W12X19	W8X15	11.25	6.0	45	0.0	18.7	$ 16.71
25	17.5	W14X22	W10X17	12.50	6.2	46	0.0	20.2	$ 17.30
27.5	17.5	W16X26	W8X15	9.17	6.7	49	0.0	22.2	$ 18.82
30	17.5	W16X31	W8X15	10.00	6.8	50	0.0	22.4	$ 19.26
15	20	W8X15	W8X15	7.50	6.3	47	0.0	14.6	$ 17.70
17.5	20	W10X17	W10X17	8.75	6.4	47	0.0	16.6	$ 17.83
20	20	W12X19	W10X17	10.00	6.2	46	0.0	18.7	$ 17.40
22.5	20	W14X22	W10X17	11.25	6.2	46	0.0	20.2	$ 17.28
25	20	W14X22	W10X17	12.50	6.0	45	0.0	20.2	$ 16.83
27.5	20	W16X31	W10X17	9.17	7.0	51	0.0	22.4	$ 19.66
30	20	W18X35	W10X17	10.00	7.0	51	0.0	24.2	$ 19.80
15	22.5	W10X17	W10X17	7.50	6.6	48	0.0	16.6	$ 18.52
17.5	22.5	W10X17	W10X17	8.75	6.3	46	0.0	16.6	$ 17.55
20	22.5	W12X19	W12X19	10.00	6.3	47	0.0	18.7	$ 17.68
22.5	22.5	W14X22	W12X19	11.25	6.2	46	0.0	20.2	$ 17.45
25	22.5	W16X26	W12X19	12.50	6.2	46	0.0	22.2	$ 17.48
27.5	22.5	W16X31	W10X17	9.17	6.8	50	0.0	22.4	$ 19.15
30	22.5	W18X35	W12X19	10.00	7.0	51	0.0	24.2	$ 19.82
15	25	W10X17	W12X19	7.50	6.8	49	0.0	18.7	$ 19.09
17.5	25	W12X19	W12X19	8.75	6.5	48	0.0	18.7	$ 18.24
20	25	W12X19	W12X19	10.00	6.2	46	0.0	18.7	$ 17.43
22.5	25	W14X22	W14X22	11.25	6.4	47	0.0	20.2	$ 17.96
25	25	W16X26	W14X22	12.50	6.4	47	0.0	22.2	$ 17.85
27.5	25	W18X35	W12X19	9.17	7.0	51	0.0	24.2	$ 19.87
30	25	W18X35	W12X19	10.00	6.9	50	0.0	24.2	$ 19.35
15	27.5	W10X17	W12X19	7.50	6.7	49	0.0	18.7	$ 18.90
17.5	27.5	W12X19	W14X22	8.75	6.8	49	0.0	20.2	$ 19.07
20	27.5	W14X22	W14X22	10.00	6.6	48	0.0	20.2	$ 18.45
22.5	27.5	W16X26	W14X22	11.25	6.5	48	0.0	22.2	$ 18.15
25	27.5	W16X26	W16X26	12.50	6.6	48	0.0	22.2	$ 18.53
27.5	27.5	W18X35	W14X22	9.17	7.2	52	0.0	24.2	$ 20.47
30	27.5	W18X40	W14X22	10.00	7.2	52	0.0	24.4	$ 20.41
15	30	W10X17	W14X22	7.50	7.1	51	0.0	20.2	$ 19.95
17.5	30	W12X19	W14X22	8.75	6.7	49	0.0	20.2	$ 18.89
20	30	W14X22	W16X26	10.00	6.9	50	0.0	22.2	$ 19.45
22.5	30	W16X26	W16X26	11.25	6.7	49	0.0	22.2	$ 18.98
25	30	W16X26	W16X26	12.50	6.5	48	0.0	22.2	$ 18.29
27.5	30	W18X35	W14X22	9.17	7.1	52	0.0	24.2	$ 20.15
30	30	W18X40	W16X26	10.00	7.5	54	0.0	24.4	$ 21.25

Table 28 - Results, Conventional Steel WF Roof Assembly, Residential

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W8X15	18LH02	5.00	5.1	32	0.0	23.0	$ 17.50
17.5	15	W10X17	18LH02	4.38	5.6	34	0.0	23.0	$ 18.83
20	15	W12X19	18LH02	5.00	5.4	34	0.0	23.0	$ 18.30
22.5	15	W14X22	18LH02	4.50	5.8	36	0.0	23.7	$ 19.62
25	15	W14X22	18LH02	5.00	5.6	35	0.0	23.7	$ 18.90
27.5	15	W16X26	18LH02	4.58	6.1	37	0.0	25.7	$ 20.29
30	15	W16X31	18LH02	5.00	6.2	39	0.0	25.9	$ 20.70
15	17.5	W8X15	18LH02	5.00	5.0	31	0.0	23.0	$ 17.07
17.5	17.5	W10X17	18LH02	4.38	5.4	33	0.0	23.0	$ 18.34
20	17.5	W12X19	18LH02	5.00	5.2	33	0.0	23.0	$ 17.76
22.5	17.5	W14X22	18LH02	4.50	5.6	35	0.0	23.7	$ 18.99
25	17.5	W16X26	18LH02	5.00	5.6	35	0.0	25.7	$ 18.96
27.5	17.5	W16X26	18LH02	4.58	5.8	36	0.0	25.7	$ 19.55
30	17.5	W16X31	18LH02	5.00	5.9	37	0.0	25.9	$ 19.81
15	20	W10X17	18LH02	5.00	5.0	31	0.0	23.0	$ 17.05
17.5	20	W12X19	18LH02	4.38	5.4	33	0.0	23.0	$ 18.28
20	20	W12X19	18LH02	5.00	5.1	32	0.0	23.0	$ 17.35
22.5	20	W14X22	18LH02	4.50	5.5	34	0.0	23.7	$ 18.52
25	20	W16X26	18LH02	5.00	5.4	34	0.0	25.7	$ 18.40
27.5	20	W16X31	18LH02	4.58	5.9	36	0.0	25.9	$ 19.74
30	20	W18X35	18LH02	5.00	5.9	37	0.0	27.7	$ 19.75
15	22.5	W10X17	18LH02	5.00	4.9	31	0.0	23.0	$ 16.77
17.5	22.5	W12X19	18LH02	4.38	5.3	33	0.0	23.0	$ 17.96
20	22.5	W14X22	18LH02	5.00	5.1	32	0.0	23.7	$ 17.43
22.5	22.5	W16X26	18LH02	4.50	5.5	34	0.0	25.7	$ 18.69
25	22.5	W16X26	18LH02	5.00	5.3	33	0.0	25.7	$ 17.97
27.5	22.5	W16X31	18LH02	4.58	5.7	35	0.0	25.9	$ 19.22
30	22.5	W18X35	18LH02	5.00	5.7	36	0.0	27.7	$ 19.17
15	25	W10X17	18LH02	5.00	4.8	30	0.0	23.0	$ 16.54
17.5	25	W12X19	18LH02	4.38	5.2	32	0.0	23.0	$ 17.71
20	25	W14X22	18LH02	5.00	5.0	32	0.0	23.7	$ 17.14
22.5	25	W16X26	18LH02	4.50	5.4	33	0.0	25.7	$ 18.34
25	25	W16X31	18LH02	5.00	5.4	34	0.0	25.9	$ 18.22
27.5	25	W18X35	18LH02	4.58	5.7	35	0.0	27.7	$ 19.29
30	25	W18X40	18LH02	5.00	5.7	36	0.0	27.9	$ 19.30
15	27.5	W10X17	18LH02	5.00	4.8	30	0.0	23.0	$ 16.35
17.5	27.5	W12X19	18LH02	4.38	5.1	32	0.0	23.0	$ 17.50
20	27.5	W14X22	18LH02	5.00	4.9	31	0.0	23.7	$ 16.90
22.5	27.5	W16X26	18LH02	4.50	5.3	33	0.0	25.7	$ 18.06
25	27.5	W16X31	18LH02	5.00	5.3	33	0.0	25.9	$ 17.88
27.5	27.5	W18X35	18LH02	4.58	5.6	35	0.0	27.7	$ 18.91
30	27.5	W18X40	18LH02	5.00	5.6	35	0.0	27.9	$ 18.86
15	30	W10X17	18LH02	5.00	4.7	30	0.0	23.0	$ 16.20
17.5	30	W12X19	18LH02	4.38	5.1	31	0.0	23.0	$ 17.33
20	30	W14X22	18LH02	5.00	4.9	31	0.0	23.7	$ 16.70
22.5	30	W16X26	18LH02	4.50	5.2	32	0.0	25.7	$ 17.82
25	30	W16X31	18LH02	5.00	5.2	33	0.0	25.9	$ 17.60
27.5	30	W18X35	18LH02	4.58	5.5	34	0.0	27.7	$ 18.59
30	30	W21X44	18LH02	5.00	5.6	35	0.0	30.7	$ 18.90

Table 29 - Results, Conventional OWSJ Roof Assembly, Residential

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W8X15	W8X15	7.50	3.0	32	-96	12.2	$ 31.75
17.5	15	W10X17	W8X15	8.75	2.8	31	-96	14.2	$ 31.29
20	15	W12X19	W8X15	10.00	2.8	31	-96	16.3	$ 31.05
22.5	15	W14X22	W8X15	11.25	2.8	31	-96	17.8	$ 31.15
25	15	W16X26	W8X15	8.33	3.5	35	-96	19.8	$ 33.35
27.5	15	W16X26	W8X15	9.17	3.4	34	-96	19.8	$ 32.86
30	15	W16X31	W8X15	10.00	3.6	35	-96	20.0	$ 33.45
15	17.5	W10X17	W8X15	7.50	3.0	32	-96	14.2	$ 31.66
17.5	17.5	W12X19	W8X15	8.75	2.8	31	-96	16.3	$ 31.15
20	17.5	W12X19	W8X15	10.00	2.6	30	-96	16.3	$ 30.51
22.5	17.5	W14X22	W10X17	11.25	2.8	31	-96	17.8	$ 31.05
25	17.5	W16X26	W8X15	8.33	3.3	34	-96	19.8	$ 32.61
27.5	17.5	W16X31	W8X15	9.17	3.4	34	-96	20.0	$ 32.97
30	17.5	W18X35	W8X15	10.00	3.5	35	-96	21.8	$ 33.25
15	20	W10X17	W10X17	7.50	3.1	33	-96	14.2	$ 32.10
17.5	20	W12X19	W10X17	8.75	2.9	31	-96	16.3	$ 31.43
20	20	W14X22	W10X17	10.00	2.8	31	-96	17.8	$ 31.15
22.5	20	W16X26	W10X17	11.25	2.8	31	-96	19.8	$ 31.18
25	20	W16X26	W10X17	8.33	3.3	34	-96	19.8	$ 32.77
27.5	20	W16X31	W10X17	9.17	3.4	34	-96	20.0	$ 32.96
30	20	W18X35	W10X17	10.00	3.5	35	-96	21.8	$ 33.10
15	22.5	W10X17	W10X17	7.50	3.0	32	-96	14.2	$ 31.82
17.5	22.5	W12X19	W12X19	8.75	3.0	32	-96	16.3	$ 31.80
20	22.5	W14X22	W12X19	10.00	2.9	31	-96	17.8	$ 31.38
22.5	22.5	W16X26	W12X19	11.25	2.8	31	-96	19.8	$ 31.28
25	22.5	W16X31	W12X19	8.33	3.7	36	-96	20.0	$ 33.72
27.5	22.5	W18X35	W12X19	9.17	3.6	36	-96	21.8	$ 33.63
30	22.5	W18X40	W12X19	10.00	3.7	36	-96	22.0	$ 33.78
15	25	W10X17	W12X19	7.50	3.2	33	-96	16.3	$ 32.39
17.5	25	W12X19	W12X19	8.75	2.9	32	-96	16.3	$ 31.54
20	25	W14X22	W14X22	10.00	3.1	33	-96	17.8	$ 31.99
22.5	25	W16X26	W14X22	11.25	3.0	32	-96	19.8	$ 31.74
25	25	W16X31	W12X19	8.33	3.5	35	-96	20.0	$ 33.31
27.5	25	W18X35	W12X19	9.17	3.5	35	-96	21.8	$ 33.17
30	25	W18X40	W14X22	10.00	3.8	37	-96	22.0	$ 34.15
15	27.5	W12X19	W14X22	7.50	3.6	36	-96	17.8	$ 33.62
17.5	27.5	W14X22	W14X22	8.75	3.3	34	-96	17.8	$ 32.69
20	27.5	W14X22	W14X22	10.00	3.0	32	-96	17.8	$ 31.75
22.5	27.5	W16X26	W16X26	11.25	3.3	34	-96	19.8	$ 32.52
25	27.5	W18X35	W14X22	8.33	3.9	37	-96	21.8	$ 34.49
27.5	27.5	W18X40	W14X22	9.17	3.9	37	-96	22.0	$ 34.31
30	27.5	W21X44	W14X22	10.00	3.8	37	-96	24.8	$ 34.15
15	30	W12X19	W14X22	7.50	3.6	35	-96	17.8	$ 33.45
17.5	30	W14X22	W16X26	8.75	3.7	36	-96	19.8	$ 33.86
20	30	W16X26	W16X26	10.00	3.5	35	-96	19.8	$ 33.15
22.5	30	W16X31	W16X26	11.25	3.3	34	-96	20.0	$ 32.78
25	30	W18X35	W16X26	8.33	4.3	40	-96	21.8	$ 35.61
27.5	30	W18X40	W16X26	9.17	4.2	39	-96	22.0	$ 35.26
30	30	W21X44	W16X26	10.00	4.1	38	-96	24.8	$ 34.95

Table 30 - Results, Hybrid Steel WF Roof Assembly with 3-Ply CLT, Residential

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W8X15	18LH02	7.50	2.3	26	-96	22.1	$ 30.08
17.5	15	W10X17	18LH02	8.75	2.3	26	-96	22.1	$ 29.86
20	15	W12X19	18LH03	10.00	2.4	26	-96	22.1	$ 30.13
22.5	15	W14X22	18LH04	11.25	2.5	27	-96	22.8	$ 30.62
25	15	W16X26	18LH02	8.33	2.9	29	-96	24.8	$ 31.85
27.5	15	W16X26	18LH02	9.17	2.8	29	-96	24.8	$ 31.50
30	15	W16X31	18LH03	10.00	3.2	31	-96	25.0	$ 32.53
15	17.5	W10X17	18LH02	7.50	2.3	25	-96	22.1	$ 30.00
17.5	17.5	W12X19	18LH02	8.75	2.2	25	-96	22.1	$ 29.72
20	17.5	W12X19	18LH03	10.00	2.2	25	-96	22.1	$ 29.58
22.5	17.5	W14X22	18LH04	11.25	2.3	26	-96	22.8	$ 29.99
25	17.5	W16X26	18LH02	8.33	2.7	28	-96	24.8	$ 31.11
27.5	17.5	W16X31	18LH02	9.17	2.9	29	-96	25.0	$ 31.61
30	17.5	W18X35	18LH03	10.00	3.1	31	-96	26.8	$ 32.33
15	20	W10X17	18LH02	7.50	2.2	25	-96	22.1	$ 29.63
17.5	20	W12X19	18LH03	8.75	2.2	25	-96	22.1	$ 29.69
20	20	W14X22	18LH04	10.00	2.3	26	-96	22.8	$ 29.95
22.5	20	W16X26	18LH05	11.25	2.5	27	-96	24.8	$ 30.69
25	20	W16X26	18LH03	8.33	2.6	27	-96	24.8	$ 30.94
27.5	20	W16X31	20LH03	9.17	2.8	28	-96	25.0	$ 31.30
30	20	W18X35	18LH04	10.00	3.0	30	-96	26.8	$ 31.90
15	22.5	W10X17	20LH03	7.50	2.2	25	-96	24.1	$ 29.78
17.5	22.5	W12X19	18LH05	8.75	2.4	26	-96	22.1	$ 30.48
20	22.5	W14X22	20LH05	10.00	2.4	26	-96	24.1	$ 30.23
22.5	22.5	W16X26	18LH06	11.25	2.5	27	-96	24.8	$ 30.55
25	22.5	W16X31	18LH04	8.33	2.8	28	-96	25.0	$ 31.56
27.5	22.5	W18X35	18LH05	9.17	3.1	30	-96	26.8	$ 32.38
30	22.5	W18X40	20LH05	10.00	3.2	30	-96	27.0	$ 32.63
15	25	W10X17	20LH04	7.50	2.3	25	-96	24.1	$ 29.99
17.5	25	W12X19	24LH05	8.75	2.2	25	-96	28.1	$ 29.86
20	25	W14X22	18LH06	10.00	2.4	26	-96	22.8	$ 30.27
22.5	25	W16X26	24LH06	11.25	2.5	26	-96	28.1	$ 30.49
25	25	W16X31	24LH05	8.33	2.8	28	-96	28.1	$ 31.54
27.5	25	W18X35	18LH06	9.17	3.0	29	-96	26.8	$ 32.27
30	25	W18X40	18LH06	10.00	3.1	30	-96	27.0	$ 32.43
15	27.5	W12X19	24LH05	7.50	2.4	25	-96	28.1	$ 30.46
17.5	27.5	W14X22	20LH06	8.75	2.5	26	-96	24.1	$ 30.72
20	27.5	W14X22	24LH07	10.00	2.5	26	-96	28.1	$ 30.68
22.5	27.5	W16X26	24LH08	11.25	2.5	26	-96	28.1	$ 30.79
25	27.5	W18X35	20LH06	8.33	3.1	29	-96	26.8	$ 32.42
27.5	27.5	W18X40	24LH06	9.17	3.2	30	-96	28.1	$ 32.79
30	27.5	W21X44	24LH07	10.00	3.3	31	-96	29.8	$ 33.08
15	30	W12X19	24LH06	7.50	2.8	27	-96	28.1	$ 31.58
17.5	30	W14X22	24LH07	8.75	2.7	26	-96	28.1	$ 31.26
20	30	W16X26	28LH07	10.00	2.6	26	-96	32.1	$ 30.88
22.5	30	W16X31	24LH09	11.25	2.9	28	-96	28.1	$ 31.92
25	30	W18X35	24LH06	8.33	3.1	29	-96	28.1	$ 32.49
27.5	30	W18X40	24LH07	9.17	3.2	30	-96	28.1	$ 32.78
30	30	W21X44	28LH07	10.00	3.2	30	-96	32.1	$ 32.68

Table 31 - Results, Hybrid OWSJ Roof Assembly with 3-Ply CLT, Residential

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W10X17	W10X17	15.00	2.3	37	-160	17.0	$ 36.55
17.5	15	W10X17	W8X15	8.75	2.8	41	-160	17.0	$ 38.29
20	15	W12X19	W8X15	10.00	2.8	40	-160	19.1	$ 38.05
22.5	15	W14X22	W8X15	11.25	2.8	40	-160	20.6	$ 38.15
25	15	W16X26	W8X15	12.50	2.9	41	-160	22.6	$ 38.55
27.5	15	W16X31	W8X15	13.75	3.2	42	-160	22.8	$ 39.22
30	15	W18X35	W10X17	15.00	3.5	44	-160	24.6	$ 40.15
15	17.5	W10X17	W10X17	15.00	2.1	36	-160	17.0	$ 36.06
17.5	17.5	W12X19	W8X15	8.75	2.8	40	-160	19.1	$ 38.15
20	17.5	W14X22	W10X17	10.00	3.0	41	-160	20.6	$ 38.62
22.5	17.5	W14X22	W10X17	11.25	2.8	40	-160	20.6	$ 38.05
25	17.5	W16X26	W10X17	12.50	2.8	41	-160	22.6	$ 38.29
27.5	17.5	W16X31	W10X17	13.75	3.0	42	-160	22.8	$ 38.77
30	17.5	W18X35	W10X17	15.00	3.1	42	-160	24.6	$ 39.15
15	20	W10X17	W12X19	15.00	2.1	36	-160	19.1	$ 36.10
17.5	20	W12X19	W10X17	8.75	2.9	41	-160	19.1	$ 38.43
20	20	W14X22	W10X17	10.00	2.8	40	-160	20.6	$ 38.15
22.5	20	W16X26	W12X19	11.25	3.0	41	-160	22.6	$ 38.72
25	20	W16X31	W12X19	12.50	3.1	42	-160	22.8	$ 38.96
27.5	20	W18X35	W12X19	13.75	3.1	42	-160	24.6	$ 39.15
30	20	W18X40	W12X19	15.00	3.3	43	-160	24.8	$ 39.55
15	22.5	W10X17	W14X22	15.00	2.2	37	-160	20.6	$ 36.42
17.5	22.5	W12X19	W12X19	8.75	3.0	42	-160	19.1	$ 38.80
20	22.5	W14X22	W12X19	10.00	2.9	41	-160	20.6	$ 38.38
22.5	22.5	W16X26	W12X19	11.25	2.8	41	-160	22.6	$ 38.28
25	22.5	W16X31	W14X22	12.50	3.1	42	-160	22.8	$ 39.16
27.5	22.5	W18X35	W14X22	13.75	3.2	42	-160	24.6	$ 39.22
30	22.5	W18X40	W14X22	15.00	3.2	43	-160	24.8	$ 39.48
15	25	W12X19	W16X26	15.00	2.5	38	-160	22.6	$ 37.23
17.5	25	W14X22	W14X22	8.75	3.4	44	-160	20.6	$ 39.93
20	25	W14X22	W14X22	10.00	3.1	42	-160	20.6	$ 38.99
22.5	25	W16X26	W14X22	11.25	3.0	41	-160	22.6	$ 38.74
25	25	W18X35	W14X22	12.50	3.2	42	-160	24.6	$ 39.23
27.5	25	W18X40	W16X26	13.75	3.5	44	-160	24.8	$ 40.22
30	25	W21X44	W16X26	15.00	3.5	44	-160	27.6	$ 40.23
15	27.5	W12X19	W16X31	15.00	2.8	40	-160	22.8	$ 38.02
17.5	27.5	W14X22	W14X22	8.75	3.3	43	-160	20.6	$ 39.69
20	27.5	W16X26	W16X26	10.00	3.5	45	-160	22.6	$ 40.39
22.5	27.5	W16X31	W16X26	11.25	3.4	44	-160	22.8	$ 40.07
25	27.5	W18X35	W16X26	12.50	3.4	44	-160	24.6	$ 39.81
27.5	27.5	W18X40	W16X26	13.75	3.3	44	-160	24.8	$ 39.79
30	27.5	W21X44	W16X31	15.00	3.7	45	-160	27.6	$ 40.75
15	30	W12X19	W18X35	15.00	3.0	41	-160	24.6	$ 38.65
17.5	30	W14X22	W16X26	8.75	3.7	46	-160	22.6	$ 40.86
20	30	W16X26	W16X26	10.00	3.5	44	-160	22.6	$ 40.15
22.5	30	W16X31	W16X26	11.25	3.3	44	-160	22.8	$ 39.78
25	30	W18X35	W16X31	12.50	3.6	45	-160	24.6	$ 40.69
27.5	30	W21X44	W16X31	13.75	3.7	46	-160	27.6	$ 40.91
30	30	W21X44	W18X35	15.00	3.8	46	-160	27.6	$ 41.15

Table 32 - Results, Hybrid Steel WF Roof Assembly with 5-Ply CLT, Residential

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W10X17	18LH06	15.00	2.1	34	-160	24.9	$ 36.40
17.5	15	W10X17	18LH03	8.75	2.4	35	-160	24.9	$ 37.24
20	15	W12X19	18LH04	10.00	2.5	36	-160	24.9	$ 37.45
22.5	15	W14X22	18LH04	11.25	2.5	37	-160	25.6	$ 37.62
25	15	W16X26	18LH05	12.50	2.9	39	-160	27.6	$ 38.59
27.5	15	W16X31	18LH06	13.75	3.2	40	-160	27.8	$ 39.50
30	15	W18X35	18LH06	15.00	3.3	42	-160	29.6	$ 40.00
15	17.5	W10X17	18LH06	15.00	2.0	33	-160	24.9	$ 35.91
17.5	17.5	W12X19	18LH03	8.75	2.3	35	-160	24.9	$ 37.09
20	17.5	W14X22	18LH04	10.00	2.5	36	-160	25.6	$ 37.42
22.5	17.5	W14X22	18LH04	11.25	2.3	35	-160	25.6	$ 36.99
25	17.5	W16X26	18LH05	12.50	2.6	37	-160	27.6	$ 37.85
27.5	17.5	W16X31	18LH06	13.75	2.9	39	-160	27.8	$ 38.61
30	17.5	W18X35	18LH06	15.00	3.0	40	-160	29.6	$ 39.00
15	20	W10X17	20LH07	15.00	2.0	33	-160	26.9	$ 35.98
17.5	20	W12X19	20LH03	8.75	2.2	34	-160	26.9	$ 36.69
20	20	W14X22	18LH05	10.00	2.5	36	-160	25.6	$ 37.60
22.5	20	W16X26	20LH05	11.25	2.5	36	-160	27.6	$ 37.69
25	20	W16X31	18LH06	12.50	2.8	38	-160	27.8	$ 38.30
27.5	20	W18X35	18LH07	13.75	3.0	39	-160	29.6	$ 39.02
30	20	W18X40	20LH07	15.00	3.1	40	-160	29.8	$ 39.43
15	22.5	W10X17	20LH09	15.00	2.2	34	-160	26.9	$ 36.57
17.5	22.5	W12X19	18LH05	8.75	2.4	35	-160	24.9	$ 37.48
20	22.5	W14X22	18LH06	10.00	2.5	36	-160	25.6	$ 37.56
22.5	22.5	W16X26	18LH07	11.25	2.7	37	-160	27.6	$ 38.13
25	22.5	W16X31	20LH07	12.50	2.7	37	-160	27.8	$ 38.30
27.5	22.5	W18X35	18LH09	13.75	3.1	39	-160	29.6	$ 39.38
30	22.5	W18X40	20LH09	15.00	3.2	40	-160	29.8	$ 39.63
15	25	W12X19	24LH09	15.00	2.2	34	-160	30.9	$ 36.58
17.5	25	W14X22	18LH06	8.75	2.6	36	-160	25.6	$ 37.96
20	25	W14X22	24LH06	10.00	2.5	35	-160	30.9	$ 37.59
22.5	25	W16X26	24LH07	11.25	2.6	36	-160	30.9	$ 37.78
25	25	W18X35	24LH08	12.50	2.8	38	-160	30.9	$ 38.63
27.5	25	W18X40	24LH09	13.75	3.1	39	-160	30.9	$ 39.51
30	25	W21X44	24LH09	15.00	3.2	40	-160	32.6	$ 39.58
15	27.5	W12X19	28LH10	15.00	2.2	34	-160	34.9	$ 36.81
17.5	27.5	W14X22	24LH06	8.75	2.6	36	-160	30.9	$ 38.09
20	27.5	W16X26	24LH07	10.00	2.6	36	-160	30.9	$ 38.11
22.5	27.5	W16X31	24LH09	11.25	3.0	38	-160	30.9	$ 39.20
25	27.5	W18X35	24LH09	12.50	3.0	38	-160	30.9	$ 39.03
27.5	27.5	W18X40	24LH09	13.75	3.0	39	-160	30.9	$ 39.08
30	27.5	W21X44	28LH10	15.00	3.1	39	-160	34.9	$ 39.53
15	30	W12X19	28LH11	15.00	2.3	34	-160	34.9	$ 37.07
17.5	30	W14X22	24LH07	8.75	2.7	36	-160	30.9	$ 38.26
20	30	W16X26	28LH08	10.00	2.7	36	-160	34.9	$ 38.20
22.5	30	W16X31	24LH09	11.25	2.9	37	-160	30.9	$ 38.92
25	30	W18X35	28LH09	12.50	2.8	37	-160	34.9	$ 38.71
27.5	30	W21X44	28LH10	13.75	3.1	39	-160	34.9	$ 39.59
30	30	W21X44	28LH11	15.00	3.1	39	-160	34.9	$ 39.57

Table 33 - Results, Hybrid OWSJ Roof Assembly with 5-Ply CLT, Residential

Girder Span (ft)	Beam Span (ft)	Girder Size	Beam Size	Beam Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W10X17	W10X17	15.00	2.3	47	-224	19.7	$ 44.55
17.5	15	W12X19	W10X17	17.50	2.2	46	-224	21.8	$ 44.46
20	15	W12X19	W10X17	20.00	2.1	46	-224	21.8	$ 44.10
22.5	15	W14X22	W8X15	11.25	2.8	50	-224	23.3	$ 46.15
25	15	W16X26	W8X15	12.50	2.9	51	-224	25.3	$ 46.55
27.5	15	W16X31	W10X17	13.75	3.3	53	-224	25.5	$ 47.66
30	15	W18X35	W10X17	15.00	3.5	54	-224	27.3	$ 48.15
15	17.5	W10X17	W12X19	15.00	2.2	46	-224	21.8	$ 44.46
17.5	17.5	W12X19	W12X19	17.50	2.2	46	-224	21.8	$ 44.26
20	17.5	W14X22	W12X19	20.00	2.2	46	-224	23.3	$ 44.37
22.5	17.5	W16X26	W10X17	11.25	3.0	51	-224	25.3	$ 46.74
25	17.5	W16X26	W10X17	12.50	2.8	50	-224	25.3	$ 46.29
27.5	17.5	W18X35	W10X17	13.75	3.2	52	-224	27.3	$ 47.46
30	17.5	W18X40	W12X19	15.00	3.6	54	-224	27.5	$ 48.41
15	20	W10X17	W12X19	15.00	2.1	46	-224	21.8	$ 44.10
17.5	20	W12X19	W14X22	17.50	2.2	46	-224	23.3	$ 44.37
20	20	W14X22	W14X22	20.00	2.2	46	-224	23.3	$ 44.35
22.5	20	W16X26	W12X19	11.25	3.0	51	-224	25.3	$ 46.72
25	20	W16X31	W12X19	12.50	3.1	51	-224	25.5	$ 46.96
27.5	20	W18X35	W12X19	13.75	3.1	52	-224	27.3	$ 47.15
30	20	W18X40	W12X19	15.00	3.3	52	-224	27.5	$ 47.55
15	22.5	W12X19	W14X22	15.00	2.3	47	-224	23.3	$ 44.68
17.5	22.5	W14X22	W16X26	17.50	2.5	48	-224	25.3	$ 45.14
20	22.5	W14X22	W16X26	20.00	2.3	47	-224	25.3	$ 44.58
22.5	22.5	W16X26	W14X22	11.25	3.1	52	-224	25.3	$ 47.08
25	22.5	W18X35	W14X22	12.50	3.3	53	-224	27.3	$ 47.70
27.5	22.5	W18X40	W14X22	13.75	3.4	53	-224	27.5	$ 47.88
30	22.5	W21X44	W14X22	15.00	3.4	53	-224	30.3	$ 48.02
15	25	W12X19	W16X26	15.00	2.5	48	-224	25.3	$ 45.23
17.5	25	W14X22	W16X26	17.50	2.4	47	-224	25.3	$ 44.85
20	25	W16X26	W16X31	20.00	2.6	48	-224	25.5	$ 45.52
22.5	25	W16X31	W14X22	11.25	3.2	52	-224	25.5	$ 47.34
25	25	W18X35	W16X26	12.50	3.5	54	-224	27.3	$ 48.19
27.5	25	W18X40	W16X26	13.75	3.5	54	-224	27.5	$ 48.22
30	25	W21X44	W16X26	15.00	3.5	54	-224	30.3	$ 48.23
15	27.5	W12X19	W16X31	15.00	2.8	49	-224	25.5	$ 46.02
17.5	27.5	W14X22	W18X35	17.50	2.8	50	-224	27.3	$ 46.15
20	27.5	W16X26	W18X35	20.00	2.7	49	-224	27.3	$ 45.84
22.5	27.5	W16X31	W16X26	11.25	3.4	54	-224	25.5	$ 48.07
25	27.5	W18X35	W16X26	12.50	3.4	53	-224	27.3	$ 47.81
27.5	27.5	W21X44	W16X31	13.75	3.9	56	-224	30.3	$ 49.31
30	27.5	W21X44	W16X31	15.00	3.7	55	-224	30.3	$ 48.75
15	30	W12X19	W18X35	15.00	3.0	51	-224	27.3	$ 46.65
17.5	30	W14X22	W18X35	17.50	2.7	49	-224	27.3	$ 45.95
20	30	W16X26	W18X40	20.00	2.9	50	-224	27.5	$ 46.35
22.5	30	W18X35	W16X31	11.25	3.9	56	-224	27.3	$ 49.52
25	30	W18X40	W16X31	12.50	3.8	56	-224	27.5	$ 49.19
27.5	30	W21X44	W18X35	13.75	4.0	57	-224	30.3	$ 49.79
30	30	W21X50	W18X35	15.00	4.0	57	-224	30.4	$ 49.75

Table 34 - Results, Hybrid Steel WF Roof Assembly with 7-Ply CLT, Residential

Girder Span (ft)	Joist Span (ft)	Girder Size	Joist Size	Joist Spacing (ft)	Steel Weight (psf)	Global Warming Potential ($kgCO_2e/m^2$)	Maximum Potential Biogenic Carbon Content ($kgCO_2e/m^2$)	System Depth (in)	Cost ($)
15	15	W10X17	18LH07	15.00	2.3	44	-224	27.6	$ 44.83
17.5	15	W12X19	18LH08	17.50	2.4	45	-224	27.6	$ 45.08
20	15	W12X19	18LH09	20.00	2.3	45	-224	27.6	$ 44.96
22.5	15	W14X22	18LH05	11.25	2.7	47	-224	28.3	$ 46.19
25	15	W16X26	18LH06	12.50	2.9	48	-224	30.3	$ 46.85
27.5	15	W16X31	18LH06	13.75	3.2	50	-224	30.5	$ 47.50
30	15	W18X35	18LH07	15.00	3.5	52	-224	32.3	$ 48.43
15	17.5	W10X17	18LH07	15.00	2.1	43	-224	27.6	$ 44.35
17.5	17.5	W12X19	18LH08	17.50	2.2	44	-224	27.6	$ 44.54
20	17.5	W14X22	18LH09	20.00	2.3	45	-224	28.3	$ 44.93
22.5	17.5	W16X26	18LH05	11.25	2.7	47	-224	30.3	$ 46.25
25	17.5	W16X26	18LH06	12.50	2.7	47	-224	30.3	$ 46.11
27.5	17.5	W18X35	18LH06	13.75	3.1	49	-224	32.3	$ 47.30
30	17.5	W18X40	18LH07	15.00	3.4	51	-224	32.5	$ 48.29
15	20	W10X17	18LH08	15.00	2.1	43	-224	27.6	$ 44.42
17.5	20	W12X19	20LH09	17.50	2.2	44	-224	29.6	$ 44.50
20	20	W14X22	18LH11	20.00	2.4	45	-224	28.3	$ 45.11
22.5	20	W16X26	18LH06	11.25	2.6	46	-224	30.3	$ 45.98
25	20	W16X31	18LH07	12.50	2.9	48	-224	30.5	$ 46.82
27.5	20	W18X35	20LH07	13.75	3.0	49	-224	32.3	$ 47.02
30	20	W18X40	18LH08	15.00	3.3	50	-224	32.5	$ 47.87
15	22.5	W12X19	18LH10	15.00	2.4	44	-224	27.6	$ 45.27
17.5	22.5	W14X22	20LH11	17.50	2.4	45	-224	29.6	$ 45.33
20	22.5	W14X22	20LH12	20.00	2.4	45	-224	29.6	$ 45.23
22.5	22.5	W16X26	20LH07	11.25	2.7	46	-224	30.3	$ 46.13
25	22.5	W18X35	20LH08	12.50	3.1	49	-224	32.3	$ 47.36
27.5	22.5	W18X40	20LH09	13.75	3.3	50	-224	32.5	$ 48.05
30	22.5	W21X44	18LH10	15.00	3.5	51	-224	35.3	$ 48.60
15	25	W12X19	24LH09	15.00	2.2	43	-224	33.6	$ 44.58
17.5	25	W14X22	24LH11	17.50	2.3	44	-224	33.6	$ 45.03
20	25	W16X26	24LH12	20.00	2.4	45	-224	33.6	$ 45.26
22.5	25	W16X31	24LH07	11.25	2.8	47	-224	33.6	$ 46.38
25	25	W18X35	24LH09	12.50	3.1	48	-224	33.6	$ 47.41
27.5	25	W18X40	24LH09	13.75	3.1	49	-224	33.6	$ 47.51
30	25	W21X44	24LH09	15.00	3.2	49	-224	35.3	$ 47.58
15	27.5	W12X19	24LH11	15.00	2.4	44	-224	33.6	$ 45.24
17.5	27.5	W14X22	24LH12	17.50	2.3	44	-224	33.6	$ 45.16
20	27.5	W16X26	28LH13	20.00	2.4	45	-224	37.6	$ 45.46
22.5	27.5	W16X31	24LH09	11.25	3.0	47	-224	33.6	$ 47.20
25	27.5	W18X35	24LH09	12.50	3.0	47	-224	33.6	$ 47.03
27.5	27.5	W21X44	24LH10	13.75	3.3	49	-224	35.3	$ 47.99
30	27.5	W21X44	24LH11	15.00	3.3	49	-224	35.3	$ 47.97
15	30	W12X19	24LH12	15.00	2.4	44	-224	33.6	$ 45.50
17.5	30	W14X22	28LH13	17.50	2.4	44	-224	37.6	$ 45.52
20	30	W16X26	24LH14	20.00	2.6	45	-224	33.6	$ 46.04
22.5	30	W16X31	24LH09	11.25	2.9	47	-224	33.6	$ 46.92
25	30	W18X40	28LH10	12.50	3.2	49	-224	37.6	$ 47.73
27.5	30	W21X44	28LH11	13.75	3.3	49	-224	37.6	$ 48.06
30	30	W21X50	24LH12	15.00	3.5	50	-224	35.4	$ 48.60

Table 35 - Results, Hybrid OWSJ Roof Assembly with 7-Ply CLT, Residential