California Gypsum Material Flows for Life Cycle Impact Analysis and Recycling Assessment:

Emerging Research for California Policy Makers

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GYPSUM® ASSOCIATION

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EXECUTIVE SUMMARY

The following report exploring the gypsum industry's footprint in the state of California reflects commitments the Gypsum Association (GA) made to the Statewide Commission on Recycling Markets and Curbside Recycling and, by extension, CalRecycle, in November 2021. Over the course of that summer, GA staff and member company representatives met monthly with Commission members Heidi Sanborn and Sara Toyoda to consult on potential closed-loop wallboard recycling legislation. Commissioners wished to divert clean scrap waste from drywall installation into new gypsum wallboard. A minimum recycled content mandate was key to Sanborn and Toyoda's approach to closed-loop drywall recycling. The Commissioners urged manufacturers repeatedly to provide an acceptable recycled content percentage for wallboard sold in the state of California. On behalf of its member companies, the GA did not offer a potentially legally binding recycling commitment, but proposed a research effort instead. The GA's Memo Report to the California Commission was submitted to Sanborn and Toyoda in November 2021 at the end of the consultation period. The memo provides background information on the Association and its membership, gypsum panel products, their role in code compliant fire-resistant construction as well as the Association's 2021 research pledge to the Commission.

RESEARCH KEY TO INFORMED DECISION MAKING

Significant data gaps related to clean scrap volumes and locations, among other metrics, prevented the gypsum industry from assessing the viability of clean scrap closed-loop recycling or committing to a specific post-consumer content percentage. Absent such information, gypsum panel producers, Commissioners, and potentially state legislators risk making uninformed decisions, increasing the likelihood of unintended, and potentially negative, consequences.

To address this deficit, the GA began the research presented here. *California Gypsum Material Flows for Life Cycle Impact Analysis and Recycling Assessment* was conducted over three years. The information contained herein ranges from baseline information, such as the number of gypsum manufacturing facilities serving California, to less readily available data, including a reasonable estimate of the amount of clean scrap waste generated in California annually.

Compliance with anti-trust laws in the United States, Canada, and Mexico prohibit GA members from discussing information that is, or can be construed as, competitive or company specific. As a result, the Gypsum Association does not collect state-level information about its member company operations and its members do not discuss or share company specific information at GA meetings.

Therefore, neither the GA nor its member companies had data relating to volumes of gypsum panels manufactured in California for in-state distribution and volumes of panels manufactured outside of California for sale within its borders. Without this information, it was impossible to respond in a meaningful way to calls for closed-loop recycling. To fill the gap, the Athena Sustainable Materials

Institute (ASMI) was asked to determine the number of plants shipping into California via a survey. The goal was to quickly capture a high-level overview of operations and volumes related to the flow of gypsum wallboard into and within California.

BASIC INFORMATION

ASMI's report*, Determining Gypsum Board Material Flows Within and Sold into the State of California* provides a snapshot of gypsum industry activity related to California for 2019—a reference year selected to avoid potential effects of the COVID19 pandemic and retained throughout this research. Produced in 2022, the attached report probes the use of both clean scrap and internal scrap as feedstock material. While all GA members recycled internal waste, outside of California rates of clean scrap reuse were minimal. Overall, ASMI estimated that 1.5 million metric tons (MMT) of wallboard was shipped within and into California during 2019. Five plants operated in the state and supplied approximately 60% of California's product demand. Out-of-state plants met 40% of the state's needs and generally served the southern region. In fact, southern California, specifically, the Los Angeles metropolitan area and points south, accounted for approximately 60% of demand in California.

An important question remained, namely, the amount of clean scrap generated from construction activities in California on an annual basis. When standard sized panels are cut to accommodate a structure's openings and design features, scrap results. The rule of thumb is 10-15% of delivered product becomes waste. For the purposes of the study, ASMI calculated scrap generation rates of 5%, 10%, and 15% and estimated that 77,000 to 230,000 MMT were generated in 2019. Due to the demand stated above, in 2019 the majority of clean scrap was generated in the more southern regions of California.

DRILL DOWN: STAKEHOLDERS, SCRAP AVAILABILITY AND LOCATIONS

The second research phase provided in Section 2 was conducted in 2023 by Brown and Wilmanns Environmental, LLC (BWE). The firm was selected based on past work and familiarity with California, where the firm is based. *California Gypsum Wallboard Material Flow Study and Recovery and Recycling Analysis* confirmed ASMI's preliminary examination and provided greater detail by drilling down to county-level wallboard consumption and waste generation. Again, counties in the state's southern region consumed more wallboard and generated more scrap.

BWE also looked at drywall consumption by construction sector. Using 2019 data from the Construction Industry Research Board (CIRB), the firm measured both residential and nonresidential wallboard use across multiple building types. Single family home building consumes the most wallboard, double the amount of all multifamily sectors combined and exceeding the total drywall demand of non-residential construction. In fact, the residential sector consumed nearly double the amount of wallboard than all non-residential construction sectors combined. Although likely unaware of how their decisions affect waste production, current and future California home builders and homeowners are major consumers of gypsum wallboard. Changes to the current systems could affect the cost of housing—already a concern for many Californians.

Raw material extraction and manufacturing interests are only a part of a much larger wallboard "ecosystem." Other stakeholders to wallboard waste generation are identified in this report, specifically 15 entities that range across multiple sectors. From retailers and distributors to

architects and contractors, numerous actors benefit from wallboard and influence demand, use, and waste generation. Yet, interactions between stakeholder groups are extremely limited.

Final disposition of both panel manufacturing waste and construction waste is another element of this report. Both manufacturers and builders regularly provide clean drywall waste to recyclers who supply farmers with gypsum soil amendment, diverting two-thirds of the industry's manufacturing waste from landfill. According to this study, the construction industry manages to keep 50% of panel installation waste out of landfill via an existing beneficial reuse market. Notably, given that high tipping fees are often used to incentivize recycling, this open loop market has emerged in a state with relatively low landfill tipping fees.

In March of 2024, Sanborn indicated plans to promote a drywall recycling bill under the aegis of her organization, the National Stewardship Action Committee. To inform that effort, the Gypsum Association prepared to finalize and release its California wallboard research. Questions remained, including the potential environmental impacts of closed-loop wallboard recycling. Collecting and transporting clean scrap gypsum over significant distances was an inevitable aspect of a state-wide gypsum recycling program and an obvious place to start this analysis.

With a better understanding of where scrap is generated and in what quantities, the GA asked BWE to probe the environmental impacts of potential open-and closed-loop recycling scenarios. These findings are present in the final research report, "California Gypsum Wallboard Recycling Assessment."

POTENTIAL ENVIRONMENTAL IMPACTS OF STATEWIDE WALLBOARD RECYCLING

Although one California-based gypsum wallboard manufacturing facility is slated for closure by 2025, plant locations are unlikely to change in the near term. Thus, estimating the distance from future construction sites to wallboard plants is possible, providing insight into transportation impacts (monetary and environmental) of a closed-loop recycling proposal. Average distances from population centers to manufacturing sites vary significantly across the state; however, the average distance is greater than 100 miles. Return trip hauling and freight distances combined make increased vehicle emissions an inevitable result of any significant closed-loop recycling scheme.

Moreover, when state data is used to anticipate future construction and waste generation activities and locations, a high concentration of forecasted construction growth in the southern part of the state indicates that future clean scrap will continue to be generated at significant distances from most wallboard manufacturing facilities serving California. Three plants operate in the San Francisco Bay area, three operate near Las Vegas, Nevada. The remaining California wallboard plant is located in far Southern California, adjacent to a gypsum quarry and is 134 miles east of San Diego. Recycling clean scrap generated in Southern California would require significant transport.

Today, only one percent of available clean-scrap gypsum is recycled in a closed-loop manner in California. Yet, that one percent has disproportionate carbon impacts when compared to other disposition practices. While admittedly not ideal, according to BWE's study, landfilling is associated with lower pound-for-pound CO_2 transportation emissions than either open or closed loop recycling. California has ambitious carbon reduction goals, however, calls for statewide wallboard recycling must consider the carbon emissions associated with hauling.

INITIAL CONCLUSION: TRADE-OFFS ARE INEVITABLE

This GA-sponsored research project contains numerous other insights into the current wallboard ecosystem. Takeaways will vary by stakeholder group and this work is offered to address shared knowledge gaps and to fuel future conversations around the manufacture, distribution, use and recycling of this common building product. It will always be difficult to re-engineer established products, practices, and systems to accommodate changing priorities.

This research underscores that trade-offs are inevitable and the GA advocates for informed decision making about drywall recycling. “Highest and best use” is a mantra often used to justify closed-loop recycling in the face of open-loop, dissipative, or secondary beneficial reuse options. Appeals to that maxim discourage research and effectively shut down conversations about what works best for both people and planet.

An abundant naturally fire-resistive mineral, gypsum use in wallboard has been optimized by GA member companies for more than a century. The resulting product is affordable and adaptable across a vast range of building types. Ease of installation and repair, long service life—and crucially—consistent performance as a fire-resistive barrier have made gypsum wallboard ubiquitous in construction. This report is offered in a similar spirit of continuous improvement. The Gypsum Association hopes the information provided fosters mutual understanding and fact-based collaboration as stakeholders work to achieve an even better California.

DEFINITIONS

Beneficial Use or Reuse: Utilization or reuse of a material that would otherwise become solid waste. Source

Clean Scrap Wallboard or Drywall: Waste that results from sizing wallboard to meet design specifications in new construction or renovation. Clean scrap is created when cutting wallboard to accommodate window and door openings. Clean scrap must be collected and segregated from other construction wastes to remain "clean" and therefore viable for future open- or closed- loop recycling.

Closed-Loop Recycling: a process where waste is collected, recycled and then used again to make the same product. Source

Contamination: The state of containing unwanted or dangerous substances. On construction sites contamination often results from comingling waste streams, e.g. food wrappers collected with wallboard scrap, or metal fasteners intermixed with wallboard scrap. Source

Gypsum Drywall: Gypsum drywall or more simply "drywall" is a vernacular term for gypsum wallboard.

Gypsum Panels: Defined in ASTM C11 *Standard Terminology Related to Gypsum and Related Building Materials and Systems* as "the generic name for a family of sheet products consisting essentially of gypsum." This term includes gypsum board, glass mat gypsum panels, fiber reinforced gypsum panels and factory laminated gypsum panels. Source

Gypsum Wallboard: Often referred to simply as "wallboard," these gypsum panels consist of a noncombustible core primarily of gypsum with paper surfacing. Wallboard is generally used for interior walls, ceilings, and partitions. Source

Source Separation: Source separation is the process of segregating waste materials into respective categories such as recyclable [metal, wood, carpet], non-recyclable [batteries, aerosol cans], organic, inorganic and more, right from their point of generation, such as homes, construction sites, or offices. Source

Open-loop Recycling: Open-loop recycling is when products are reprocessed and the recyclate produced is used in a different application. Source

Post-consumer recycled content (PCR): Post-consumer recycled content refers to materials that have been used and discarded by consumers, such as plastic bottles, paper products, or aluminum cans, and then collected, processed, and transformed into new products. Source

Pre-consumer Content (PCC): Also known as post-industrial or pre-consumer waste, refers to materials that are recycled before they reach consumers or are used in the manufacturing process. These materials include scraps, excess materials, and faulty or defective products generated during the production or manufacturing of goods. Source

Committee: Market Development

Subject: Increasing Gypsum Board Diversion

Primary Author(s): Gypsum Association (GA)

Status: Proposed Research Plan

Date: November 30, 2021

Background:

This report reflects the Gypsum Association's ongoing work to contribute to a Drywall Diversion Policy initiated by California's Statewide Commission on Recycling Markets and Curbside Recycling. It should be noted that a previous policy proposal combined drywall diversion with a closed-loop recycling element. The GA has identified significant data gaps that prevent the gypsum industry from assessing its ability to engage in and commit to closed-loop recycling of clean scrap diverted from landfill. Lack of data around the amount of clean scrap (i.e. cut-offs from new construction) available to recycle, potential clean scrap contamination rates, and the industry's extant recycling infrastructure makes policy development impossible at this time. This report lays out the industry's previous effort to recycle, what the industry understands about the existing life-cycle of gypsum board in California, and what it does not know at this juncture. Finally, the GA proposes an effort to address these and other data limitations.

About the Gypsum Association

The vision of the Gypsum Association (GA), a not-for-profit trade association founded in 1930, is to ensure a future where gypsum products are recognized and relied upon as being essential to the health, safety, comfort, sustainability and resilience of our buildings and quality of life. In support of this vision, the Association's mission is to promote the use of gypsum products while advancing the development, growth, and general welfare of the gypsum product industry on behalf of its member companies.

GA members include all the active gypsum board (panel) manufacturers in the United States and Canada. To be eligible for membership in the Association, a firm or corporation must calcine gypsum and manufacture gypsum board under the provisions of ASTM Standard C1396.

The GA is the technical center for the specification, application, finishing, handling and storage, and overall use of gypsum panel products. In addition to responding to technical inquiries, the Association maintains a library of technical publications most of which are free to architects, specifiers, builders, contractors and code officials. The code-referenced *GA-600 Fire Resistance and Sound Control Design Manual*, now in its 23rd edition, is the GA's flagship publication.

In the spirit of stewardship, the GA member companies foster an accountable and environmentally responsible attitude. A commitment to preservation of natural resources,

establishment of recycling and waste management programs, and dedication to land reclamation inform the actions of today's gypsum panel producers.

In 2016, the GA led a four year process within ASTM to develop a recycling standard for clean scrap; ASTM C1881-20 *Standard Guide for Closed-Loop Recycling of Scrap Gypsum Panel Products* was published in May 2020. The GA is presently party to several exciting research initiatives intended to expand secondary markets for clean scrap and construction and demolition (C&D) waste. Recently, the Association announced its financial support for Dalhousie University's Phase II research exploring the viability of using C&D waste gypsum in concrete. The GA has also agreed to serve as an industry partner with the National Science Foundation (NSF) for research at the University of Wisconsin at Milwaukee (UWM) into the use of recycled gypsum feedstock to enhance the fire resistance of polymer-based products.

Reflecting the importance of stewardship and sustainability, the Gypsum Association has taken a lead in communicating the environmental performance of gypsum panels. A variety of sustainability tools, including type III, industry-average, cradle-to-gate environmental product declarations (EPDs) for both 5/8th inch type X gypsum board and glass mat gypsum panels have been prepared for the United States and Canadian markets. In 2016, the industry's early engagement in life-cycle assessment (LCA) prompted the U. S. Green Building Counsel to invite the Association to participate in an EPD Consortium. That effort aimed to encourage additional building product manufacturers to transparently report the environmental impacts of their products.

The gypsum industry has also embraced transparency and was recently singled out as a "Leader" in transparency by the Healthy Building Network (HBN), a reflection of the numerous health product declarations (HPDs) generated by GA member companies. HPDs provide consumers with access to detailed material content information about building products.

Gypsum panels currently incorporate post-consumer recycled materials. Paper facers for gypsum panels have been made from 100 percent recycled paper for more than 50 years. According to one estimate, the gypsum industry annually recycles 40 million cubic yards of paper material into facers. Moreover, many gypsum panel manufacturers—in California, and elsewhere—engage in take-back of clean scrap derived from their own or other GA member company products, diverting this material from landfill.

Not all manufacturing plants are currently able to reintroduce clean scrap gypsum into production. Only a single manufacturer in California has the equipment necessary to produce clean scrap gypsum feedstock. Most manufacturers would be willing to take clean scrap feedstock from a third-party processor; however, such a processor does not operate in California at this time.

As a result, most clean scrap gypsum is directed to other end markets, including agriculture. Recycled gypsum is widely used in California, a state highly dependent on crop irrigation, to boost essential nutrients in depleted soils, promote better root development, and improve soil

aeration and water percolation. Gypsum also reduces phosphorus movement out of the field. Using clean scrap gypsum instead of mined gypsum for agricultural applications is a beneficial reuse that should neither be dismissed nor overlooked as a means of diverting the material from landfill.

An earlier drywall diversion policy proposal considered by the Commission mandated that manufacturers operating in California and selling into California include increasing percentages of clean scrap gypsum in new product over the course of six years, ranging from 10 percent in 2024, to 25 percent in 2030. It is important to note that such a plan may not be feasible. In the case of fire-rated assemblies for floors, ceilings, and etc., gypsum manufacturers rely on formal tests conducted by certified testing laboratories located in the United States and Canada to determine the specific fire-rating of each assembly. Ratings can vary considerably based on numerous factors including the amount of post-consumer content in the tested wallboard product and the type of equipment used to calcine gypsum feedstock. These tests determine how much recycled clean scrap can be incorporated into new product. Further study and numerous testing regimes will dictate how much post-consumer content can be introduced into new gypsum board. This is a life-safety issue governed by the building code itself.

Why is gypsum wallboard the preferred interior surface finish for structures?

Gypsum board is used in more than 95 percent of construction projects because these panels provide passive fire resistance. For reasons of life safety, building codes require gypsum board use as a thermal barrier.

Gypsum board, also known as drywall or wallboard, is defined in ASTM C11 *Standard Terminology Relating to Gypsum and Related Building Materials and Systems* as "the generic name for a family of sheet products consisting of a noncombustible core primarily of gypsum with paper surfacing."

Calcium Sulfate Dihydrate ($CaSO_4 \cdot 2H_2O$), otherwise known as gypsum, is an inert compound containing 21 percent by weight chemically combined water. When gypsum board is exposed to high temperatures it does not ignite. Instead, the surface releases steam as the chemically combined water in the core is released. Heat transmission is obstructed until this slow process, known as calcination, is complete.

During a fire, wood or steel structural members covered with gypsum panels are protected and fire is contained because the temperature behind the panel is significantly lower than the temperature at which steel loses strength or wood ignites. Without the passive fire resistance provided by gypsum board walls, ceilings, and floor-ceiling and roof-ceiling assemblies, and other protective systems used in code-compliant construction today, occupants would have less time to escape and fewer structures would be saved by fire services.

Benefits of Diverting Gypsum Board From Landfills

A common C&D material, gypsum board diminishes landfill capacity. Currently, gypsum board from demolition activities and most clean scrap gypsum board (i.e. waste generated from cutting sheets to accommodate windows, doors and other openings in new construction) can be landfilled in California. How much is actually landfilled is unclear. Based on publically available data from 2019, the Gypsum Association estimates that approximately 300,000 million square feet of gypsum board was recoverable clean scrap. This equates to about 268,000 tons of clean scrap drywall feedstock. However, the Gypsum Association cautions that this is an estimate only. No clear numbers, beyond estimates, regarding the amount of recoverable clean scrap exist. Furthermore, there is no known data that captures the amount of clean scrap currently being diverted from landfills for beneficial reuse in agriculture and other end markets. This lack of data makes the amount of recoverable clean scrap that could be potentially diverted from landfills entirely unknown.

Drywall Diversion and the Potential for Recycling

A lack of data has prevented the Gypsum Association from truly evaluating both the potential and the feasibility of drywall diversion and recycling. For example, while we understand that some clean scrap is processed for diversion into agricultural markets, information about volumes is not accessible and it is unclear to the GA what entity might collect such information. The GA can only report what it understands to be the case.

- Economics: The earth contains an abundant supply of gypsum. Recycled gypsum feedstock must be competitive with virgin sources. Costs will reflect collection, processing and transportation logistics as clean scrap is moved from jobsites to processers and on to gypsum board manufacturing facilities. Due to long standing anti-trust compliance policies, the Gypsum Association membership is prevented from discussing issues of a competitive nature among themselves. As a result, the industry lacks an understanding of the potential economics a closed-loop or other diversion mechanism.

- Environmental impacts: Unknown factors, such as distances between and among clean scrap collection points, potential processors, and manufacturing facilities means the GA cannot know if recycled feedstocks will produce an environmentally preferable product. As engagement with LCA among building product manufacturers has grown over the course of the last decade, so has awareness and concern about the carbon footprint of the products they produce. Environmental impacts must be understood within the context of AB 32, the *California Global Warming Solutions Act of 2006*.

- Level of member company engagement in California: The GA does not collect state-level data related to volumes. It also does not collect sales figures of any kind. We do not

know how many member companies sell into the state of California. We suspect that California's need for gypsum board is not met by the five plants operating in the state; however, this important fact has not been validated. Without the statewide data, validation of assumptions, and engagement from non-Gypsum Association stakeholders, any proposals could be based on skewed data and may lead to ineffective solutions and unattainable goals.

- Safety: Due to valid concerns about contamination of drywall during use, including the pre-1978 application of lead-based paint and earlier use of asbestos in joint compounds, GA member companies will not recycle demolition waste gypsum board. Compliance with the *Drywall Safety Act of 2012*, a response to the Chinese drywall crises of the mid-2000s, underscores the GA's commitment to recycling clean scrap only. (See, *Drywall Safety Act of 2012* discussion, below.)

- Experience of previous gypsum board recycling efforts:

    - Massachusetts banned landfilling of clean scrap drywall in 2011. Despite the availability of a recycled drywall processor, and the willingness of two Boston-area gypsum panel manufacturers to use the resulting feedstock, not enough clean scrap was delivered to the processing facility to provide a consistent stream of post-consumer gypsum feedstock to manufacturers. The lack of clean scrap for processing was attributed to the ease with which clean scrap gypsum board could be landfilled inexpensively across state lines. Although the ban remains in place, Massachusetts has had little success finding appropriate end markets for scrap gypsum board. Given this history, which underscores a lack of certainty around post-consumer feedstock supply, manufacturers are hesitant to commit to specific percentages of post-consumer recycled content in new product. Even the *Massachusetts 2030 Solid Waste Master Plan*, released in October 2021 by the Department of Environmental Protection (MassDEP), lists Drywall/Gypsum Board as a "medium-low" goal reduction material among 70 listed material categories.

    - Manufacturer participants in Building Product Ecosystems' (BPE) San Francisco Bay-area closed-loop gypsum board recycling pilots reported a high level of contamination in clean scrap received from jobsites. Contamination was less notable in New York City pilot projects. In the case of large scale projects, such as those in California, it will be extremely challenging to "retrain" construction workers of all trades, not to mention other publics, who have long discarded both trash (such as food and beverage containers) and construction waste into mixed waste receptacles.

      Notably, while the BPE pilots demonstrated the feasibility of very limited clean scrap gypsum board recycling, the so-called pilots lacked a data collection

component. As a result, the information, above, is strictly anecdotal and cannot be used to estimate contamination rates. Terry Weaver of USA Gypsum, who processed clean scrap from BPE's New York City pilots, reports that material from construction sites coming directly to his Denver, Pennsylvania, processing facility have contamination rates close to 5 percent.

- The European Union's (EU) experience with recycling gypsum, as evidenced by the ongoing efforts of Eurogypsum, is often cited as a precedent for recycling drywall in the United States. Yet, drywall recycling is not widespread across the EU. The average recycled content rate in the EU today is closer to 5 percent, according to the 2019 4th European Gypsum Recyclers Forum and as confirmed by Eurogypsum in conversation with the Gypsum Association in March 2021. Drywall recycling varies widely across the EU for reasons consistent with concerns expressed by U.S. manufacturers. At the 5th European Gypsum Recyclers Forum 26 May 2021, Eurogypsum reported that "Numbers are progressing over the years, although at a low pace. Further efforts are needed to overcome the barriers to actual recycling." Barriers cited as major disincentives for higher recycling rates include the high cost of recycled feedstock when compared to natural rock or flue gas desulfurization (FGD) gypsum, concerns about contamination, and low landfill tipping fees. It should be noted that landfill tipping fees are significantly higher in the EU than in California or the U.S., per CalRecycle's 2015 report Landfill Tipping in California.

- Compliance with *Drywall Safety Act of 2012*: Passed by the 112th Congress and signed into law by President Barak Obama, the Act addresses the issue of high sulfur content in gypsum board imported from China by mandating that the Consumer Product Safety Commission (CPSC) promulgate a final rule for drywall manufactured or imported for domestic use that "limits sulfur content to a level not associated with elevated rates of corrosion in the home." In addition, the Act provides that ASTM's gypsum board labeling standard C1264 *Standard Specification for Sampling, Inspection, Rejection, Certification, Packaging, Marking, Shipping, Handling, and Storage of Gypsum Panel Products* be treated as a rule promulgated by the CPSC. Finally, the Act requires that CPSC recommendations "specify that problematic drywall . . . should not be reused or used as a component in production of new drywall."

  GA member companies' products are compliant with the Drywall Safety Act, however, the level of enforcement aimed at imported drywall remains unclear. According to the United States Census Bureau, three ports of entry in California continue to receive drywall from foreign sources. Moreover, as the CPSC noted in its own 2017 report *Chinese Product Safety: A Persistent Challenge to U.S. Regulators and Importers*, "U.S. product safety regulators have limited resources to monitor imports. While the U.S. Consumer Product Safety Commission (CPSC) has implemented a proactive methodology to monitor imports as they enter the country, they do not have staff to man every port and have not been able to inspect every high-risk shipment." Even at

this early stage, GA member companies are adamant that should a recycling scenario emerge, ensuring compliance with the Act means that only clean scrap or recycled feedstock derived from GA member company gypsum board will be acceptable.

Data Collection Key to Maximizing Future Gypsum Board Diversion

Study Goal: The GA will sponsor a third-party study to collect available data on volumes of clean scrap available for potential landfill diversion through recycling, beneficial reuse and/or other means. Manufacturers will use the data to consider the alternative uses of clean scrap including impact on carbon footprint, while also considering future changes in the methods of building construction. The GA will provide periodic industry-average reports on volumes of clean scrap taken back by manufacturers selling in California.

Data collection will include, but not be limited to, the following:

Current gypsum board production

- Total volume of gypsum board produced inside California.
- Total volume of gypsum board sold in California from out of state.
- Total volume of post-consumer content currently being recycled in a closed-loop manner by manufacturers selling in California.
- Audit of plants selling in California to understand existing recycling capacity.

Clean scrap

- Confirm potential volume available.
- Relative location(s) of scrap generation to plants and processors.
- Clean scrap disposal sites.
- Contamination levels of clean scrap to include how much will be unacceptable due to country of origin (e.g. non-member company imports) and jobsite, or other contamination.
- Feasibility of source separation including engagement with interested stakeholders outside the GA and throughout the design and construction value chain.

- Current beneficial reuse activity outside of closed-loop recycling, to include volumes of clean scrap currently beneficially reused in agricultural as a soil amendment, or animal bedding.

- Future diversion possibilities and rates as building methods evolve.

- Environmental impacts of landfill diversion efforts and how they impact lifecycle assessments.

Scope of participation: All GA member companies selling in / into California.

The GA believes, but will rely on third-party verification, that 5 of 6 regular member companies consistently sell gypsum board in or into the state of California.

Policy recommendations: Groundwork for successful diversion

The study report will provide data to inform the feasibility and timing of future policy options.

Schedule: The GA will issue a Request for Proposals (RFP) for the work described, above, in early 2022. Proposals will be reviewed and a candidate selected in March 2022. The work will commence on or about May 2022 in alignment with the GA's FY 2023 budget cycle.

Athena Sustainable Materials Institute

www.athenasmi.org

Determining gypsum board material flows within and sold into the state of California

Prepared for: Gypsum Association

By: Athena Sustainable Materials Institute

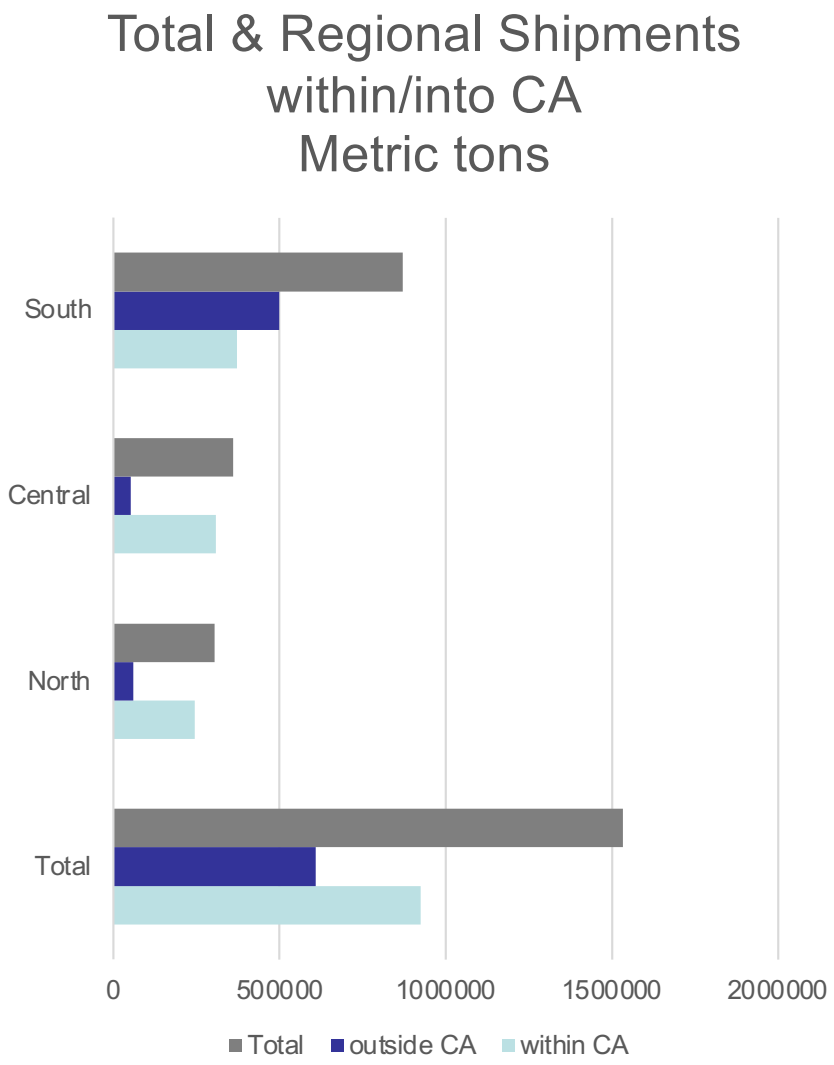
Preliminary findings

Project Objectives

- Survey GA members to determine:
  - Total volume of gypsum board shipped within and sold into various California (CA) state regions.
    - North (SF), Central (Fresno) and South (LA)
  - Total volume of post-consumer (clean scrap cut-offs) available and currently recycled by manufactures within and selling into the state.
  - For GA members selling in/into CA what are their capabilities/capacity to recycle cut-offs going forward.
  - Typical transport mode and distance of GWB shipments and inputs faced by plants serving CA.

Survey Participants & Shipments

- A total of 18 plants serving the CA market completed the survey.
  - of which 5 plants shipped <1,000 metric tons representing less than 1% of shipments and were ignored for data roll-up purposes.
- In total,13 plants shipped **1.5 million m tons of GWB within and into CA**
  - of which 5 plants operate in the state and supply 60% of GWB
- Regionally
  - Southern destination accounts for more than half of shipments
  - Out-of-state plants generally serve southern region



CA GWB Composition by Supply Region

- Based on 13 plants
  - Weighted average basis

    (may not add to 100% due to rounding)
  - Virgin ore may be either natural or FGD gypsum
- Clean cut-offs input minor but higher for plants operating within CA

Percent Board Composition

All Plants	Virgin Ore	Int Fab Scrap	Clean Cut-offs
Total	96%	4%	1%
North	98%	3%	1%
Central	95%	2%	4%
South	96%	5%	0%
CA Plants	Virgin Ore	Int Fab Scrap	Clean Cut-offs
Total	97%	2%	2%
North	99%	2%	1%
Central	95%	1%	4%
South	98%	3%	0%
Outside CA Plants	Virgin Ore	Int Fab Scrap	Clean Cut-offs
Total	94%	6%	0.02%
North	95%	5%	0.17%
Central	95%	5%	0.04%
South	94%	6%	0.00%

Technical Capability to Recycle Clean Cut-Offs into Board

- For all plants reporting
  - Off-cut recycling capability ranged from 0 to 12%
  - On average, may recycle up to 7%
- For plants operating in CA
  - May recycle up to 8%
- For plants operating outside CA, but serving CA
  - May recycle up to 4%

Potential Cut-off availability by CA market region

- Based on 1.5 million m tons
  - Cut-off availability may range between 77k to 230K m tons
  - More than half of which would be available in southern part of the state
  - The south region would be a better location to initiate a cut-off recycling pilot

Potential Cut-off availability @5%

	m tons
Total	76,687
North	15,179
Central	17,989
South	43,519

Potential Cut-off availability @10%

	m tons
Total	153,375
North	30,359
Central	35,977
South	87,039

Potential Cut-off availability @15%

	m tons
Total	230,062
North	45,538
Central	53,966
South	130,558

GWB Shipments - mode and distance (miles) by source and market destination

Destination	All Plants		Plants within CA		Plants outside CA	
	Road	Rail	Road	Rail	Road	Rail
North	251	152	205	152	436	153
Central	156	32	98	42	509	68
South	223	0	152	0	276	0

- Generally, use a combination of road and rail
  - More road than rail; especially when serving the larger southern (LA) market

Virgin Ore Sourcing by Plant Location and Market Serviced

Destination	All Plants		Plants within CA		Plants outside CA	
	Road	Ocean	Road	Ocean	Road	Ocean
North	2	1003	1	1153	6	383
Central	11	1512	13	1750	3	87
South	10	183	<1	427	17	2

Plants outside CA source virgin input from closer proximity (less ocean transport)

Clean Scrap Cut-offs Collection Distance

- Only 3 plants answered this Q?
  - They represent only 1% of all shipments in/into CA
  - Average collection distance was 50 miles (83 km)
  - Likely single unit truck with varying packed densities

Final Observations

- The southern region of the state (LA and south) represents 60% of the California GWB market
  - Out-of-state plants target the southern market (e.g., 500k m tons)
  - CA plants equally serve all regions
- Clean cut-off recycling is currently a minor input for GWB production but higher within CA than out-of-state
- Across GA members, cut-off recycling capabilities are highly variable (0% to12%), but generally higher within CA
  - However, if cut-offs are equivalent to 15% of shipments, CA board plants would need to takeback 230k mtons, which is equivalent to 25% of all CA plant shipments (925k mtons).
  - Unlikely closed-loop recycling scenario
- Transport distance of virgin ore is considerable for plants within CA.
  - Raising possibility of environmental advantage when using within state cut-offs
  - Need to determine t-km impact by mode and distance as opposed to just distance implications.

Brown and Wilmanns Environmental, LLC

California Gypsum Wallboard Material Flow Study And Recovery and Recycling Analysis

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Technical Review and Additional Analysis
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for
Gypsum Association

September 2023

Introduction

The Gypsum Association engaged Brown and Wilmanns Environmental, LLC (BWE) to conduct a study of gypsum wallboard (GW) material flows in the state of California and identify opportunities to reduce and potentially eliminate the disposition of waste GW in California landfills. The results of the study are intended to help the Gypsum Association and its members address their sustainability goals and provide California policymakers with relevant data to inform decision making.

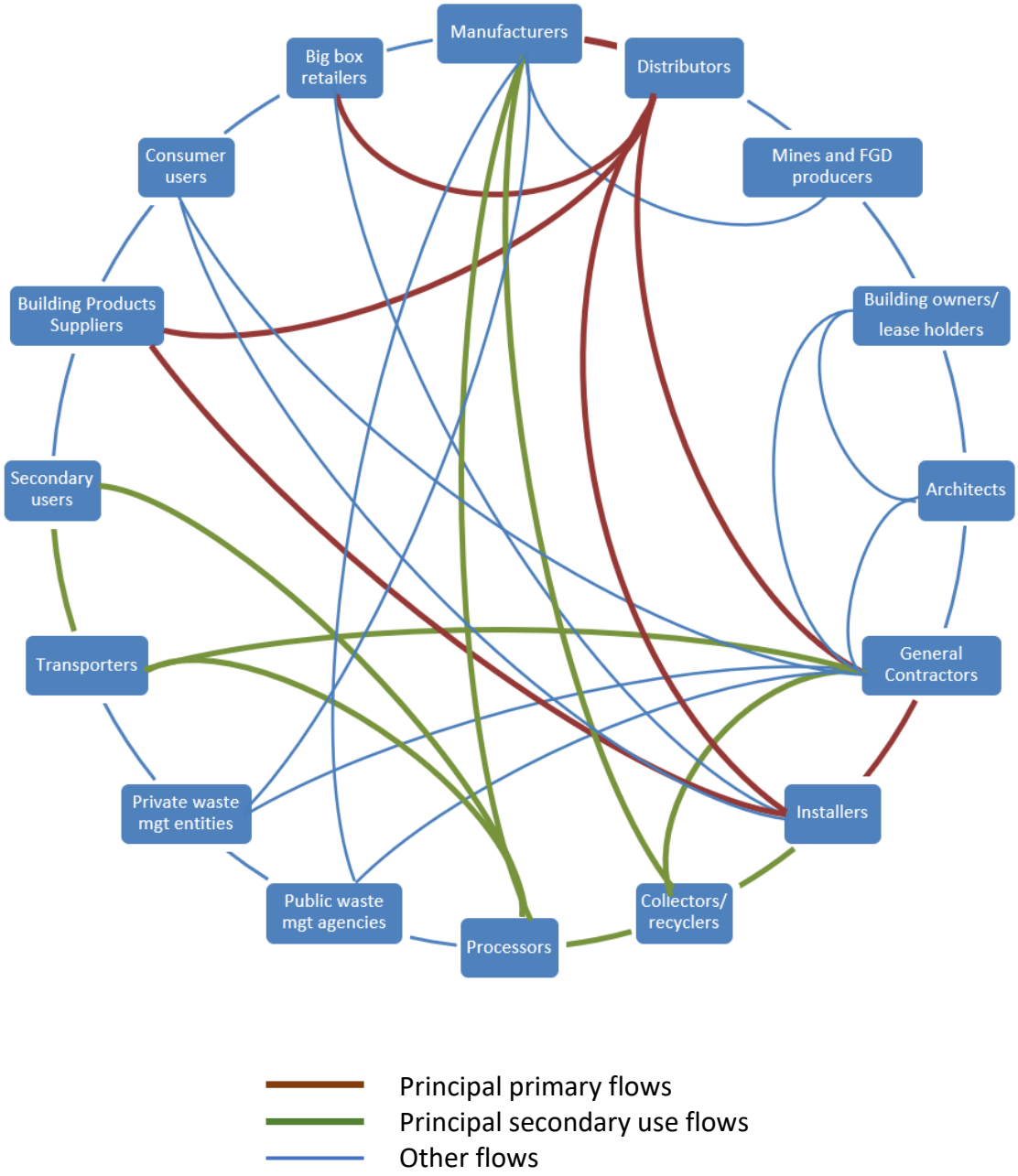
In conjunction with the material flow study, the Gypsum Association asked Athena Sustainable Materials Institute (Athena) to conduct a survey of California and out-of-state GW manufacturers to determine the quantities of a) GW shipped within and to California; b) clean GW construction scrap (CGWCS) generated in the state; c) scrap recovered and reused by manufacturers; d) recovered CGWCS that manufacturers potentially could use); and e) typical distances and transportation modes for shipments of CGWCS from job sites and/or processors. The results of this study along with other relevant California data and background literature on GW were provided to BWE by the Gypsum Association. In addition, BWE conducted a literature review to augment the provided information, particularly in regard to international efforts to improve GW waste management.

Given that shipping distances were identified as a critical factor for the potential reuse of CGWCS in manufacturing new GW, BWE identified a source for statewide building permit data that could be used to estimate GW use and the associated CGWCS generation by county. This information is useful for generating a map of estimated volumes that could be transported economically to panel manufacturing plants. The estimates could also serve as an input to a similar analysis for alternative reuse pathways (e.g., agricultural uses, industrial uses, etc.).

Gypsum Wallboard Ecosystem

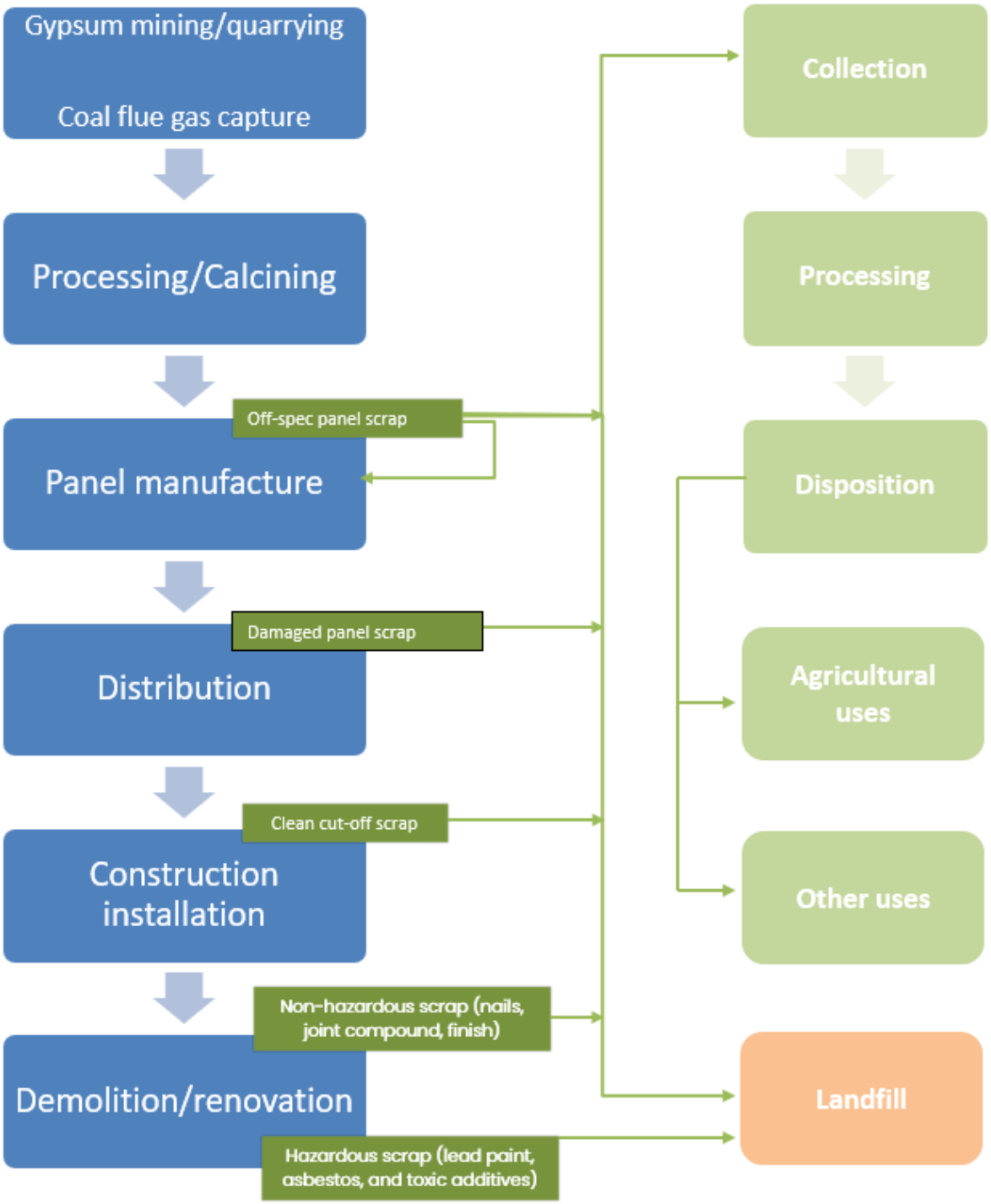
The "ecosystem" encompassing gypsum wallboard reflects a network of entities across the life cycle of GW products that includes mines and quarries, FGD (flue-gas desulfurization) and other secondary sources, product manufacturers, building industry entities, recyclers, transporters, distributors and retailers, and end users.

Figure 1. Relationships among the entities in the GW ecosystem.



Material Flows

Figure 2. Schematic of the life cycle material flows for GW from origin to waste disposition



The scope of this study is limited to the flows from the wallboard production phase of the material life cycle to the wastes generated during the installation process. While we engaged with the Gypsum Association to analyze the GW scrap generated from demolition and renovation processes, we found that there are few alternatives to landfilling due to the potential for hazardous contaminants (lead paint, asbestos in joint compound) in the removed panels.[1] An analysis of the scrap from the demolition and renovation phase may be completed in a second phase of the study.

California GW production, shipments, and manufacturing waste flows

For this study, we are including the production flows that could contribute to California GW scrap flows—GW manufactured and distributed in California by GA members, manufactured in the U.S. outside of California and distributed in the state by GA member, foreign manufactured and imported directly into California, and foreign imports into other states that are then distributed in California. Domestic production at locations outside of California as well as international production are included as GW shipments when they are shipped into California.

Table 1. Gypsum production facilities in California and nearby states

Company	Location	Product/Operation
American Gypsum	Albuquerque, NM	Wallboard
American Gypsum	Bernalillo, NM	Wallboard
CertainTeed	Las Vegas, NV	Wallboard
CertainTeed	Napa, CA	Wallboard
Georgia-Pacific	Antioch, CA	Wallboard
Georgia-Pacific	Las Vegas, NV	Wallboard, quarry (outside of LV)
National Gypsum	Long Beach, CA	Wallboard
National Gypsum	Phoenix, AZ	Wallboard
National Gypsum	Richmond, CA	Wallboard
PABCO	Las Vegas, NV	Wallboard, quarry
PABCO	Newark, CA	Wallboard
PABCO	Vernon, CA	Paper
USG	Plaster City, CA	Wallboard, gypsum mine and quarry
USG	Stockton, CA	Ceiling suspension systems

Manufacturer distribution channels typically include distributors and a few large-scale retailers (e.g., Home Depot, Lowes) which sell to smaller suppliers and retailers and some larger end users. Major volume end users are typically GW contractors although some may be general contractors, with homeowners representing smaller quantity users. Imports, whether directly into California or via a port of entry in another state, may be managed by manufacturers or distributors. There is a potential for generation of GW scrap during shipments due to panel damage in shipping and in distribution centers.

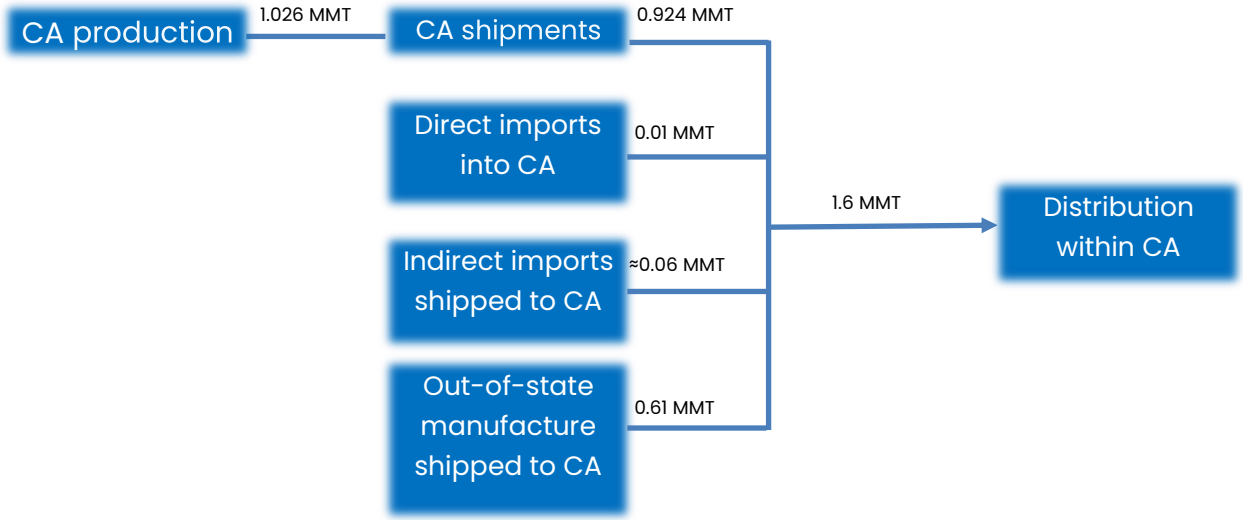
Due to limited data availability, we cannot describe all GW flows within the production and distribution life cycle stages. We have located data on 2021 GW shipments within and to California by domestic manufacturers[2] and imports to California and Arizona ports of entry. We assume that all California ports

of entry are used to import into the state.[3] We have not been able to identify the quantity of GW that may have been shipped to California after entering through Nogales, AZ.

Production flows in Figure 3 reflect first quality GW that is manufactured and shipped to customers, plus recovered and reused GW that doesn't meet specifications but is used in making new wallboard, sent to processors for agricultural uses, or sent to landfills (see section *GW waste generation and disposition*).

We estimate total distribution of GW panels to be 1.51 million metric tons (MMT)[4] plus an unknown quantity of indirect imports (imported to a state other than California and then shipped to California). Making an assumption that the quantity is between 0.02 and 0.1 MMT, we estimate the quantity to be the midpoint—0.06 MMT. The resulting total use quantity is 1.6 MMT.

Figure 3. Production and shipment flows



GW use by geographic location and building type

In its survey of manufacturers, Athena estimated that the following quantities of GW were shipped to customers in the northern, central and southern regions of California:

Table 2. Regional shipments of GW panels

Region	**Quantity (MMT)**
Northern	0.304
Central	0.360
Southern	0.870
Total	1.534

While overall California production data are useful to assess the scale of generation and potential recovery and reuse, the geographic distribution of scrap generation and subsequent transport distances are significant factors for recovery and reuse rates (see the "Economic factors" subsection below). Thus, there is a need for more detailed data on actual GW use locations.

We developed a general method to estimate GW use from building permit valuation data (labor and materials cost) obtained from all California cities and counties by the Construction Industry Research Board (CIRB).[5] Using the CIRB residential and non-residential data in conjunction with average construction costs per square foot (sf) for different types of construction prepared by the International Code Council (ICC),[6] we estimated the total sf of construction for each building type in the CIRB dataset (5 categories of residential[7] and 16 non-residential categories[8]). We then used that total sf and various other factors to estimate GW usage for each building type.

Given the significant amount of variation among the building types and within building types, and the unknown amount of unpermitted construction that uses GW, our estimates should be considered preliminary at best and used with caution.

Residential GW Calculations

For the residential calculations, we divided the CIRB $ valuation by the ICC sf cost factor for each of the four building types (residential alterations calculated separately) for the individual statewide, countywide, and municipal and unincorporated geographic areas and then multiplied the resulting total sf by a multiplier to estimate the total GW sf for each area.[9]

Calculations:

"Value"	CIRB total $ valuation of permitted residential construction
"Total Units"	CIRB total units
"ICC $/SF"	ICC cost factor per sf of permitted residential construction
"Total SF"	"Value" divided by the "ICC $/SF"
"Multiplier"	Factor for estimating GW sf quantity per "Total SF" (residential = 3.6)
"Total GW SF"	Calculated as "Total SF" * 3.6

The basic calculation is "Value" ÷ "ICC $/SF" * "Multiplier" = "Total GW SF"

The ICC cost factors do not include a residential alterations category. We assumed that alterations were a mix of building types where we estimated a $/sf cost ($122.46[10]) and a sf/permit factor (250 sf/permit) and then followed the calculations for the other residential building types to get a Total GW SF value.

For residential GW use, the total 2019 statewide permit valuation for all building types is $34.3 billion, the estimated statewide total number of units for all building types (excluding existing residential alterations) is 111,284 (including our estimate of residential alterations), the estimated statewide total construction area footprint is 307M sf, and the estimated total statewide GW use is 0.918B sf (918M in 1,000 sf).

Estimated total residential GW use for individual counties is listed in Annex 1.

Table 3. CIRB residential units and permit valuations, and BWE estimated GW use

Residential Type	Units	State Totals $1,000 Valuation	Total Residential 1,000 sq ft Wallboard
Single Family	58,052	$18,132,856	501,986
Multi-Family (2 Units)	2,757	$640,760	17,739
Multi-Family (3-4 Units)	1,838	$351,089	8,701
Multi-Family (5+ Units)	48,637	$8,272,502	185,563
Residential Alterations		$6,951,768	204,364
Totals	111,284	$34,348,976	918,352

Non-Residential GW Calculations

The calculations for non-residential GW use follow the same basic structure as the residential calculations. However, the range of building types (e.g., hotels, warehouse, churches, offices) and structural designs makes it difficult to determine individual sf/unit values. We identified a range of values for the number of units and the average size of the units for some of the categories (hotel/motel, schools, stores), and used professional judgement to estimate values for the remaining categories. As such, the calculated total non-residential GW use value is subject to a relatively high degree of uncertainty.

For non-residential GW use, the total 2019 permit valuation for all building types is $29.7 billion, the estimated total number of units for all building types is 115,324 (including an estimate of non-residential alterations and residential garages), the estimated total construction sf is 253M, and the estimated total GW use is 0.46B sf (460M in 1,000 sf). Estimated total non-residential GW use for individual counties is in Annex 2.

Table 4. Non-residential permit valuations and estimated GW use

Non-Residential Type	State Totals $1,000 Valuation	Total Non-Residential 1,000 sq ft Wallboard
Hotels & Motels	$1,535,110	29,554
Non-Housekeeping Shelter	$333,304	6,131
Amusement & Recreation	$802,706	13,758
Churches	$83,791	787
Industrial & Manufacturing	$1,408,157	19,796
Service Stations	$97,384	2,325
Hospitals	$324,686	5,015
Offices	$3,146,012	66,016
Schools Education	$532,116	10,806
Stores, Merchantile, Warehouses	$4,585,744	54,731
Other Non-Residential Buildings	$1,790,091	13,720
Non-Residential Alterations	$14,743,409	234,618
Residential Garages	$270,521	3,314
Totals	$29,653,029	460,571

Combined Residential and Non-Residential GW Calculations

The combined residential and non-residential total GW estimated use is 1.38B sf (1,380M in 1,000 sf) (see Annex 3a-3c). The 15 largest use quantities by county are in Table 5.

Table 5. Largest use quantities (1,000 sf) by county

County	1,000 Sq Ft		
	Residential	Non-Residential	Combined
Los Angeles	170,455	92,270	262,725
Santa Clara	48,370	82,260	130,630
Orange	69,529	45,264	114,793
San Diego	55,186	32,970	88,156
Riverside	61,862	17,652	79,515
Alameda	51,455	25,927	77,381
Sacramento	45,425	23,141	68,566
San Francisco	44,112	24,420	68,532
San Bernardino	39,250	19,124	58,374
San Mateo	31,491	23,019	54,510
San Joaquin	27,597	12,333	39,930

County	1,000 Sq Ft		
	Residential	Non-Residential	Combined
Contra Costa	27,542	6,260	33,801
Fresno	24,532	6,382	30,914
Placer	21,942	3,221	25,162
Sonoma	20,014	2,595	22,610

GW waste generation

CalRecycle identifies the following sources of GW waste: 64% from new construction, 14% from demolition and renovation, 12% from panel manufacturing, and 10% from renovation.[11] CalRecycle also estimated a 12% waste factor for GW installation in new construction. Using the 12% waste factor with our estimate of 1.6 MMT total GW distribution in California, we approximate that GW waste from new construction was about 0.196 MMT. Based on this estimate, we calculated the amounts of waste from demolition, panel manufacturing, and renovation as show in Table 6.

Table 6. GW manufacturing scrap, construction scrap, and demolition scrap

GW Waste Source	Percent of Total GW Waste	MMT
New construction (based on 12% of 1.6 MMT)	64%	0.196
Demolition	14%	0.043
Panel manufacturing	12%	0.037
Renovation	10%	0.031
Total GW waste	**100%**	**0.306**

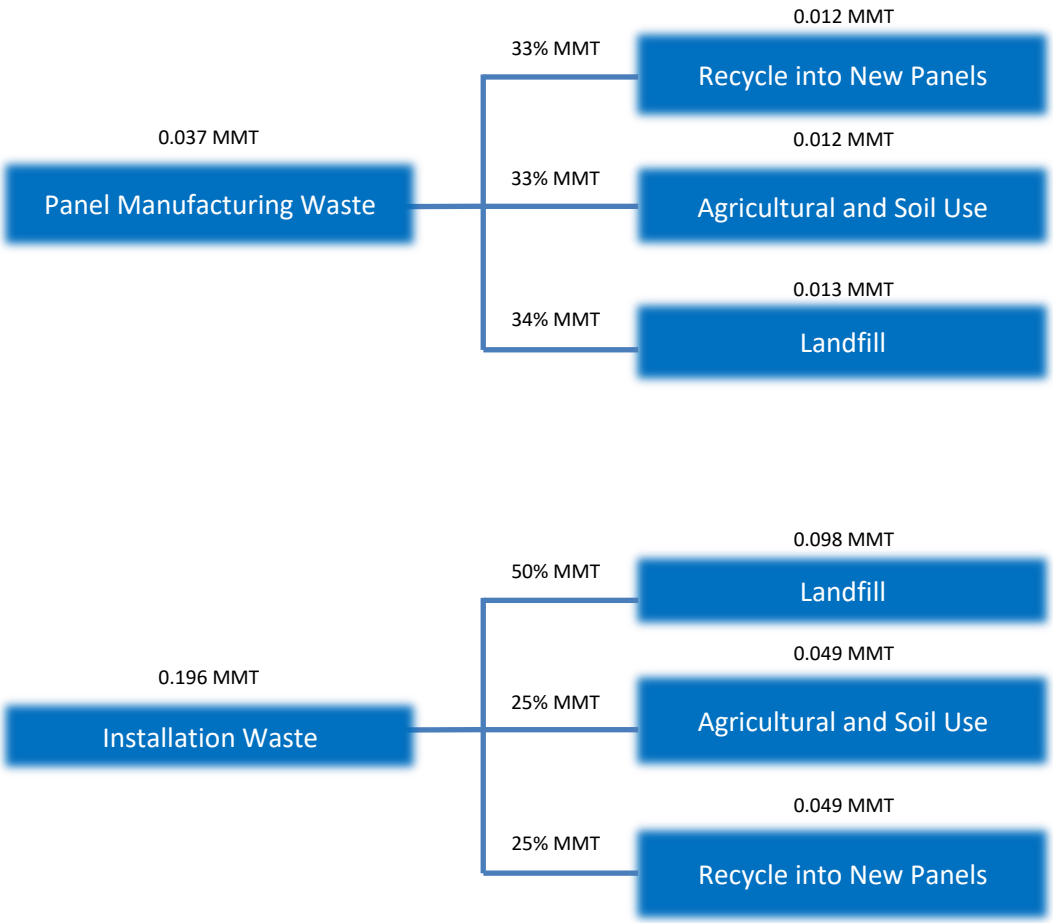
We did not identify any specific factors for loss in the distribution of GW but suspect that it is <1% and have not incorporated this loss in waste calculations.[12]

Disposition of GW waste[13]

Clean GW scrap from panel manufacturing and CGWCS from new construction ends up either being recovered and recycled back into new panel production, used in agricultural, soil, and other applications, or disposed of in landfills. Existing GW waste generated from demolition and renovation activities is likely to be contaminated with nails or screws, joint compound, and paint or other finishes and, in most cases, it is landfilled. Some recyclers, however, will take this waste as long as it does not have any hazardous substances (e.g., asbestos, lead paint) and process it to recover the gypsum primarily for agricultural and related uses.

We could not ascertain reliable rates of internal panel manufacturing scrap generation but speculate that it is approximately 10-12% of production of which roughly a third gets recycled back into new GW production, a third goes to agricultural use, and the remaining third is landfilled.

Figure 4. Panel Manufacturing and Installation Waste Flows



We could not identify percentages for the disposition of existing GW waste (demolition/renovation), but would make an assumption[14] that at least 90% is landfilled and the rest would go to agricultural and new panel uses. This suggests that of the estimated 0.74 MMT of existing GW waste, roughly 0.67 MMT is landfilled and 0.074 MMT are recycled via agricultural and related uses and panel manufacturing.

Circularity Potential and Challenges

Growing awareness of environmental impacts associated with the life cycle of materials and products along with increasing concerns about resource availability have prompted more attention to practices

that maximize the use value of extracted resources. Much of the attention is focused on creating circular systems for materials and products, where products are designed to incorporate recovered materials, to be efficient in the use of materials, to get the maximum use life out of the product, to recover and reuse the product and/or materials in making new product, and to avoid sending useful material/products to landfills. Overall, a focus on circularity is a focus on driving waste out of product systems while gaining benefits from a reduction in virgin material extraction and use, with concurrent reductions in environmental impact, in energy and water use across the material and product life cycle, and emissions to air, water, and land.

In our economy, there have always been circular systems for certain products and materials. Scrap metals (e.g., steel, aluminum, copper, brass, and precious metals) generally have had sufficient economic value to drive private sector recovery and recycling systems. Textiles were routinely recovered (rag pickers) and recycled until the advent and growth of synthetics fibers. Used vehicles, furniture and other products that have a sufficiently high secondary economic value continue to have a role in commerce.

In contrast, materials such as thermoset plastics (epoxy, polycarbonate) and composites of mixed materials (fiberglass and resin matrix), along with uses that result in degradation and dispersive distribution of materials (tire wear, combustion of fuels) eliminate the potential for being fully within a circular system. Proper disposal is the option for these materials if they lack sufficient economic value to create a private system of reuse or collection, recovery and recycling.

The building industry has historically relied on linkages to the raw material resources industry for its origin materials (minerals, forests, fossil fuels) and the waste industry for managing product end-of-useful life.[15] This mostly linear system (extract, make, use, dispose) is bumping up against resource and environmental constraints such climate change, habitat loss, and ecosystem damage. In the public sector, which has much of the responsibility for waste management, there has been a recognition that diversion of materials from disposal should be given primacy, due to growing costs, as well as political, environmental, and economic limits on siting new landfills. This is the context in which the government and industry are increasingly driving a change towards more circular systems including the building sector.

The key aspects of GW that make it a relatively good fit for circular building systems include its long use life (≈75 years for residential; 30-50 years for commercial[16]) and the gypsum and the paper facing can be recovered from waste GW, processed and recycled into making new GW as well as other building products or used in other nonbuilding applications. However, there are other aspects of GW that complicate the development of circular systems—the product is typically not used in its entirety at the point of installation, installation and product finishes introduce contaminants, waste GW product generally cannot be reused as is, and the waste is relatively heavy and bulky.

This study looks for ways to expand on the elements of a circular system that currently exist—the manufacturers that recover some internal waste and reintroduce it into the production process and the construction sites where some clean GW scrap (and some sites where demolition GW waste is not likely to have hazardous contaminants) is collected for processing and recycling—to create a more robust circular system for GW that reduces the GW waste that goes to landfill with the ultimate goal of eliminating disposal.

Recovery, processing, and recycling flows for clean GW scrap

A typical scenario for recovery and recycling of construction-site GW scrap involves:

- the GW installers maintaining a separate bin for the waste and placing scrap in the appropriate bin,
- a hauler taking the filled bin to a processing facility, and
- the processor typically crushing the scrap into small-sized pieces and mechanically (grinding, shredding, milling, sieving) processing it to separate the gypsum and paper, remove nails and screws, and produce consistent products for targeted markets—GW manufacture, agricultural applications, and various other markets.

Potential uses for recovered manufacturing and installation GW scrap

A key issue for uses of recovered GW is that it be free of contamination, such as nails and other metals, wood, paints, etc. There is minor potential for reuse of cut-offs including repairs, filling voids in wall cavities, and as support for gunite applications. Most recovered GW will need processing to separate the paper facing (and fiberglass in certain products) from the gypsum.

Potential scrap applications include:

- Reuse in manufacturing new GW
- Agricultural amendments
- Mushroom cultivation
- Nurseries
- Urban parks and recreation areas
- Residential lawns (sod)
- Golf courses
- Compost (additive)
- Portland cement manufacture
- Grease absorption
- Sludge drying
- Water treatment
- Soil remediation
- Athletic field marking
- Animal bedding (recovered paper)

Most of these applications would be considered as a dissipative secondary use that extends the useful life of the materials, but is not recoverable for future reuse/recycling. As such, the environmental benefits of each alternative would need to be evaluated to determine if the added material use life is environmentally preferable to using virgin material.

Environmental factors[17]

A key assumption underlying circular systems is that displacement of virgin origin material and subsequent processing into raw materials for a product will be environmentally preferable. Life cycle assessment is typically used to compare the environmental impacts of products that use virgin materials or recovered and recycled inputs. Material flow analysis is the primary tool to compare the scale at

which a product is used and therefore the impacts that scale might have on resources or environmental burdens.

While standard LCA metrics (e.g., resource depletion, water consumption, GHG emissions, etc.) are useful in comparing two product systems, there are some specific environmental aspects of the current GW system (mostly linear, elements of circular) and potential alternatives (mostly circular with limited linear elements) that should be evaluated:

- Impacts on climate change (GHG emissions) of increased recovery and reuse of manufacturing and installation scrap and displacement of virgin materials.[18]
- Degradation products associated with landfilling GW waste and use of processed GW on land applications.[19]
- Changes in resource depletion and habitat with increased recovery and reuse of scrap materials downstream (land application and substitution in product uses) and upstream (displacement of virgin materials).
- Energy requirements for scrap recovery and processing, transport, and reuse and displacement of collection and landfilling energy.[20]

Depending on the life extension application, other environmental aspects may need careful evaluation.

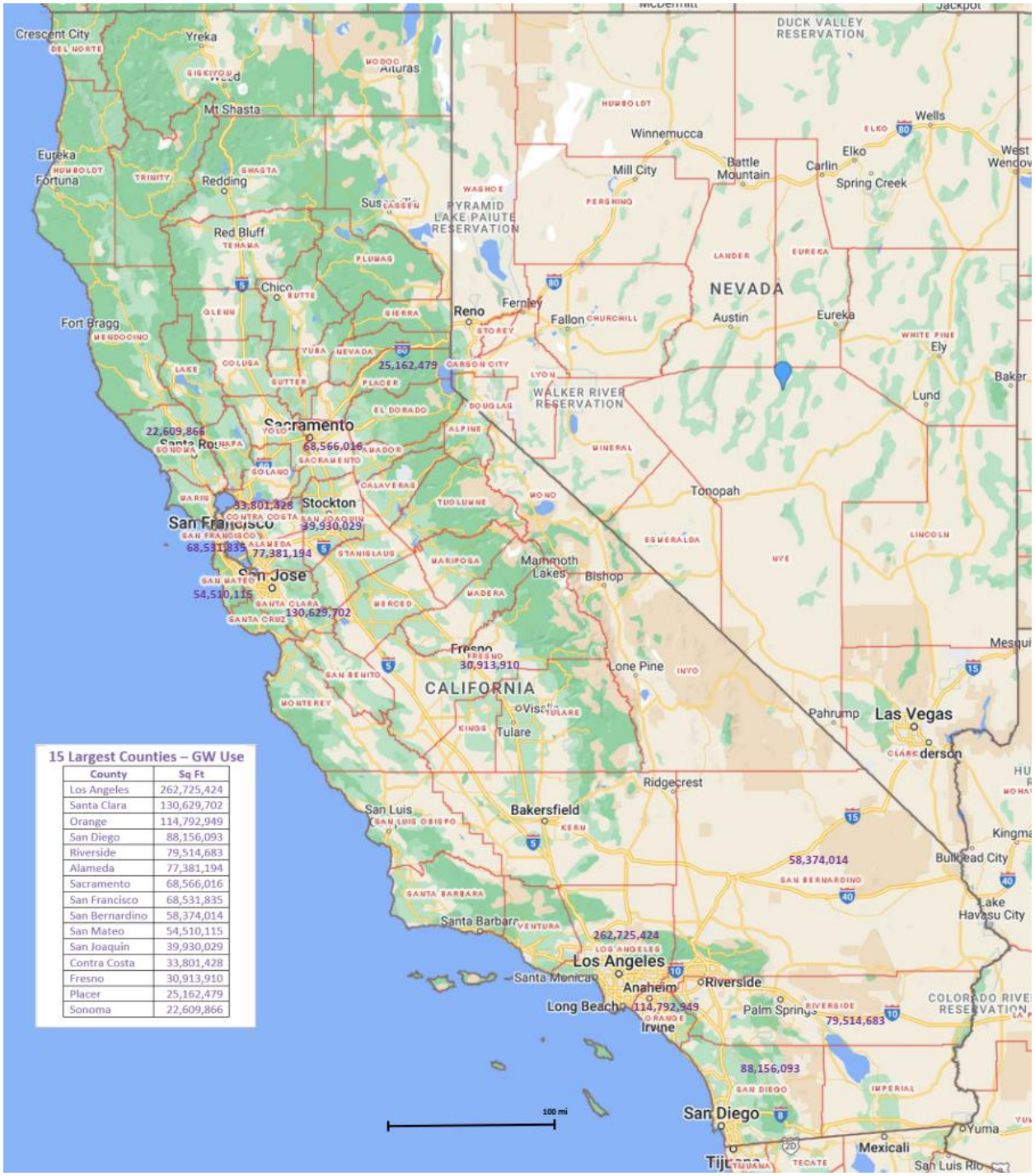
Economic factors

The relatively low cost of virgin gypsum and to some extent the paper facing make it necessary to understand the cost factors involved in recovering and processing GW waste whether from manufacturing or from installation. Key factors include the following:

- Manufacturing waste—costs include setting up a system for collecting and storing seconds/rejects, installing processing equipment (separation of paper facing, grinding gypsum), processing rejects, testing resulting secondary gypsum, and metering secondary gypsum into the production line.
- Disposal to landfill—cost of transport and tipping fees.
- Installation waste--on-site segregation of GW waste from other wastes. For construction sites, this involves setting up a separate bin for the cut-offs and making sure that non-GW wastes are kept out of the bin. Where GW is installed and replaced for whatever reason, nails and screws need to be removed. Labor costs increase due to additional time for segregation and possible cleaning activity. Potential costs of CGWCS transport to a processor/recycler. Research suggests that the maximum economically feasible transport distance varies between 50 and 200 mi, with the cost of fuel being a significant variable. [21]
- GW waste processors—equipment costs (similar to manufacturers), storage costs (covered, etc.), potential transport costs to obtain GW waste and to transport to customers. Mobile units that process the GW scrap on a construction site[22] may offer benefits through reduce transportation cost.
- Recovered gypsum and/or paper facing customers—processed product cost and transport costs to get recycled products delivered.
- Other aspects that affect the economics: where construction and demolition (C&D) waste is banned from municipal landfills, transport distance to C&D landfills may increase the transport cost; LEED projects may offer economic benefits for use of GW products in closer proximity, thereby reducing transport costs and by segregating and recovering/recycling GW wastes.

In regards to transport costs for CGWCS and potential recycled gypsum, Figure 5 shows the 15 counties with the largest estimated wallboard use and consequently where the CGWCS is likely to be generated.

Figure 5. 15 largest GW Use Counties[23]



County	Sq Ft
Los Angeles	262,725,424
Santa Clara	130,629,702
Orange	114,792,949
San Diego	88,156,093
Riverside	79,514,683
Alameda	77,381,194
Sacramento	68,566,016
San Francisco	68,531,835
San Bernardino	58,374,014
San Mateo	54,510,115
San Joaquin	39,930,029
Contra Costa	33,801,428
Fresno	30,913,910
Placer	25,162,479
Sonoma	22,609,866

Quality factors

As mentioned above, contamination is a concern. Certain types of contamination (e.g., metals) may affect reuse in some applications, particularly use in new GW manufacture as metal contamination may damage the production equipment. In general, limiting impurities to ≤ 2% and wet gypsum to ≤ 10% are tolerable. We conducted interviews with all the manufacturers that have California production facilities and heard a range of concerns regarding acceptance of CGWCS. Some manufacturers expressed concerns about using CGWCS from competitor products due to additives that differ from their product. Others were successfully using CGWCS from other manufacturers in their manufacturing operations.

For other uses of recovered GW waste, avoidance of contamination is needed along with processing to obtain physical characteristics (e.g., particle size) that are appropriate to the end use; in general, smaller particle size is preferred for agricultural, nursery, and other soil related uses.

In the early 2010s, Eurogypsum, the trade association for the European gypsum industry, led a multiyear project funded by the EU to increase recovery and recycling of production, construction, and demolition GW waste for reincorporation into the panel production process and with a goal of achieving 30% recycled content in European panel production. Criteria for acceptance of recovered and processed gypsum waste is in Table 7.[24]

Table 7. Gypsum to Gypsum Project: General Acceptance Criteria for GW waste[25]

Acceptance criteria—General	Acceptance
Free moisture content	Y
Impurities (insulation material, wood, metal, plastic, foils, concrete, sand, wallpaper, glass tissue and other wall coverings)	2%–3%

U.S. standards for acceptability of GW wastes and recycled gypsum product are limited. ASTM C1881-20, Standard Guide for Closed-Loop Recycling of Scrap Gypsum Panel Products[26] is useful guidance for construction site collection of GW scrap and processing into recycled gypsum for new panel manufacturing. In 2018, CDRA issued an executive summary document "Standard Specification for the Production of Recycled Gypsum from Scrap Gypsum Drywall." However, the full document is not available. We have not been able to identify any other U.S. based standards (see section on Circularity Outside the U.S.).

Reduction of installation waste

The construction industry and the role of GW has existed with relatively little change for many decades. A truism is that a loss rate for the GW product of 12% is acceptable and built into the cost structure of the industry. Stated differently, the customer is paying a 12% premium for which they are not getting any value; the premium is paying for product waste. When a drywall contractor scores standard size GW on-site to fit walls with windows and doors and ceilings with skylights and other openings, the building owner typically has no choice but to accept the contractor's approach of optimizing labor time rather than GW yield increasing the cost of the resulting waste.

The problem is similar in other industries. In apparel, for example, a long-standing practice was to lay out a textile in multiple layers on a cutting table, manually fit pattern pieces onto the top layer, and then cut.

With the advent of modern software and laser cutters, multiple sizes of the pattern could be placed on a "marker" to maximize fabric yield before precision cutting. Feedback to designers and pattern makers could also contribute to increased yields. Similar opportunities may exist for the GW and construction industry.

There are three potential pathways to reducing installation waste: design, cutting, and project management:

- **Design**
  The use of building information modeling (BIM) software allows designers, contractors and everyone involved in building projects and operations to improve planning, design, and coordination of activities. It is particularly useful for increasing the accuracy of material estimation for wallboard panels. Contractors can also use BIM software to plan full panel cuts and the use of resulting cut-off pieces for further cuts. Much like what occurs in the apparel industry, software could also be used to mix panel sizes to optimize for waste minimization when using standardized size materials. While the primary responsibility for GW panel utilization is at the contractor level, the potential for the design team to expand their use of BIM software to get feedback on panel utilization during the design process may result in even greater reductions in GW scrap.
- **Cutting**
  CNC (computer numerical control) cutting systems have been widely used in creating custom shapes and complicated panel parts for GW installations. Use in large scale projects (e.g., high-rise residential and offices, tract housing development) is less common. The potential for the integration of BIM software with off-site (or mobile on-site) CNC cutting offers the promise of maximum yield from purchased panels and limiting the quantity of unused panel square footage. To achieve the potential, a variety of issues need to be addressed including standards for labeling and identifying pieces, transport and storage of cut pieces, and installer training.
- **Project management**
  In addition to the typical expectations for GW installation performance (meeting specifications, quality standards, deadlines, etc.), project managers should include performance goals for scrap generation (e.g., < 6%), clean scrap separation and collection, and certification of processing for recycled use and track performance with appropriate metrics. Including language holding GW contractors accountable for accurate tracking and performance in meeting the project goals in contract agreements emphasizes the seriousness of reducing GW scrap during installation and managing waste in a manner that facilitates recovery and recycling.

Approaching design, cutting, and project management as an integrated process is critical for achieving significant reductions in scrap and thereby providing increased value to the customer.

Increasing recovery

A significant incentive to recovery of CGWCS on job-sites is the intention of the owner to obtain a higher level of LEED certification for the building or possibly to meet LEED requirements without going through the certification process. To support that goal, the general contractor would typically require the subcontractor to have and use a separate bin for cut-offs, maintain strict segregation of waste materials to avoid contamination, and track GW waste at least to the bin level and pickup for transport to a processor/recycler. Whether or not that happens depends on the contract language between the general contractor (or owner) and GW contractor and the commitment to meet the letter and spirit of the

language. In this situation it may be helpful to have a widely agreed upon standard that focuses on tracking from the job site to a processor, processing into usable products, and through to the recycled use of the resulting products to complement the ASTM C1881-20 standard for collection. Such a standard could be modeled on chain of custody rules for certified organic ingredients and products that track from farm to retail shelf.

While LEED does provide an incentive, other approaches are needed to incentivize high levels of recovery by subcontractors, while at the same time reducing GW cut-off wastes. This may involve an approach that combines eliminating landfilling of CGWCS by implementing a fee on GW panels (sold in California) that is subsequently used to support collecting and recycling of CGWCS:

- Legislative and regulatory initiatives to prohibit landfilling all CGWCS from construction sites and manufacturers.
- GW recycling fee to help create a collection infrastructure and tracking methods from cradle (panel manufacture) to recycle use (closed loop panel manufacture, agricultural use, etc.)

Increasing recycled content in new wallboard (closed loop)

Athena surveys, interviews with manufacturers and the literature on GW recycling all support the efficacy of increased gypsum recycled content in new GW. While the Athena survey found an average of 4% recycled content among manufacturers products, primarily using internal "rejects" board, interviews suggest that doubling recycled content is achievable by both internal recovery and installation CGWCS. Percentages of recycled clean GW scrap in the manufacture of new GW is constrained when the scrap is processed solely with physical treatments due to moisture absorption changing the material viscosity.[27] As noted above, some manufacturers are concerned about potential additives used by other GW manufacturers and would prefer to use CGWCS from job-sites using their products. Others are open to using CGWCS from any manufacturer. Some of the ways closed loop recycling may be facilitated include:

- Agreement on standards for segregation and collection of CGWCS at job sites, quality testing of collected CGWCS, functional attributes for recovered gypsum, and transport and processing of CGWCS to specified qualities. Meeting agreed upon standards may address concerns about the integrity of the waste delivered to manufacturing sites.
- Agreement on a restricted substance list and/or disclosure of listed substances present in recovered GW products.
- Building regional recycling infrastructure that ensures environmental benefits through reduced transportation.
- Facilitating R&D in manufacturing to address issues associated with increasing levels of recycled content in GW products. It is fairly common in other industries to begin incorporating recycled content at relatively low levels and increase recycled content levels as more entities across the value chain gain experience in all aspects of the recovery and recycling system.

Increasing diversion to non-landfill dissipative end use (no further recovery)

Much of the infrastructure that is required to increase the use of recovered CGWCS in new GW manufacturing would apply to recovery and reuse of CGWCS derived gypsum and paper facing in applications that are outside of the building industry. Careful evaluation of environmental impacts is needed to avoid cases where impacts of recovered gypsum and/or paper may be greater than the virgin

alternatives for specific applications. Again, significant transport distances and more intensive processing of recovered CGWCS may negate benefits of a partial circular system.

- Quantitative and qualitative analyses of end uses (ag, cement, etc.)

Circularity Outside the U.S

We reviewed GW circularity programs and legislative/regulatory initiatives in the EU and selected Asian countries. While we identified some noteworthy activities, we did not uncover any groundbreaking actions that have institutionalized a transformation to a circular GW ecosystem.

European activities

GW recovery and recycling is covered by the EU's Waste Framework Directive (WFD, Directive 2008/98/EC) directing EU Member States to apply the waste hierarchy that makes reuse a priority over landfilling and specifically calls for increasing diversion of non-hazardous C&D waste to 70% by 2020 (weight-based) (see Article 11 section 3). This would include GW products if Member States include them in their waste lists (EU WFD, 2008, 2018). Across Europe the application of the WFD has been mixed. Greater efforts have occurred in the UK (prior to Brexit), France, and Belgium, while Germany lags. Eurogypsum with EU Commission funding sponsored several pilot efforts to increase recovery, recycling and reuse of GW demolition waste in the manufacture of new GW to meet a 30% recycled content target.[28] Key takeaways from the pilots:

- 30% recycled content is possible using both production and C&D waste.
- Construction recycling may be improved by taking into account the interests of all parties.
- Deconstruction instead of demolition at building end of life improves the quality of GW waste streams; need for design that facilitates deconstruction.
- Legal framework needed to discourage landfilling of recyclable waste and improve economic competitiveness of recycling.
- Classifying recycled GW as a resource is necessary to increase confidence in recycling.

Beyond the pilot results, a critical barrier to recycling is lagging implementation of EU waste legislation in member states, which limits the development of a widespread recycling infrastructure. Some of the key aspects of EU legislation that requires greater implementation include:

- Requirements to keep records of type and quantity of waste being disposed (Council Directive 1999/31/EC), which is critical to identify flows of GW that are landfilled.
- Requirements for separation of gypsum and biodegradable waste (e.g., paper facing) to minimize generation of hydrogen sulfide (Council Directive 2003/33/EC).
- Guidelines for member state creation of extended producer responsibility (EPR) systems for specific products (WFD, Articles 8 and 8a).

Recent developments include:

- 3% of total gypsum (26 MMT) used in the EU in 2022 was from recycling C&D waste; the key driver was the comparative cost of recycling CDW versus landfilling, mining/FGD and reuse of internal waste.[29]
- Ragn-Sells, a Swedish company that operates in four countries, collects and recycles CGWCS all over Sweden for recycling into in new GW panels in partnership with Gyro Gypsum recycling and S-G's Gyproc[30]; France is ramping up GW recycling via S-G subsidiary Placo's recycling facility with a current capacity of 30KMT which it plans to increase to 200 KMT by 2030; the UK has a robust recycling industry due to a lack of access to FGD with multiple recycling plants and one manufacturer (Etex subsidiary Siniat) introducing a GW product with 20% recycled content; minimal recycling in Spain, Portugal, Italy, Greece, and Eastern Europe.[31]

Canadian Activities

The recycling infrastructure for drywall is increasing across Canada:

- The City of Vancouver does not accept GW waste from new construction for landfilling; it does accept cut-offs from new construction for recycling at its transfer station and landfill (residents and commercial); GW waste from demolition/renovation of existing buildings is accepted from residents only (no commercial).[32]
- New West Gypsum Recycling currently has plants in British Columbia, Ontario, and Alberta (as well as in Belgium, France, Germany, and Norway and as previously mentioned in the UK);[33] Recycle Gypse operates in Quebec.[34]
- CertainTeed Canada recycled 1 MMT of gypsum at its Vancouver GW plant partnering with New West Gypsum Recycling.
- Access to cheap landfilling in the U.S. limits GW recovery and recycling in Canada.[35]

Asian and Australian Activities

We identified relevant legislation/regulations and related activities in China, Japan, Korea, Taiwan, and Australia:

- Article 33 of the Circular Economy Promotion Law of the People's Republic of China requires contractors to maximize utilization of construction wastes and/or find others who will use them; disposal is a last resort. Article 37 of the same law encourages the local development of waste recovery and recycling infrastructure.[36]
- A review of C&D waste management in China by B. Huang, et al.,[37] identified a number of issues:
    - Barriers to reducing C&D waste quantities include lack of design standards for reducing C&D waste, the low cost of C&D waste disposal, and poor urban planning.
    - Barriers to recovery and recycling of C&D waste include lack of information about effective collection and sorting, standards for recovered wastes, and robust markets for collected wastes, further complicated by lack of access to mature recycling technologies and management capacity.
- Achievement of significant improvement in recovery, reuse, and recycling of C&D waste including GW will require a broad mix of policy initiatives including adoption of mandatory source separation of C&D waste, landfill bans, subsidies, technical guidance, and standards for recovered materials.[38]

- The Taiwan Environmental Protection Administration (TEPA) promoted the use of products made from recyclable and reusable waste materials in government agency construction projects, slowly increasing the usage of these products.[39]
- Taiwan has a relatively sophisticated management system for CDW integrating information about materials use construction sites, transport, recycling facilities, treatment facilities, landfills, and reuse/recycling facilities to generate high rates of diversion from landfills.[40]
- Australia has a comprehensive set of legislative acts covering CDW at both the federal and state levels, which while not uniform, typically include landfill fees and targets for recovery and/or recycling. The fees usually go to improving recovery of wastes for reuse and recycling and research funding.[41]
- The private sector is generally the key resource for collection, reuse, and recycling of GW (commonly called plasterboard in Australia). Regyp offers collection and recycling nationally and handled approximately 200Kt of recycled gypsum product in 2022, primarily to agricultural markets.[42]
- Several GW manufactures in Japan incorporate recovered and recycled CDW including Yoshino Gypsum Co. and Chiyoda Ute Co (a subsidiary of Knauf).
    - Yoshino uses standard physical processes to separate gypsum and paper, while removing contaminates and averages 7% recycled content.[43]
    - Chiyoda Ute has developed a 100% recycled GW product using technology developed by Tokuyama Chiyoda Gypsum (TGC, a joint venture of Tokuyama Co. and CU) that treats gypsum that has initially been physically processed with a proprietary recrystallisation process to manufacture new GW from 100% recycled gypsum from construction waste. The product will be commercially available in 2023.[44]

Key Findings

- The gypsum “ecosystem” is complicated and relatively few of the entities interact with more than two or three other entities in the system.
- The current major incentive to recover and reuse clean scrap is voluntary pursuit of LEED certification; specifically, the potential to obtain points towards certification for recycling construction waste.
- Coordination among all the stakeholder entities with a potential interest in recovery and secondary use of clean scrap does not exist.
- There is a lack of infrastructure to support recovery and secondary use.
- Existing regulatory drivers and current market conditions are insufficient for driving the development of a robust recovery and recycling infrastructure for GW.
- While more stringent regulations regarding landfilling of gypsum waste may not be imminent, there is potential for increasing pressure on the industry to adopt practices that lead to greater diversion from landfills.

Recommendations

- Manufacturers have the opportunity to take the lead on increasing the potential for greater diversion through recovery and reuse of their products.
- Goal: achieve a circular ecosystem for gypsum products.
- Convene a working group of key entities in the gypsum ecosystem to develop guidelines for development of a circular infrastructure for gypsum products.
    - In addition to manufacturers, suggested members at a minimum include the larger GW contractors and general contractors, collectors/recyclers, processors and the potential participation of distributors, GW suppliers and major retailers, private waste management companies, and transporters.
    - Potential objectives for working group:
        - In-depth survey of 8-10 GW installation contractors regarding ratio of GW purchased/installed and scrap rates, disposition of scrap, how to reduce scrap by half and eliminate sending waste to landfill, and what works for different building types.
        - Development of guidelines for development of gypsum products that fit into circular GW ecosystems.
        - Development of best practice guidelines for on-site management of cut-offs to facilitate collection and processing for reuse.
        - Review and updating of ASTM C1881, *Standard Guide for Closed-Loop Recycling of Scrap Gypsum Panel Products,* CDRA *Standard Specification for the Production of Recycled Gypsum from Scrap Gypsum Drywall*, and other existing standards for the quality/performance of processed gypsum and facing materials (paper and fiberglass) to facilitate use in producing recycled content products.
        - Development of guidelines for storage and transport of processed materials to maintain quality and performance attributes.
        - A thorough search for current best practices in collecting and recycling CGWCS and demolition and renovation GW waste globally with an analysis of what constitutes the key factors in establishing successful programs.
        - Creation of training materials for contractors, installers, collectors, and processors to manage gypsum products and wastes consistent with circular ecosystems.
        - Identify where additional facilities for processing and storage may be needed to support collection and reuse.
        - Identify additional infrastructure for facilitating agricultural uses of recovered gypsum.
        - Discuss the potential for a “deposit” or “processing fee” system to help create needed infrastructure and increase collection and reuse.
        - Investigate methods for demolition/renovation of existing installed GW that has the potential to meet quality standards for collection and reuse including identification of

potential hazardous contaminants (e.g., lead and asbestos), methods of addressing surface coverings (nonhazardous paint, wallpaper, etc.), and processing for secondary reuse.

- ♦ Conduct life cycle assessments of secondary uses to help identify and address potential environmental risks.

- ○ Sponsor research on "zero waste" approaches for GW products in buildings.
  - ♦ Novel methods for panel manufacturing and panel installation for current on-site construction methods.
  - ♦ Novel methods to manufacture and integrate GW panels into factory-built construction.
  - ♦ Novel methods to use CGWCS without separation of paper faces.
  - ♦ Recovery and processing methods for fiberglass wallboard products.
  - ♦ Methods for processing recovered existing installed GW from demolition and renovation.
- ○ Sponsor research on innovative uses for recovered gypsum products that have positive environmental benefits.

ANNEX 1 CIRB 2019 Residential Units and Valuation, BWE Wallboard Estimation

	Single Family		Multi-Family (2 Units)		Multi-Family (3-4 Units)		Multi-Family (5+ Units)			
County Totals	Units	Valuation	Units	Valuation	Units	Valuation	Units	Valuation	Residential Alterations Valuation	Sq Ft Wallboard Totals
Alameda	1,871	$675,129,834	59	$14,959,746	143	$29,373,964	3,943	$738,202,676	$512,409,929	
Alameda Sq Ft Wallboard		18,690,152		414,142		727,954		16,558,849	15,063,496	**51,454,594**
Alpine	4	$924,190	0	$0	0	$0	0	$0	$587,257	
Alpine Sq Ft Wallboard		25,585		0		0		0	17,264	**42,849**
Amador	130	$36,702,766	0	$0	0	$0	0	$0	$5,796,429	
Amador Sq Ft Wallboard		1,016,072		0		0		0	170,400	**1,186,471**
Butte	804	$186,053,472	10	$1,332,492	64	$6,307,007	489	$59,898,089	$11,986,613	
Butte Sq Ft Wallboard		5,150,665		36,888		156,302		1,343,592	352,375	**7,039,823**
Calaveras	104	$26,676,623	0	$0	0	$0	0	$0	$20,560,407	
Calaveras Sq Ft Wallboard		738,510		0		0		0	604,422	**1,342,932**
Colusa	38	$5,993,720	10	$880,000	4	$400,000	6	$276,000	$3,249,750	
Colusa Sq Ft Wallboard		165,929		24,362		9,913		6,191	95,534	**301,929**
Contra Costa	1,573	$502,567,660	10	$2,693,711	0	$0	1,219	$211,004,169	$300,066,431	
Contra Costa Sq Ft Wallboard		13,912,977		74,572		0		4,733,099	8,821,159	**27,541,807**
Del Norte	28	$6,259,500	0	$0	0	$0	0	$0	$1,693,220	
Del Norte Sq Ft Wallboard		173,287		0		0		0	49,776	**223,063**
El Dorado	595	$404,049,358	2	$750,000	0	$0	16	$13,500,000	$39,291,331	
El Dorado Sq Ft Wallboard		11,185,617		20,763		0		302,823	1,155,061	**12,664,264**
Fresno	2,732	$770,423,817	4	$585,869	149	$10,294,103	536	$76,938,166	$41,033,636	

County Totals	Single Family		Multi-Family (2 Units)		Multi-Family (3-4 Units)		Multi-Family (5+ Units)		Residential Alterations Valuation	Sq Ft Wallboard Totals
	Units	Valuation	Units	Valuation	Units	Valuation	Units	Valuation		
Fresno Sq Ft Wallboard		21,328,251		16,219		255,111		1,725,823	1,206,280	**24,531,685**
Glenn	45	$7,860,909	2	$124,000	0	$0	0	$0	$1,634,568	
Glenn Sq Ft Wallboard		217,620		3,433		0		0	48,052	**269,105**
Humboldt	170	$35,200,891	6	$911,403	28	$3,274,951	277	$36,566,212	$12,327,756	
Humboldt Sq Ft Wallboard		974,494		25,231		81,161		820,228	362,403	**2,263,517**
Imperial	267	$49,234,937	4	$356,000	26	$1,915,400	364	$34,522,483	$4,984,289	
Imperial Sq Ft Wallboard		1,363,010		9,855		47,468		774,384	146,525	**2,341,242**
Inyo	19	$3,363,784	0	$0	0	$0	80	$24,952,721	$2,685,831	
Inyo Sq Ft Wallboard		93,122		0		0		559,722	78,956	**731,801**
Kern	2,260	$521,228,126	106	$8,225,739	49	$3,632,240	504	$24,478,263	$29,902,080	
Kern Sq Ft Wallboard		14,429,570		227,720		90,015		549,079	879,042	**16,175,426**
Kings	445	$108,621,913	0	$0	0	$0	25	$1,858,971	$8,857,706	
Kings Sq Ft Wallboard		3,007,066		0		0		41,699	260,393	**3,309,158**
Lake	71	$15,156,702	0	$0	0	$0	0	$0	$7,134,094	
Lake Sq Ft Wallboard		419,595		0		0		0	209,723	**629,318**
Lassen	11	$2,413,798	0	$0	3	$167,000	0	$0	$1,998,684	
Lassen Sq Ft Wallboard		66,823		0		4,139		0	58,756	**129,718**
Los Angeles	5,738	$1,967,219,268	1,525	$294,205,681	402	$97,764,657	13,957	$2,569,287,072	$1,625,839,308	
Los Angeles Sq Ft Wallboard		54,460,084		8,144,728		2,422,833		57,632,460	47,795,374	**170,455,479**

County Totals	Single Family		Multi-Family (2 Units)		Multi-Family (3-4 Units)		Multi-Family (5+ Units)		Residential Alterations Valuation	Sq Ft Wallboard Totals
	Units	Valuation	Units	Valuation	Units	Valuation	Units	Valuation		
Madera	670	$183,449,505	2	$259,220	0	$0	42	$3,754,544	$3,692,517	
Madera Sq Ft Wallboard		5,078,577		7,176		0		84,219	108,550	**5,278,523**
Marin	130	$115,771,908	0	$0	0	$0	86	$13,650,175	$202,353,818	
Marin Sq Ft Wallboard		3,205,005		0		0		306,191	5,948,667	**9,459,863**
Mariposa	35	$8,636,943	0	$0	0	$0	0	$0	$3,630,532	
Mariposa Sq Ft Wallboard		239,103		0		0		0	106,728	**345,831**
Mendocino	137	$22,296,224	8	$1,630,682	0	$0	0	$0	$9,095,012	
Mendocino Sq Ft Wallboard		617,244		45,143		0		0	267,369	**929,757**
Merced	1,072	$231,067,494	0	$0	0	$0	0	$0	$6,179,286	
Merced Sq Ft Wallboard		6,396,824		0		0		0	181,655	**6,578,479**
Modoc	8	$1,121,000	0	$0	0	$0	0	$0	$622,600	
Modoc Sq Ft Wallboard		31,034		0		0		0	18,303	**49,336**
Mono	17	$4,234,533	2	$593,569	21	$4,876,228	0	$0	$3,977,551	
Mono Sq Ft Wallboard		117,228		16,432		120,844		0	116,929	**371,434**
Monterey	574	$142,474,050	2	$600,000	14	$4,081,208	100	$18,988,774	$65,196,115	
Monterey Sq Ft Wallboard		3,944,222		16,610		101,142		425,943	1,916,593	**6,404,510**
Napa	232	$128,284,003	8	$1,861,992	0	$0	9	$1,911,541	$55,059,875	
Napa Sq Ft Wallboard		3,551,387		51,547		0		42,878	1,618,615	**5,264,427**
Nevada	386	$143,874,324	0	$0	0	$0	37	$2,850,000	$51,933,205	

County Totals	Single Family		Multi-Family (2 Units)		Multi-Family (3-4 Units)		Multi-Family (5+ Units)		Residential Alterations Valuation	Sq Ft Wallboard Totals
	Units	Valuation	Units	Valuation	Units	Valuation	Units	Valuation		
Nevada Sq Ft Wallboard		3,982,987		0		0		63,929	1,526,699	**5,573,615**
Orange	3,125	$1,094,668,191	190	$136,645,144	117	$21,050,266	6,862	$852,860,158	$537,089,805	
Orange Sq Ft Wallboard		30,304,564		3,782,855		521,674		19,130,766	15,789,019	**69,528,878**
Placer	2,080	$693,647,729	6	$1,040,914	0	$0	65	$6,855,761	$86,964,208	
Placer Sq Ft Wallboard		19,202,798		28,816		0		153,784	2,556,518	**21,941,916**
Plumas	47	$8,713,864	0	$0	0	$0	0	$0	$1,057,150	
Plumas Sq Ft Wallboard		241,233		0		0		0	31,077	**272,310**
Riverside	6,563	$1,834,821,883	55	$15,000,823	20	$1,919,995	1,723	$265,544,276	$158,117,962	
Riverside Sq Ft Wallboard		50,794,823		415,280		47,582		5,956,504	4,648,250	**61,862,439**
Sacramento	3,981	$1,108,399,879	184	$29,840,313	38	$6,411,083	1,786	$228,937,409	$293,210,533	
Sacramento Sq Ft Wallboard		30,684,709		826,093		158,881		5,135,365	8,619,614	**45,424,662**
San Benito	634	$219,517,080	4	$798,703	0	$0	0	$0	$3,158,952	
San Benito Sq Ft Wallboard		6,077,065		22,111		0		0	92,865	**6,192,041**
San Bernardino	4,096	$1,078,797,667	86	$11,389,592	32	$4,466,403	1,766	$216,223,310	$139,761,121	
San Bernardino Sq Ft Wallboard		29,865,208		315,307		110,688		4,850,171	4,108,607	**39,249,980**
San Diego	3,045	$1,022,156,945	116	$18,624,270	432	$91,617,360	3,857	$558,607,412	$393,649,144	
San Diego Sq Ft Wallboard		28,297,178		515,590		2,270,488		12,530,293	11,572,243	**55,185,793**
San Francisco	135	$31,284,168	34	$23,919,224	40	$13,355,271	3,134	$945,925,151	$715,519,125	
San Francisco Sq Ft Wallboard		866,064		662,175		330,974		21,218,335	21,034,369	**44,111,917**

County Totals	Single Family		Multi-Family (2 Units)		Multi-Family (3-4 Units)		Multi-Family (5+ Units)		Residential Alterations Valuation	Sq Ft Wallboard Totals
	Units	Valuation	Units	Valuation	Units	Valuation	Units	Valuation		
San Joaquin	2,564	$843,700,934	76	$10,426,957	0	$0	385	$46,844,186	$98,681,855	
San Joaquin Sq Ft Wallboard		23,356,839		288,658		0		1,050,776	2,900,985	**27,597,258**
San Luis Obispo	697	$346,246,747	16	$5,284,414	16	$4,503,740	172	$17,265,777	$36,741,360	
San Luis Obispo Sq Ft Wallboard		9,585,422		146,293		111,613		387,294	1,080,099	**11,310,720**
San Mateo	497	$486,257,369	18	$5,390,892	8	$2,222,717	1,023	$315,283,027	$365,784,661	
San Mateo Sq Ft Wallboard		13,461,447		149,240		55,084		7,072,209	10,753,101	**31,491,082**
Santa Barbara	439	$206,618,051	14	$3,381,028	62	$10,444,176	384	$67,870,923	$136,906,858	
Santa Barbara Sq Ft Wallboard		5,719,971		93,600		258,831		1,522,433	4,024,699	**11,619,534**
Santa Clara	1,814	$693,032,599	40	$18,333,463	40	$9,747,990	3,136	$539,645,264	$555,483,050	
Santa Clara Sq Ft Wallboard		19,185,769		507,540		241,578		12,104,947	16,329,732	**48,369,565**
Santa Cruz	215	$47,986,301	0	$0	0	$0	76	$27,676,723	$31,453,175	
Santa Cruz Sq Ft Wallboard		1,328,443		0		0		620,825	924,640	**2,873,908**
Shasta	517	$139,125,806	0	$0	0	$0	116	$12,620,623	$16,569,811	
Shasta Sq Ft Wallboard		3,851,530		0		0		283,097	487,109	**4,621,735**
Sierra	8	$2,663,673	0	$0	0	$0	0	$0	$339,662	
Sierra Sq Ft Wallboard		73,741		0		0		0	9,985	**83,726**
Siskiyou	35	$8,016,478	6	$719,973	0	$0	0	$0	$2,194,496	
Siskiyou Sq Ft Wallboard		221,926		19,932		0		0	64,512	**306,370**
Solano	1,147	$295,149,792	0	$0	6	$2,710,196	50	$33,179,060	$69,033,403	

	Single Family		Multi-Family (2 Units)		Multi-Family (3-4 Units)		Multi-Family (5+ Units)			
County Totals	Units	Valuation	Units	Valuation	Units	Valuation	Units	Valuation	Residential Alterations Valuation	Sq Ft Wallboard Totals
Solano Sq Ft Wallboard		8,170,865		0		67,165		744,250	2,029,399	**11,011,679**
Sonoma	1,722	$527,761,241	26	$5,543,206	20	$3,254,705	1,010	$108,535,851	$93,044,998	
Sonoma Sq Ft Wallboard		14,610,431		153,457		80,659		2,434,601	2,735,277	**20,014,425**
Stanislaus	561	$117,995,946	4	$765,150	0	$0	174	$18,363,438	$36,671,889	
Stanislaus Sq Ft Wallboard		3,266,575		21,182		0		411,916	1,078,057	**4,777,730**
Sutter	111	$34,731,137	0	$0	0	$0	24	$2,968,500	$11,452,863	
Sutter Sq Ft Wallboard		961,489		0		0		66,587	336,684	**1,364,761**
Tehama	141	$31,207,193	0	$0	0	$0	0	$0	$4,409,662	
Tehama Sq Ft Wallboard		863,933		0		0		0	129,632	**993,566**
Trinity	52	$5,322,759	0	$0	0	$0	0	$0	$952,456	
Trinity Sq Ft Wallboard		147,354		0		0		0	28,000	**175,354**
Tulare	1,612	$334,633,468	82	$12,881,042	58	$5,280,463	287	$35,868,213	$20,579,930	
Tulare Sq Ft Wallboard		9,263,923		356,596		130,862		804,571	604,995	**11,160,947**
Tuolumne	58	$16,776,920	6	$868,820	0	$0	0	$0	$5,078,226	
Tuolumne Sq Ft Wallboard		464,449		24,052		0		0	149,286	**637,787**
Ventura	731	$261,552,969	28	$8,366,292	46	$12,018,254	623	$73,433,562	$71,533,972	
Ventura Sq Ft Wallboard		7,240,777		231,611		297,840		1,647,211	2,102,910	**11,520,348**
Yolo	716	$215,616,789	6	$1,570,000	0	$0	286	$64,536,034	$28,875,989	
Yolo Sq Ft Wallboard		5,969,090		43,464		0		1,447,627	848,878	**8,309,058**
Yuba	543	$120,161,193	0	$0	0	$0	8	$817,848	$3,671,911	
Yuba Sq Ft Wallboard		3,326,517		0		0		18,345	107,944	**3,452,807**

County Totals	Single Family		Multi-Family (2 Units)		Multi-Family (3-4 Units)		Multi-Family (5+ Units)		Residential Alterations Valuation	Sq Ft Wallboard Totals
	Units	Valuation	Units	Valuation	Units	Valuation	Units	Valuation		
										918,352,250
State Total **Units | $1,000 Valuation**	**58,052**	**$18,132,856**	**2,757**	**$640,760**	**1,838**	**$351,089**	**48,637**	**$8,272,502**	**$6,951,768**	**$34,348,976**
State Total 1,000 sq ft wallboard	501,986		17,739		8,701		185,563		204,364	918,352

ANNEX 2 CIRB 2019 Non-Residential Valuation, BWE Wallboard Estimation

County Totals	Hotels & Motels	Non-Housekeeping Shelter	Amusement & Recreation	Churches	Industrial & Manufacturing	Service Stations	Hospitals	Offices	Schools Education	Stores, Mercantile Warehouses	Other Non-Residential Buildings	Non-Residential Alterations	Residential Garages	Totals
Alameda	$95,611,151	$650,000	$23,236,842	$760,308	$5,638,452	$0	$15,744,830	$120,771,927	$13,062,685	$317,403,524	$121,053,458	$992,668,102	$2,752,137	
Alameda Sq Ft Wallboard	1,840,741	11,956	398,265	7,143	79,268	0	243,178	2,534,297	265,273	3,788,234	927,779	15,796,755	33,711	25,926,600
Alpine	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$298,800	$0	
Alpine Sq Ft Wallboard	0	0	0	0	0	0	0	0	0	0	0	4,755	0	4,755
Amador	$0	$0	$0	$0	$0	$0	$0	$0	$0	$250,000	$1,641,914	$1,641,653	$1,767,873	
Amador Sq Ft Wallboard	0	0	0	0	0	0	0	0	0	2,984	12,584	26,124	21,654	63,347
Butte	$11,885,925	$0	$31,618	$589,662	$2,463,696	$1,770,171	$0	$5,006,768	$4,725,841	$1,861,862	$9,904,011	$25,371,099	$7,887,016	
Butte Sq Ft Wallboard	228,832	0	542	5,540	34,636	42,254	0	105,063	95,971	22,221	75,906	403,741	96,607	1,111,314
Calaveras	$0	$0	$509,220	$0	$0	$0	$0	$0	$0	$7,938,031	$2,310,535	$2,086,788	$1,989,654	
Calaveras Sq Ft Wallboard	0	0	8,728	0	0	0	0	0	0	94,741	17,708	33,208	24,371	178,756
Colusa	$0	$4,000	$0	$0	$4,523,130	$0	$0	$1,100,000	$0	$5,420,000	$6,932,094	$1,226,268	$267,640	
Colusa Sq Ft Wallboard	0	74	0	0	63,588	0	0	23,083	0	64,688	53,129	19,514	3,278	227,354
Contra Costa	$0	$1,056,000	$28,115,955	$250,000	$2,974,493	$0	$0	$25,132,587	$16,268,670	$52,597,452	$41,503,720	$240,542,993	$6,748,697	
Contra Costa Sq Ft Wallboard	0	19,424	481,890	2,349	41,817	0	0	527,386	330,379	627,754	318,093	3,827,864	82,664	6,259,620
Del Norte	$0	$0	$0	$0	$0	$0	$0	$0	$0	$73,612	$311,955	$776,309	$1,427,485	
Del Norte Sq Ft Wallboard	0	0	0	0	0	0	0	0	0	879	2,391	12,354	17,485	33,108
El Dorado	$0	$0	$0	$0	$0	$728,212	$0	$0	$0	$35,825,877	$6,067,931	$27,883,575	$6,318,497	

County Totals	Hotels & Motels	Non-Housekeeping Shelter	Amusement & Recreation	Churches	Industrial & Manufacturing	Service Stations	Hospitals	Offices	Schools Education	Stores, Mercantile Warehouses	Other Non-Residential Buildings	Non-Residential Alterations	Residential Garages	Totals
El Dorado Sq Ft Wallboard	0	0	0	0	0	17,383	0	0	0	427,584	46,506	443,723	77,395	1,012,591
Fresno	$16,217,853	$0	$0	$2,350,992	$7,105,120	$2,927,253	$11,374,215	$49,481,515	$2,205,000	$118,552,574	$67,108,807	$163,703,563	$6,940,224	
Fresno Sq Ft Wallboard	312,232	0	0	22,086	99,887	69,874	175,674	1,038,328	44,778	1,414,934	514,336	2,605,085	85,010	6,382,225
Glenn	$0	$0	$0	$0	$950,000	$1,700,000	$0	$0	$0	$950,000	$1,578,579	$707,112	$999,150	
Glenn Sq Ft Wallboard	0	0	0	0	13,356	40,579	0	0	0	11,338	12,099	11,253	12,238	100,863
Humboldt	$0	$0	$0	$0	$39,375	$0	$0	$2,180,215	$0	$8,518,309	$4,282,706	$12,381,341	$3,325,824	
Humboldt Sq Ft Wallboard	0	0	0	0	554	0	0	45,750	0	101,667	32,824	197,030	40,738	418,561
Imperial	$0	$0	$0	$0	$30,000	$0	$1,475,000	$327,344	$2,900,000	$20,384,775	$11,500,325	$18,683,113	$1,611,081	
Imperial Sq Ft Wallboard	0	0	0	0	422	0	22,781	6,869	58,892	243,294	88,141	297,312	19,734	737,445
Inyo	$0	$0	$0	$0	$0	$0	$0	$0	$0	$195,000	$949,453	$4,927,451	$277,738	
Inyo Sq Ft Wallboard	0	0	0	0	0	0	0	0	0	2,327	7,277	78,413	3,402	91,419
Kern	$10,047,760	$0	$869,059	$2,993,146	$596,863	$0	$0	$22,706,652	$670,260	$130,627,415	$24,184,070	$140,850,140	$5,033,017	
Kern Sq Ft Wallboard	193,443	0	14,895	28,119	8,391	0	0	476,480	13,611	1,559,048	185,352	2,241,409	61,649	4,782,397
Kings	$0	$0	$0	$196,859	$0	$0	$0	$0	$0	$10,593,542	$7,078,373	$16,810,455	$1,131,747	
Kings Sq Ft Wallboard	0	0	0	1,849	0	0	0	0	0	126,435	54,250	267,512	13,863	463,909
Lake	$370,840	$0	$0	$0	$0	$0	$0	$836,407	$0	$960,711	$1,085,485	$2,242,277	$675,306	
Lake Sq Ft Wallboard	7,140	0	0	0	0	0	0	17,551	0	11,466	8,319	35,682	8,272	88,430
Lassen	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$782,511	$1,697,610	$368,481	
Lassen Sq Ft Wallboard	0	0	0	0	0	0	0	0	0	0	5,997	27,015	4,513	37,526

County Totals	Hotels & Motels	Non-Housekeeping Shelter	Amusement & Recreation	Churches	Industrial & Manufacturing	Service Stations	Hospitals	Offices	Schools Education	Stores, Mercantile Warehouses	Other Non-Residential Buildings	Non-Residential Alterations	Residential Garages	Totals
Los Angeles	$203,212,049	$53,678,731	$32,212,079	$16,411,685	$63,727,761	$1,306,605	$31,313,790	$474,984,247	$98,296,926	$1,338,475,399	$340,620,387	$3,404,012,421	$43,678,724	
Los Angeles Sq Ft Wallboard	3,912,313	987,372	552,095	154,180	895,913	31,189	483,641	9,967,144	1,996,181	15,974,802	2,610,585	54,169,517	535,016	92,269,946
Madera	$0	$0	$0	$0	$4,310,000	$0	$1,175,000	$913,396	$2,075,849	$6,220,357	$15,177,899	$7,205,898	$1,883,921	
Madera Sq Ft Wallboard	0	0	0	0	60,592	0	18,148	19,167	42,156	74,240	116,327	114,671	23,076	468,376
Marin	$0	$0	$0	$0	$0	$0	$0	$1,520,500	$0	$49,415,600	$17,780,924	$150,484,023	$3,265,712	
Marin Sq Ft Wallboard	0	0	0	0	0	0	0	31,906	0	589,779	136,277	2,394,717	40,001	3,192,680
Mariposa	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,482,852	$1,562,852	$4,832,706	$1,084,335	
Mariposa Sq Ft Wallboard	0	0	0	0	0	0	0	0	0	17,698	11,978	76,905	13,282	119,863
Mendocino	$3,046,923	$0	$0	$1,099,424	$14,633	$0	$0	$3,624	$0	$2,171,043	$12,476,451	$8,771,284	$2,490,573	
Mendocino Sq Ft Wallboard	58,660	0	0	10,329	206	0	0	76	0	25,912	95,622	139,581	30,507	360,892
Merced	$0	$0	$0	$0	$453,083	$0	$0	$2,883,509	$1,664,582	$11,121,726	$13,393,208	$37,796,845	$2,303,712	
Merced Sq Ft Wallboard	0	0	0	0	6,370	0	0	60,508	33,804	132,739	102,648	601,477	28,218	965,764
Modoc	$0	$0	$0	$0	$0	$0	$0	$3,694,000	$0	$730,000	$4,308,550	$836,000	$353,000	
Modoc Sq Ft Wallboard	0	0	0	0	0	0	0	77,515	0	8,713	33,022	13,304	4,324	136,877
Mono	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,052,880	$137,363	
Mono Sq Ft Wallboard	0	0	0	0	0	0	0	0	0	0	0	16,755	1,683	18,437
Monterey	$0	$423,474	$0	$0	$2,007,050	$0	$0	$0	$0	$13,944,993	$39,948,527	$130,399,835	$3,215,042	
Monterey Sq Ft Wallboard	0	7,789	0	0	28,216	0	0	0	0	166,435	306,174	2,075,109	39,381	2,623,103
Napa	$1,093,528	$0	$0	$3,000,000	$24,645,792	$0	$0	$540,000	$0	$103,573,515	$11,702,551	$29,822,907	$3,972,780	

County Totals	Hotels & Motels	Non-Housekeeping Shelter	Amusement & Recreation	Churches	Industrial & Manufacturing	Service Stations	Hospitals	Offices	Schools Education	Stores, Mercantile Warehouses	Other Non-Residential Buildings	Non-Residential Alterations	Residential Garages	Totals
Napa Sq Ft Wallboard	21,053	0	0	28,184	346,481	0	0	11,331	0	1,236,157	89,691	474,585	48,662	2,256,144
Nevada	$909,978	$0	$962,919	$4,000,000	$400,000	$8,311,980	$0	$285,000	$0	$47,721,797	$3,393,842	$15,696,831	$1,815,043	
Nevada Sq Ft Wallboard	17,519	0	16,504	37,578	5,623	198,408	0	5,980	0	569,563	26,011	249,790	22,232	1,149,210
Orange	$548,902,100	$205,000	$219,912,984	$6,402,094	$2,412,500	$1,010,000	$55,023,736	$145,735,367	$25,520,084	$264,662,950	$246,007,295	$1,334,453,123	$8,091,928	
Orange Sq Ft Wallboard	10,567,664	3,771	3,769,173	60,145	33,916	24,109	849,840	3,058,134	518,253	3,158,772	1,885,450	21,235,728	99,117	45,264,071
Placer	$162,267	$0	$25,000	$23,939,929	$268,700	$0	$22,961,971	$23,509,343	$13,892,857	$39,105,709	$10,807,388	$78,159,737	$5,296,640	
Placer Sq Ft Wallboard	3,124	0	428	224,904	3,778	0	354,647	493,324	282,131	466,729	82,830	1,243,790	64,878	3,220,563
Plumas	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,753,775	$698,782	$34,044	$1,090,358	
Plumas Sq Ft Wallboard	0	0	0	0	0	0	0	0	0	20,931	5,356	542	13,356	40,184
Riverside	$24,517,767	$434,157	$5,257,773	$1,392,559	$493,872,270	$65,349,791	$1,981,736	$41,566,617	$14,275,500	$170,790,294	$34,297,191	$300,086,800	$24,217,582	
Riverside Sq Ft Wallboard	472,025	7,986	90,115	13,082	6,943,072	1,559,909	30,608	872,240	289,902	2,038,395	262,861	4,775,411	296,639	17,652,244
Sacramento	$38,500,000	$1,719,343	$338,565,964	$0	$31,851,425	$1,762,434	$32,249,950	$99,643,556	$8,082,244	$162,460,800	$24,012,169	$700,603,971	$4,135,462	
Sacramento Sq Ft Wallboard	741,216	31,626	5,802,811	0	447,781	42,070	498,099	2,090,936	164,131	1,938,982	184,034	11,149,013	50,655	23,141,354
San Benito	$0	$0	$0	$0	$434,665	$0	$0	$0	$0	$8,874,683	$1,678,936	$5,243,670	$500,244	
San Benito Sq Ft Wallboard	0	0	0	0	6,111	0	0	0	0	105,920	12,868	83,445	6,127	214,471
San Bernardino	$15,433,986	$31,555	$33,561,559	$0	$476,322,279	$1,698,716	$13,526,569	$56,857,721	$9,015,092	$305,852,502	$36,562,479	$365,127,043	$15,354,101	
San Bernardino Sq Ft Wallboard	297,141	580	575,224	0	6,696,346	40,549	208,917	1,193,111	183,075	3,650,372	280,222	5,810,424	188,071	19,124,034
San Diego	$236,564,178	$537,894	$31,686,835	$5,548,530	$40,892,222	$569,772	$44,519,046	$168,021,601	$16,792,997	$204,846,710	$57,748,254	$1,234,198,170	$11,437,016	
San Diego Sq Ft Wallboard	4,554,420	9,894	543,093	52,126	574,881	13,601	687,595	3,525,792	341,026	2,444,860	442,594	19,640,327	140,091	32,970,301

County Totals	Hotels & Motels	Non-Housekeeping Shelter	Amusement & Recreation	Churches	Industrial & Manufacturing	Service Stations	Hospitals	Offices	Schools Education	Stores, Mercantile Warehouses	Other Non-Residential Buildings	Non-Residential Alterations	Residential Garages	Totals
San Francisco	$1,900,000	$0	$6,500,000	$0	$0	$0	$2,950,000	$243,648,408	$72,500,000	$31,605,153	$1,723,170	$1,082,572,971	$1,913,747	
San Francisco Sq Ft Wallboard	36,579	0	111,406	0	0	0	45,563	5,112,756	1,472,305	377,210	13,207	17,227,450	23,441	24,419,918
San Joaquin	$6,800,000	$0	$6,100,000	$0	$120,003,781	$1,466,250	$10,584,595	$10,911,429	$0	$335,134,872	$19,849,770	$363,840,897	$3,334,516	
San Joaquin Sq Ft Wallboard	130,916	0	104,550	0	1,687,066	35,000	163,479	228,967	0	3,999,859	152,133	5,789,957	40,844	12,332,770
San Luis Obispo	$11,185,796	$0	$645,515	$0	$10,977,770	$876,227	$0	$1,675,989	$1,050,792	$35,336,908	$15,319,593	$36,883,329	$5,582,363	
San Luis Obispo Sq Ft Wallboard	215,353	0	11,064	0	154,330	20,916	0	35,169	21,339	421,749	117,413	586,940	68,378	1,652,650
San Mateo	$10,000,000	$0	$14,188,399	$0	$0	$0	$0	$525,285,669	$13,751,200	$94,477,066	$23,723,162	$618,727,337	$10,279,521	
San Mateo Sq Ft Wallboard	192,524	0	243,180	0	0	0	0	11,022,677	279,255	1,127,591	181,819	9,846,075	125,913	23,019,033
Santa Barbara	$31,670,424	$3,505,000	$8,128,523	$4,070,000	$4,279,000	$1,500,000	$0	$2,217,700	$35,360,568	$46,167,603	$19,680,726	$108,270,143	$7,143,172	
Santa Barbara Sq Ft Wallboard	609,731	64,471	139,318	38,236	60,156	35,805	0	46,537	718,090	551,014	150,837	1,722,949	87,496	4,224,640
Santa Clara	$183,514,699	$270,500,000	$33,920,845	$0	$41,875,842	$0	$47,616,389	$1,079,264,388	$159,932,516	$349,660,403	$291,867,387	$2,467,938,997	$21,804,253	
Santa Clara Sq Ft Wallboard	3,533,092	4,975,602	581,382	0	588,709	0	735,434	22,647,453	3,247,855	4,173,223	2,236,932	39,273,377	267,078	82,260,137
Santa Cruz	$11,456,562	$0	$40,000	$575,474	$619,758	$0	$0	$0	$2,340,000	$4,137,847	$1,344,367	$41,089,283	$962,259	
Santa Cruz Sq Ft Wallboard	220,566	0	686	5,406	8,713	0	0	0	47,520	49,386	10,304	653,871	11,787	1,008,238
Shasta	$0	$0	$0	$0	$51,112	$0	$10,070,948	$618,173	$0	$30,549,591	$9,690,383	$14,286,469	$4,402,964	
Shasta Sq Ft Wallboard	0	0	0	0	719	0	155,545	12,972	0	364,612	74,269	227,347	53,931	889,395
Sierra	$1,319,168	$0	$0	$0	$0	$0	$0	$0	$0	$5,000	$0	$150,000	$124,032	
Sierra Sq Ft Wallboard	25,397	0	0	0	0	0	0	0	0	60	0	2,387	1,519	29,363
Siskiyou	$0	$264,780	$282,246	$0	$0	$4,785,000	$0	$0	$0	$180,360	$7,795,630	$6,585,950	$698,374	

County Totals	Hotels & Motels	Non-Housekeeping Shelter	Amusement & Recreation	Churches	Industrial & Manufacturing	Service Stations	Hospitals	Offices	Schools Education	Stores, Mercantile Warehouses	Other Non-Residential Buildings	Non-Residential Alterations	Residential Garages	Totals
Siskiyou Sq Ft Wallboard	0	4,870	4,838	0	0	114,219	0	0	0	2,153	59,747	104,805	8,554	299,186
Solano	$11,000,000	$0	$7,100,236	$0	$7,350,216	$0	$0	$1,017,735	$0	$61,497,431	$19,034,988	$79,382,352	$1,699,902	
Solano Sq Ft Wallboard	211,776	0	121,694	0	103,333	0	0	21,356	0	733,976	145,888	1,263,246	20,822	2,622,090
Sonoma	$26,875,053	$0	$1,974,190	$0	$199,008	$0	$0	$1,733,274	$2,088,372	$15,320,760	$14,343,092	$97,259,177	$9,968,906	
Sonoma Sq Ft Wallboard	517,408	0	33,836	0	2,798	0	0	36,371	42,410	182,854	109,928	1,547,727	122,108	2,595,442
Stanislaus	$545,563	$0	$0	$0	$30,302,646	$784,503	$894,344	$315,937	$7,500,000	$71,093,711	$25,240,368	$104,465,776	$3,222,810	
Stanislaus Sq Ft Wallboard	10,503	0	0	0	426,008	18,726	13,813	6,630	152,307	848,509	193,447	1,662,409	39,476	3,371,828
Sutter	$0	$0	$0	$0	$748,174	$415,000	$0	$970,000	$832,000	$2,600,000	$4,367,585	$7,246,731	$436,984	
Sutter Sq Ft Wallboard	0	0	0	0	10,518	9,906	0	20,355	16,896	31,031	33,474	115,320	5,353	242,853
Tehama	$0	$0	$0	$0	$0	$0	$0	$2,100,000	$0	$2,858,701	$4,784,488	$3,185,892	$1,270,643	
Tehama Sq Ft Wallboard	0	0	0	0	0	0	0	44,067	0	34,119	36,669	50,698	15,564	181,117
Trinity	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$12,718,291	$80,032	$760,031	
Trinity Sq Ft Wallboard	0	0	0	0	0	0	0	0	0	0	97,476	1,274	9,310	108,059
Tulare	$0	$24,000	$7,827,465	$9,085,000	$7,119,931	$0	$1,000,000	$17,853,500	$0	$40,516,595	$45,708,696	$41,474,632	$4,912,559	
Tulare Sq Ft Wallboard	0	441	134,158	85,349	100,095	0	15,445	374,641	0	483,569	350,321	660,004	60,173	2,264,196
Tuolumne	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,358,095	$4,674,448	$8,526,742	$1,822,906	
Tuolumne Sq Ft Wallboard	0	0	0	0	0	0	0	0	0	16,209	35,826	135,690	22,329	210,053
Ventura	$0	$269,931	$452,232	$1,124,919	$12,262,892	$264,561	$20,223,559	$1,304,015	$7,312,074	$6,387,310	$30,336,934	$91,837,738	$4,127,605	
Ventura Sq Ft Wallboard	0	4,965	7,751	10,568	172,397	6,315	312,352	27,364	148,491	76,233	232,508	1,461,454	50,559	2,510,957

County Totals	Hotels & Motels	Non-Housekeeping Shelter	Amusement & Recreation	Churches	Industrial & Manufacturing	Service Stations	Hospitals	Offices	Schools Education	Stores, Mercantile Warehouses	Other Non-Residential Buildings	Non-Residential Alterations	Residential Garages	Totals
Yolo	$32,366,071	$0	$598,571	$0	$4,106,260	$0	$0	$9,393,411	$0	$9,041,067	$55,735,299	$104,473,678	$652,257	
Yolo Sq Ft Wallboard	623,123	0	10,259	0	57,728	0	0	197,113	0	107,906	427,167	1,662,535	7,989	3,093,820
Yuba	$0	$0	$0	$0	$2,327,079	$157,636	$0	$0	$0	$2,457,918	$1,698,850	$1,813,879	$1,555,927	
Yuba Sq Ft Wallboard	0	0	0	0	32,715	3,763	0	0	0	29,335	13,020	28,865	19,058	126,757
														460,571,237
State $1,000 Valuation	$1,535,109,641	$333,303,865	$802,706,029	$83,790,581	$1,408,156,978	$97,384,111	$324,685,678	$3,146,011,524	$532,116,109	$4,585,743,780	$1,790,090,839	$14,743,408,842	$270,520,834	$29,653,028,811
State 1,000 Sq Ft Wallboard	29,554	6,131	13,758	787	19,796	2,325	5,015	66,016	10,806	54,731	13,720	234,618	3,314	460,571

ANNEX 3a-c BWE Wallboard Estimations by County

ANNEX 3a
Residential and Non-Residential
BWE Wallboard Estimations by County (Alpha Sort)

County	Residential Totals	Non-Residential Totals	Combined Total Wallboard
Alameda County Sq Ft Wallboard	51,454,594	25,926,600	77,381,194
Alpine County Sq Ft Wallboard	42,849	4,755	47,604
Amador County Sq Ft Wallboard	1,186,471	63,347	1,249,818
Butte County Sq Ft Wallboard	7,039,823	1,111,314	8,151,136
Calaveras County Sq Ft Wallboard	1,342,932	178,756	1,521,688
Colusa County Sq Ft Wallboard	301,929	227,354	529,282
Contra Costa County Sq Ft Wallboard	27,541,807	6,259,620	33,801,428
Del Norte County Sq Ft Wallboard	223,063	33,108	256,171
El Dorado County Sq Ft Wallboard	12,664,264	1,012,591	13,676,855
Fresno County Sq Ft Wallboard	24,531,685	6,382,225	30,913,910
Glenn County Sq Ft Wallboard	269,105	100,863	369,967
Humboldt County Sq Ft Wallboard	2,263,517	418,561	2,682,078
Imperial County Sq Ft Wallboard	2,341,242	737,445	3,078,688
Inyo County Sq Ft Wallboard	731,801	91,419	823,219
Kern County Sq Ft Wallboard	16,175,426	4,782,397	20,957,823
Kings County Sq Ft Wallboard	3,309,158	463,909	3,773,067
Lake County Sq Ft Wallboard	629,318	88,430	717,749
Lassen County Sq Ft Wallboard	129,718	37,526	167,243
Los Angeles County Sq Ft Wallboard	170,455,479	92,269,946	262,725,424
Madera County Sq Ft Wallboard	5,278,523	468,376	5,746,899
Marin County Sq Ft Wallboard	9,459,863	3,192,680	12,652,544
Mariposa County Sq Ft Wallboard	345,831	119,863	465,694
Mendocino County Sq Ft Wallboard	929,757	360,892	1,290,649
Merced County Sq Ft Wallboard	6,578,479	965,764	7,544,242
Modoc County Sq Ft Wallboard	49,336	136,877	186,214
Mono County Sq Ft Wallboard	371,434	18,437	389,871
Monterey County Sq Ft Wallboard	6,404,510	2,623,103	9,027,613
Napa County Sq Ft Wallboard	5,264,427	2,256,144	7,520,572
Nevada County Sq Ft Wallboard	5,573,615	1,149,210	6,722,825
Orange County Sq Ft Wallboard	69,528,878	45,264,071	114,792,949

County	Residential Totals	Non-Residential Totals	Combined Total Wallboard
Placer County Sq Ft Wallboard	21,941,916	3,220,563	25,162,479
Plumas County Sq Ft Wallboard	272,310	40,184	312,495
Riverside County Sq Ft Wallboard	61,862,439	17,652,244	79,514,683
Sacramento County Sq Ft Wallboard	45,424,662	23,141,354	68,566,016
San Benito County Sq Ft Wallboard	6,192,041	214,471	6,406,511
San Bernardino County Sq Ft Wallboard	39,249,980	19,124,034	58,374,014
San Diego County Sq Ft Wallboard	55,185,793	32,970,301	88,156,093
San Francisco County Sq Ft Wallboard	44,111,917	24,419,918	68,531,835
San Joaquin County Sq Ft Wallboard	27,597,258	12,332,770	39,930,029
San Luis Obispo County Sq Ft Wallboard	11,310,720	1,652,650	12,963,371
San Mateo County Sq Ft Wallboard	31,491,082	23,019,033	54,510,115
Santa Barbara County Sq Ft Wallboard	11,619,534	4,224,640	15,844,174
Santa Clara County Sq Ft Wallboard	48,369,565	82,260,137	130,629,702
Santa Cruz County Sq Ft Wallboard	2,873,908	1,008,238	3,882,145
Shasta County Sq Ft Wallboard	4,621,735	889,395	5,511,130
Sierra County Sq Ft Wallboard	83,726	29,363	113,089
Siskiyou County Sq Ft Wallboard	306,370	299,186	605,556
Solano County Sq Ft Wallboard	11,011,679	2,622,090	13,633,769
Sonoma County Sq Ft Wallboard	20,014,425	2,595,442	22,609,866
Stanislaus County Sq Ft Wallboard	4,777,730	3,371,828	8,149,558
Sutter County Sq Ft Wallboard	1,364,761	242,853	1,607,614
Tehama County Sq Ft Wallboard	993,566	181,117	1,174,683
Trinity County Sq Ft Wallboard	175,354	108,059	283,413
Tulare County Sq Ft Wallboard	11,160,947	2,264,196	13,425,143
Tuolumne County Sq Ft Wallboard	637,787	210,053	847,841
Ventura County Sq Ft Wallboard	11,520,348	2,510,957	14,031,305
Yolo County Sq Ft Wallboard	8,309,058	3,093,820	11,402,878
Yuba County Sq Ft Wallboard	3,452,807	126,757	3,579,564
Totals	**918,352,250**	**460,571,237**	**1,378,923,487**
Totals 1,000 sq ft	**918,352**	**460,571**	**1,378,923**

ANNEX 3b
Residential and Non-Residential
BWE Wallboard Estimations by County (Largest to Smallest Sort)

County	Residential Totals	Non-Residential Totals	Combined Total Wallboard
Los Angeles County Sq Ft Wallboard	170,455,479	92,269,946	262,725,424
Santa Clara County Sq Ft Wallboard	48,369,565	82,260,137	130,629,702
Orange County Sq Ft Wallboard	69,528,878	45,264,071	114,792,949
San Diego County Sq Ft Wallboard	55,185,793	32,970,301	88,156,093
Riverside County Sq Ft Wallboard	61,862,439	17,652,244	79,514,683
Alameda County Sq Ft Wallboard	51,454,594	25,926,600	77,381,194
Sacramento County Sq Ft Wallboard	45,424,662	23,141,354	68,566,016
San Francisco County Sq Ft Wallboard	44,111,917	24,419,918	68,531,835
San Bernardino County Sq Ft Wallboard	39,249,980	19,124,034	58,374,014
San Mateo County Sq Ft Wallboard	31,491,082	23,019,033	54,510,115
San Joaquin County Sq Ft Wallboard	27,597,258	12,332,770	39,930,029
Contra Costa County Sq Ft Wallboard	27,541,807	6,259,620	33,801,428
Fresno County Sq Ft Wallboard	24,531,685	6,382,225	30,913,910
Placer County Sq Ft Wallboard	21,941,916	3,220,563	25,162,479
Sonoma County Sq Ft Wallboard	20,014,425	2,595,442	22,609,866
Kern County Sq Ft Wallboard	16,175,426	4,782,397	20,957,823
Santa Barbara County Sq Ft Wallboard	11,619,534	4,224,640	15,844,174
Ventura County Sq Ft Wallboard	11,520,348	2,510,957	14,031,305
El Dorado County Sq Ft Wallboard	12,664,264	1,012,591	13,676,855
Solano County Sq Ft Wallboard	11,011,679	2,622,090	13,633,769
Tulare County Sq Ft Wallboard	11,160,947	2,264,196	13,425,143
San Luis Obispo County Sq Ft Wallboard	11,310,720	1,652,650	12,963,371
Marin County Sq Ft Wallboard	9,459,863	3,192,680	12,652,544
Yolo County Sq Ft Wallboard	8,309,058	3,093,820	11,402,878
Monterey County Sq Ft Wallboard	6,404,510	2,623,103	9,027,613
Butte County Sq Ft Wallboard	7,039,823	1,111,314	8,151,136
Stanislaus County Sq Ft Wallboard	4,777,730	3,371,828	8,149,558
Merced County Sq Ft Wallboard	6,578,479	965,764	7,544,242
Napa County Sq Ft Wallboard	5,264,427	2,256,144	7,520,572
Nevada County Sq Ft Wallboard	5,573,615	1,149,210	6,722,825
San Benito County Sq Ft Wallboard	6,192,041	214,471	6,406,511
Madera County Sq Ft Wallboard	5,278,523	468,376	5,746,899
Shasta County Sq Ft Wallboard	4,621,735	889,395	5,511,130

County	Residential Totals	Non-Residential Totals	Combined Total Wallboard
Santa Cruz County Sq Ft Wallboard	2,873,908	1,008,238	3,882,145
Kings County Sq Ft Wallboard	3,309,158	463,909	3,773,067
Yuba County Sq Ft Wallboard	3,452,807	126,757	3,579,564
Imperial County Sq Ft Wallboard	2,341,242	737,445	3,078,688
Humboldt County Sq Ft Wallboard	2,263,517	418,561	2,682,078
Sutter County Sq Ft Wallboard	1,364,761	242,853	1,607,614
Calaveras County Sq Ft Wallboard	1,342,932	178,756	1,521,688
Mendocino County Sq Ft Wallboard	929,757	360,892	1,290,649
Amador County Sq Ft Wallboard	1,186,471	63,347	1,249,818
Tehama County Sq Ft Wallboard	993,566	181,117	1,174,683
Tuolumne County Sq Ft Wallboard	637,787	210,053	847,841
Inyo County Sq Ft Wallboard	731,801	91,419	823,219
Lake County Sq Ft Wallboard	629,318	88,430	717,749
Siskiyou County Sq Ft Wallboard	306,370	299,186	605,556
Colusa County Sq Ft Wallboard	301,929	227,354	529,282
Mariposa County Sq Ft Wallboard	345,831	119,863	465,694
Mono County Sq Ft Wallboard	371,434	18,437	389,871
Glenn County Sq Ft Wallboard	269,105	100,863	369,967
Plumas County Sq Ft Wallboard	272,310	40,184	312,495
Trinity County Sq Ft Wallboard	175,354	108,059	283,413
Del Norte County Sq Ft Wallboard	223,063	33,108	256,171
Modoc County Sq Ft Wallboard	49,336	136,877	186,214
Lassen County Sq Ft Wallboard	129,718	37,526	167,243
Sierra County Sq Ft Wallboard	83,726	29,363	113,089
Alpine County Sq Ft Wallboard	42,849	4,755	47,604
Totals	**918,352,250**	**460,571,237**	**1,378,923,487**
Totals 1,000 sq ft	**918,352**	**460,571**	**1,378,923**

ANNEX 3c
Residential and Non-Residential
BWE Wallboard Estimations by County (Cumulative Total Sort)

County	Cumulative Total Sq Ft
Los Angeles County Sq Ft Wallboard	262,725,424
Santa Clara County Sq Ft Wallboard	393,355,126
Orange County Sq Ft Wallboard	508,148,076
San Diego County Sq Ft Wallboard	596,304,169
Riverside County Sq Ft Wallboard	675,818,852
Alameda County Sq Ft Wallboard	753,200,045
Sacramento County Sq Ft Wallboard	821,766,062
San Francisco County Sq Ft Wallboard	890,297,897
San Bernardino County Sq Ft Wallboard	948,671,911
San Mateo County Sq Ft Wallboard	1,003,182,026
San Joaquin County Sq Ft Wallboard	1,043,112,055
Contra Costa County Sq Ft Wallboard	1,076,913,483
Fresno County Sq Ft Wallboard	1,107,827,393
Placer County Sq Ft Wallboard	1,132,989,872
Sonoma County Sq Ft Wallboard	1,155,599,738
Kern County Sq Ft Wallboard	1,176,557,561
Santa Barbara County Sq Ft Wallboard	1,192,401,735
Ventura County Sq Ft Wallboard	1,206,433,040
El Dorado County Sq Ft Wallboard	1,220,109,895
Solano County Sq Ft Wallboard	1,233,743,664
Tulare County Sq Ft Wallboard	1,247,168,806
San Luis Obispo County Sq Ft Wallboard	1,260,132,177
Marin County Sq Ft Wallboard	1,272,784,721
Yolo County Sq Ft Wallboard	1,284,187,599
Monterey County Sq Ft Wallboard	1,293,215,212
Butte County Sq Ft Wallboard	1,301,366,348
Stanislaus County Sq Ft Wallboard	1,309,515,906
Merced County Sq Ft Wallboard	1,317,060,148
Napa County Sq Ft Wallboard	1,324,580,720
Nevada County Sq Ft Wallboard	1,331,303,545
San Benito County Sq Ft Wallboard	1,337,710,056
Madera County Sq Ft Wallboard	1,343,456,955
Shasta County Sq Ft Wallboard	1,348,968,085

County	Cumulative Total Sq Ft
Santa Cruz County Sq Ft Wallboard	1,352,850,230
Kings County Sq Ft Wallboard	1,356,623,298
Yuba County Sq Ft Wallboard	1,360,202,862
Imperial County Sq Ft Wallboard	1,363,281,550
Humboldt County Sq Ft Wallboard	1,365,963,628
Sutter County Sq Ft Wallboard	1,367,571,241
Calaveras County Sq Ft Wallboard	1,369,092,929
Mendocino County Sq Ft Wallboard	1,370,383,578
Amador County Sq Ft Wallboard	1,371,633,396
Tehama County Sq Ft Wallboard	1,372,808,079
Tuolumne County Sq Ft Wallboard	1,373,655,920
Inyo County Sq Ft Wallboard	1,374,479,139
Lake County Sq Ft Wallboard	1,375,196,888
Siskiyou County Sq Ft Wallboard	1,375,802,445
Colusa County Sq Ft Wallboard	1,376,331,727
Mariposa County Sq Ft Wallboard	1,376,797,421
Mono County Sq Ft Wallboard	1,377,187,292
Glenn County Sq Ft Wallboard	1,377,557,260
Plumas County Sq Ft Wallboard	1,377,869,754
Trinity County Sq Ft Wallboard	1,378,153,167
Del Norte County Sq Ft Wallboard	1,378,409,338
Modoc County Sq Ft Wallboard	1,378,595,551
Lassen County Sq Ft Wallboard	1,378,762,795
Sierra County Sq Ft Wallboard	1,378,875,884
Alpine County Sq Ft Wallboard	1,378,923,487

Endnotes

[1] New West Gypsum Recycling accepts existing wallboard removed during demolition and renovation. https://www.nwgypsum.com/.
[2] Athena Sustainable Materials Institute, "Determining gypsum board material flows within and sold into the state of California," Preliminary findings, 2022.
[3] US International Trade Commission, dataweb.usitc.gov, accessed 2/14/23.
[4] Note: In this report, we are using several different units for GW products and waste—million metric tons (MMT) and square feet (sf); the latter is reported as sf or 1,000 sf for large quantities. In general, we have used the particular unit that is used in the information source or reference document. We have chosen to not convert to a single unit as that we did not gather data on the mix of wallboard products to make an adequate assessment of a density factor for use in doing conversions. This may be a task for a future phase of the project.
CA production calculation is derived from Athena shipments using Athena's 2.5% estimate of production loss and rework—CA shipments / 0.975 (see GW waste section).
CA shipments—Athena survey data (p. 3 PPT; cell H5 in XLSX)
Direct imports—ITC Port of Entry data to CA, AZ
Indirect imports—ITC Port of Entry data to other states that is then shipped to CA (unknown but estimated)
Out of state to CA-- Athena survey data (p. 3 PPT; cell M5 in XLSX)
[5] https://www.cirb.org/about. Custom reports are available on request. We obtained a custom report for 2019 to try minimize the impact of Covid on construction.
[6] International Code Council, "Building Valuation Data," August 2022, Square Foot Construction Costs table listed by Group (2021 International Building Code). Different cost factors are given for standard occupancy groups IA through VA. We chose what we thought is the most appropriate group for the different types of occupancy.
[7] Single family; 2 unit multi-family; 3-4 unit multi-family; 5+ unit multi-family; and residential alterations.
[8] Hotels & motels; non-housekeeping shelter; amusement & recreation; churches; industrial & manufacturing; parking garages; service stations; hospitals; offices; public works; schools / education; stores, mercantile warehouses; other non-residential buildings; structures other than buildings; non-residential alterations; and residential garages. We excluded parking garages, public works, and structures other than buildings.
[9] As a check on the values, we estimated the average sf per unit using the CIRB total units data and our estimate for total sf for each of the four residential building types in each geographic area to make a reasonableness evaluation.
[10] This is the 2019 value of occupancy category Vb in the ICC cost/sf BVD table—the low end of residential.
[11] https://calrecycle.ca.gov/ConDemo/Wallboard/.
[12] Loss may occur due to improper storage, leaks causing water damage, material handling accidents, and general lack of care in handling.
[13] In contrast to our calculations of GW waste that ends up in landfills, CalRecycle in their 2021 statewide landfill waste characterization study, identified 0.665 MMT (732,835 short tons) of clean GW scrap and GW waste from demolition and renovation sent to landfills—roughly double our estimate. We have not identified the source(s) of the difference and have asked for clarification from CalRecycle. It may be that there is some amount of GW demolition and renovation waste coming from other states into California, but that may be just part of the explanation. CalRecycle, "2021 Disposal Facility-based Waste Characterization Data Tables," Nov. 2022, https://www2.calrecycle.ca.gov/Docs/Web/122544. The 2018 study (https://www2.calrecycle.ca.gov/Publications/Download/1458) had similar results (0.684 MMT) for total statewide GW disposal to landfills.
[14] The potential presence of hazardous materials such as asbestos and lead is a factor related to the age of the structures from which the existing GW is removed. For demolition and renovation removals of GW in these older structures, testing would be required to ensure that hazardous materials are not present before recovering and recycling the gypsum and paper facing. We are assuming that there is a high likelihood that in these nearly all the GW is landfilled without bothering to test. For demolition and renovation removals of GW in newer structures that

have little or no potential for asbestos and lead, we assumed that unless it was a LEED project, most of the GW waste will also go to landfills.

[15] B. Guerra and F. Leite, "Circular economy in the construction industry: An overview of United States stakeholders' awareness, major challenges, and enablers," Resources, Conservation and Recycling, Vol. 170, July 2021.

[16] Residential--http://www.inspectoroutlet.com/life-expectancy-chart.aspx; commercial--https://ccpia.org/estimated-life-expectancy-chart-for-commercial-building-systems-and-components/.

[17] A partial list of papers discussing environmental impacts of GW:
https://www.sciencedirect.com/science/article/pii/S0959652620301037
https://sciendo.com/pdf/10.2478/mape-2018-0100
https://portal.ct.gov/-/media/DEEP/waste_management_and_disposal/Solid_Waste_Management_Plan/GypsumWallboard/Dec2009/DrywallRecyclingbyBroud2009pdf.pdf
https://www.sciencedirect.com/science/article/pii/S0921344917304147

[18] New product transportation emissions (greenhouse gas emissions, air pollutants, and particulates) generally reflect full load truck and (some) rail distribution from manufacturers to distributors to suppliers/retailers to construction sites and return trips that are empty; that may be an opportunity to create a GW scrap backhaul logistics system from construction sites to processors and recyclers.

[19] Recent work has identified some promising methods for treating GW waste to reduce the risks from degradation. One example is mycelium treatment of GW scrap to eliminate H_2S and deliver a commercially valuable material (https://mycocycle.com/).

[20] One study showed no energy benefit to recycling GW, but did show reductions in GHG emissions for recycling due to degradation of paper facing in end-of-life disposal. A. Rivero, et al., "Life cycle energy and material flow implications of gypsum plasterboard recycling in the European Union," Resources, Conservation and Recycling, Vol. 108, March–April 2016.

[21] https://p2infohouse.org/ref/23/22738.pdf; increase in fuel costs may change this figure.

[22] Gyp Monster (http://www.gypmonster.com/),

[23] Map source: https://www.randymajors.org/.

[24] Eurogypsum, "GtoG (Gypsum to Gypsum) - From Production to Recycling a circular economy for the European Gypsum Industry with the Demolition and Recycling Industry," LIFE 11 ENV/BE/001039, 30/03/2016, available at https://eurogypsum.org/wp-content/uploads/2022/09/G-to-G-reports.zip.

[25] A. Jiménez-Rivero and J. García-Navarro, "Management of end-of-life gypsum in a circular economy," in F. Pacheco-Torgal, et al., Advances in Construction and Demolition Waste Recycling, Woodhead Publishing, 2020.

[26] https://www.astm.org/c1881-20.html.

[27] F. Knauf, et al, "100% recycled gypsum wallboard with Chiyoda Ute," Global Gypsum Magazine, July 2022.

[28] Eurogypsum, Gypsum to Gypsum, A Circular Economy for the Construction Sector: Layman's Report," 2014, https://cinea.ec.europa.eu/system/files/2021-03/gypsum.pdf. Also, LIFE 11 ENV/BE/001039, Final Report, 30/03/2016, accessed through https://webgate.ec.europa.eu/life/publicWebsite/index.cfm?fuseaction=search.dspPage&n_proj_id=4191.

[29] Comments of Jean -Luc Marchand, Saint-Gobain, reported in R. McAffrey, "Review: Global Gypsupply Conference," Global Gypsum, April 23.

[30] https://www.ragnsells.com/what-we-do/inspired/gypsum-in-sweden/.

[31] Comments of Marteen Henriks, New West Gypsum Recycling, reported in R. McAffrey, "Review: Global Gypsupply Conference," Global Gypsum, April 23; J. Winskell, "Gypsum in Northwest Europe," Global Gypsum, April 23.

[32] City of Vancouver, "Transfer & Landfill Operations Drywall Policy," https://vancouver.ca/files/cov/transfer-landfill-operations-drywall-policy.pdf.

[33] https://www.nwgypsum.com.

[34] https://recyclegypse.com.

[35] Comments of Marteen Henriks, New West Gypsum Recycling, reported in R. McAffrey, "Review: Global Gypsupply Conference," Global Gypsum, April 23.
[36] https://www.cecc.gov/resources/legal-provisions/circular-economy-promotion-law-of-the-peoples-republic-of-china-chinese.
[37] B. Huang, et al., "Construction and demolition waste management in China through the 3R principle," Resources, Conservation and Recycling, 129: 36-44, 2018.
[38] M. Bains, et al., International Policy Perspectives on Construction Waste Minimisation and Recycling, Proceedings of the Institution of Civil Engineers Journal of Waste and Resource Management 172(3): 76–85, 2019. https://doi.org/10.1680/jwarm.18.00020.
[39] https://www.epa.gov.tw/eng/D6DCECB911CD0DEB
[40] Ying-Ying Lai et al., "Management and Recycling of Construction Waste in Taiwan," Procedia Environmental Sciences 35: 723 – 730, 2016.
[41] X. Zhao, et al, "Construction and demolition waste management in Australia: A mini-review," Waste Management & Research, 40(1): 34–46, 2022.
[42] https://www.regyp.com.au/.
[43] https://yoshino-gypsum.com/en/csr/recycle.
[44] F. Knauf, et al, "100% recycled gypsum wallboard with Chiyoda Ute," Global Gypsum Magazine, July 2022; Japan: Chiyoda-Ute launches 100% recycled wallboard," Global Gypsum Magazine, July 2023.

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California Gypsum Wallboard Recycling Assessment

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December 2024

California Gypsum Wallboard (GW) Recycling Assessment

- Purpose
  - Research current gypsum recycling processes across California
  - Explore potential impacts of changes to current recycling efforts

- Goals
  - Provide CA legislators and staff with background on the California gypsum wallboard industry and key market stakeholders
  - Highlight key insights and critical information for decision-makers
  - Assess data and resources required for development of GW recycling/processing infrastructure in CA

Assessment Approach

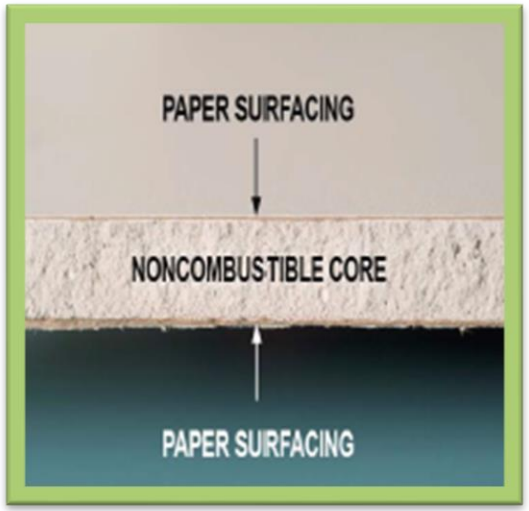
- Gypsum wallboard ecosystem mapping
  - Conducted background research and stakeholder interviews to map current standard practices and near-term changes to stakeholders, anticipated facility closures, new investments, technology advancements, etc.
- Data collection
  - Researched best available data sources, including:
    - California new construction forecasting
    - GW material flows
    - Landfill locations and costs
    - Transportation emission factors
    - Secondary recycling markets
    - Recycling processing facility technology and costs
- Statewide analysis
  - Evaluated current industry practice and potential impacts to stakeholder ecosystem associated with recycling process changes
  - Identified gaps and opportunities for consideration in any future recycling efforts
- Summarized key findings and conclusions

Gypsum Wallboard

Product Basics & Variations

Gypsum Wallboard – Product Basics

Gypsum Raw Materials (Source)



Gypsum Panel Profile (Source)

- GW products are manufactured to the ASTM C1396 (Source), Standard Specification for Gypsum Board and contain three categories of materials:
  - *Gypsum*:
    - Mined gypsum (calcium sulfate dihydrate or $CaSO_4 \cdot 2H_2O$) which is a mineral found in abundant deposits around the world. In 2023, the leading crude gypsum-producing US states were estimated to be California, Iowa, Kansas, Nevada, Oklahoma, and Texas (Source). Gypsum is also imported from Mexico (Baja) for GW manufacturing in the Western U.S.
    - Flue gas desulfurization (FDG) gypsum, also referred to as synthetic gypsum, is a byproduct of coal energy production (elimination of sulfur dioxide pollution). As a result of the closure of coal-fired power plants across the state, FGD gypsum is not typically used in wallboard manufactured in California.
  - *Paper*:
    - Used for panel facing
    - Cellulose fiber--virgin, recycled, or kraft
  - *Additives*:
    - Improve product performance, e.g., strength, mold and mildew resistance, and proper material hardening
    - Examples: silicates, fungicides, foaming agents, starches
- Gypsum is a noncombustible mineral with naturally occurring, chemically bonded moisture content of ~20%
- Gypsum as a wallboard core acts as a natural fire-resistant building material

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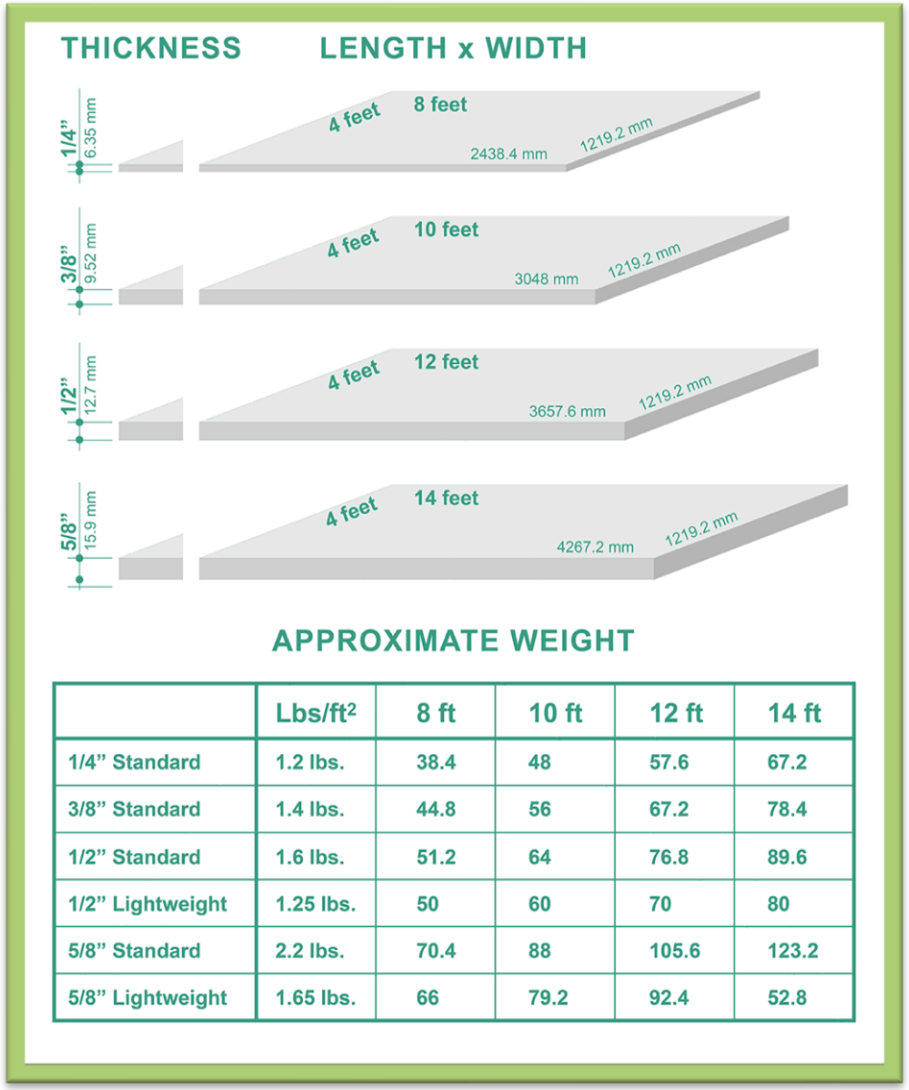
Gypsum Wallboard – Product Basics



APPROXIMATE WEIGHT

	Lbs/ft²	8 ft	10 ft	12 ft	14 ft
1/4" Standard	1.2 lbs.	38.4	48	57.6	67.2
3/8" Standard	1.4 lbs.	44.8	56	67.2	78.4
1/2" Standard	1.6 lbs.	51.2	64	76.8	89.6
1/2" Lightweight	1.25 lbs.	50	60	70	80
5/8" Standard	2.2 lbs.	70.4	88	105.6	123.2
5/8" Lightweight	1.65 lbs.	66	79.2	92.4	52.8

Example Wallboard Panel Sizing
(Source)

- GW also called drywall or gypsum board:
  - A widely-used building industry product
  - Distributed through both wholesale and retail sales channels
  - Used in the finishing of new, remodeled, and repaired walls and ceilings for nearly all building types: single & multi-family residential, commercial, institutional and industrial building types
- GW products vary by manufacturer and some products can be cut for special orders
- GW products are generally offered with standard sizes for use in different applications:
  - Thickness (e.g., 1/4-inch, 3/8-inch, 1/2-inch and 5/8-inch)
  - Length (e.g., 8-foot, 10-foot, 12-foot, 14-foot and 16-foot)
  - Width (e.g., 48-inch and 54-inch)

Gypsum Wallboard – Product Basics

- GW thickness correlates with gypsum content and board weight
- Thickness varies across applications for building types and the location within the building
  - 1/2-in thickness is considered standard for most residential spaces
  - 5/8-in thickness is used for ceilings, improved sound-proofing, and increased fire rating residential zones; also used extensively in non-residential applications
  - 1/4-in thickness is more flexible, economical, and lighter in weight

Product Installation Example
(Source)

- During standard construction site installations, approximately 10-15% of boards that are cut to fit the application become waste
- Cut-offs of GW material in new/remodel construction waste is termed "clean scrap"

Gypsum Wallboard- Product Variations

- Several different options for specialty panel products are also manufactured and available in the CA market today:
  - Insulated panels: for cold space (attics, basements, etc.) application that may have foil backing and or polyfoam core
  - Moisture/mold resistant panels: for high moisture exposure rooms (bathrooms, laundry, kitchen, etc.) that may have waterproofing fiberglass, recycled paper, or wax-covered backing
  - Fire-rated/resistant panels (Type X/Type C): for high fire risk areas (garages, multifamily units, stairwells, and around battery storage installations) that may have glass fibers or other added compounds during manufacturing process
  - Soundproof panels: for noise reduction that may have adhesives or other additives
  - Ultralight panels: for lighter weight boards that maintain performance that may have foaming agents or other added compounds during manufacturing process
- Most specialty panels are not considered to be recyclable today. This is primarily due to inclusion of:
  - additives and proprietary materials mixed into the gypsum during the manufacturing process, or
  - backing materials that cannot be cleanly separated from the gypsum core.
- Specialty panels represent an estimated 10-15% of today's GW market with proprietary processes and technology continuing to evolve to meet building industry demands.

GW Example Variations (Source)

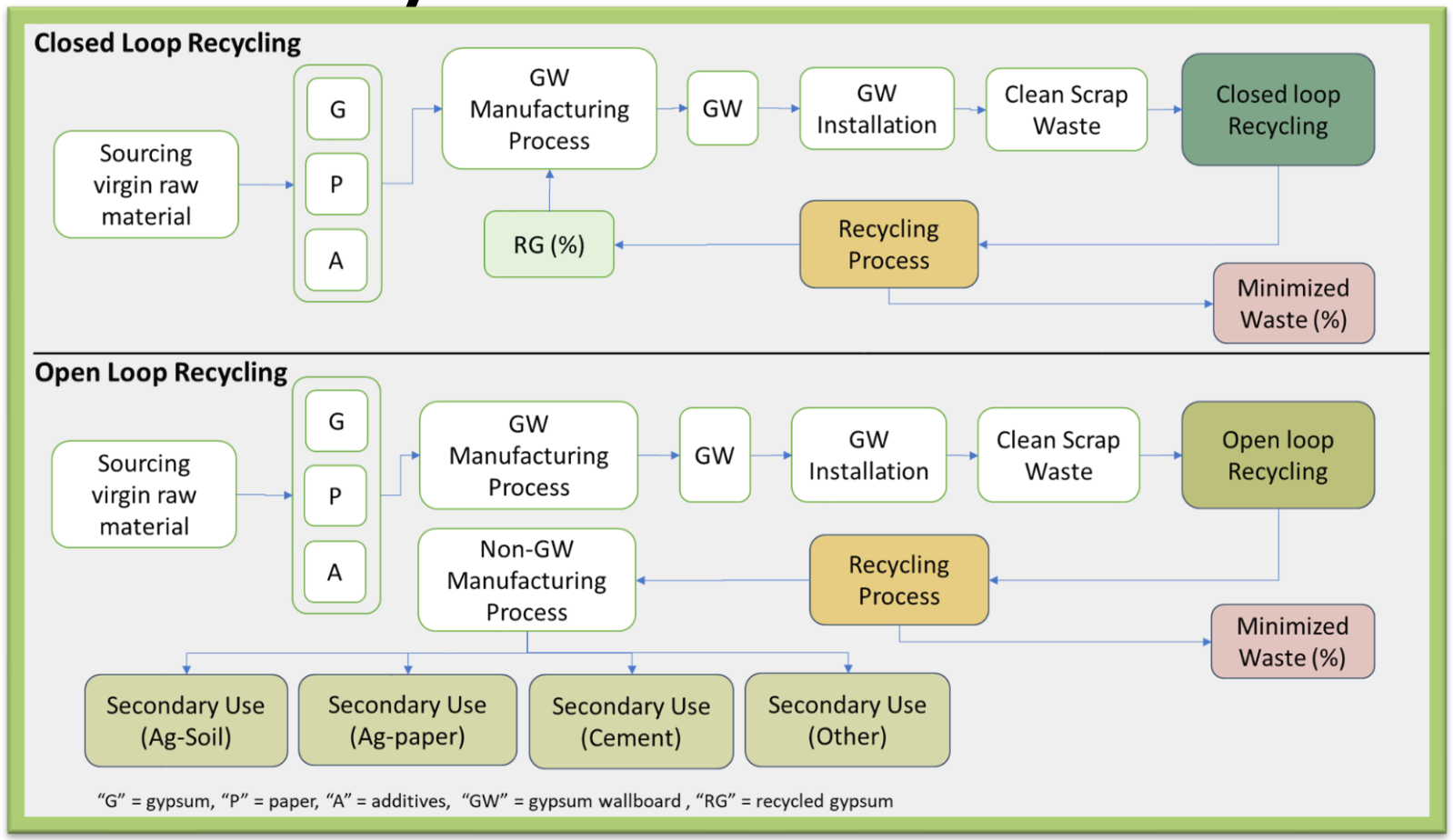
Gypsum Wallboard: CA Recycling

Process, Key Stakeholders, & GW Flows in CA

GW Recycling Pathways

GW clean scrap can be recycled or reused in two main pathways that result in minimization of waste disposal:

- *Closed loop*: recovery of clean GW scrap by recycling back into new GW products—requires processing
  - Clean gypsum waste from out-of-spec GW or other in-plant waste is a routinely recovered and recycled back into new product within manufacturing facilities as a standard practice
  - Data on the % of *post-consumer* recycled gypsum that can be blended with virgin gypsum and maintain product performance is sparse
  - Recycled gypsum must be free of contaminants from construction waste or transport



- *Open loop*: recovery of clean GW scrap for beneficial reuse in new non-GW products including agricultural soil amendment and paper reuse, use as a cement additive, and other uses occurs today via bilateral agreements.
  - Secondary use markets may require additional processing or manufacturing

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GW Recycling Process & Standards

- The majority of post-consumer GW waste today is disposed of in approved construction demolition (C&D) landfills
- Gypsum's mineral composition does not substantially degrade during recycling; therefore, GW recycling is of keen interest as a means of avoiding environmental impacts of landfilling, e.g., potential hydrogen sulfide gas emissions and diminished landfill capacity
- Demolition or deconstruction GW waste may be contaminated during finishing and lifetime use via paints, chemicals and other materials (e.g. lead, asbestos, affixed metal, and wood) and requires testing to be viable for recycling into closed or open loop processes
- Contamination of clean scrap GW also occurs if the clean scrap is not managed and stored properly at construction job sites, during transportation, and at recycling facilities prior to processing
- ASTM Standard Guidelines C1881 provides three options for closed-loop recycled gypsum materials:
    1. Known Source (e.g., take back program or directly supplied product)
    2. Visible Identification or Source Tracking (chain of custody documentation)
    3. Source Quality Assurance (testing program/protocols for chemical content as agreed upon between recycler and manufacturer)

GW Recycling Process & Standards

- Physical processing of GW scrap to recycled gypsum generally requires:
  - Separation of paper from gypsum
  - Grinding to meet recycled end use specifications (size, moisture, content)
  - Additional permitting of existing operations due to potential air quality, noise, and other local environmental concerns
  - Testing protocols (according to end-use pathway) on a bilateral agreement (between recycler and user) basis
- Source separation at construction site
  - Jobsite source separation reduces contamination risk from mixed construction waste
  - ASTM C1881 provides standard guidelines for closed loop source separation only
  - Guidelines for open loop source separation do not currently exist
- Hauling and transport
  - Weight and distance of GW and processed recycled gypsum are the key factors for cost, convenience, and environmental impacts
  - Stationary processing sites favor proximity to end-use customers (manufacturers, agricultural demand centers) rather than to geographically variable scrap sources (new construction sites)
  - Future mobile processing may favor proximity to scrap sources
  - Currently gypsum processing is conducted at stationary sites, typically located near secondary use markets
  - Mobile processing technology is not yet commercially available in the U.S. and appears to be an early emerging technology solution globally

Separation of paper backing (Source)

Wallboard crusher (Source)

Processed recycled gypsum (Source)

GW Recycling Process to Panel Manufacturing Process

GW RECYCLING PROCESS OVERVIEW

Manual and mechanical magnetic separation + major contaminant removal

Using a series of screens to separate gypsum from paper and any other contaminants

Sorting & Processing

Screening & Separation

01. 02. 03. 04. 05.

Clean Scrap GW Received

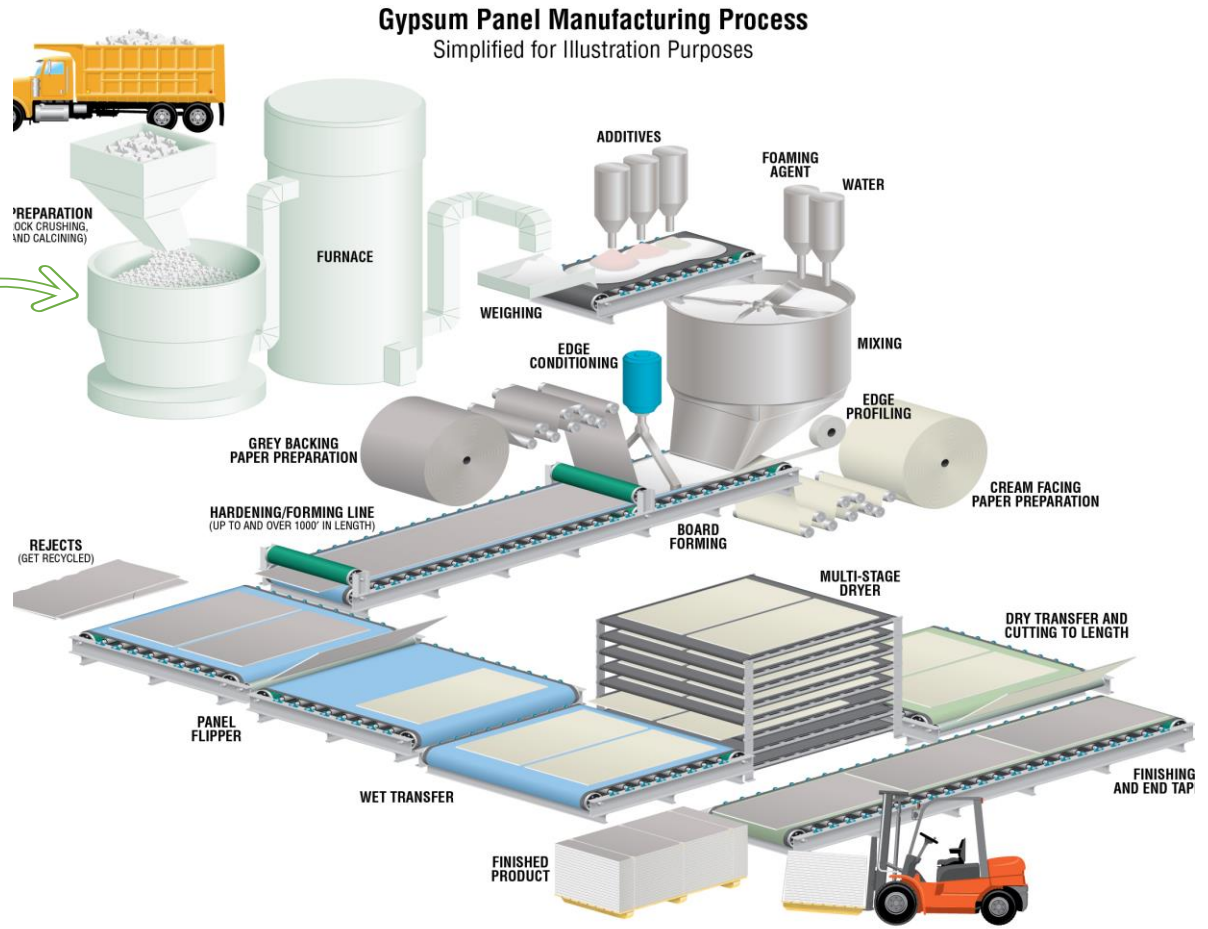
Per Waste Acceptance Criteria (WAC) + proper site source separation practices

Size Reduction

Crushing, grinding, pulverizing to break up wallboard into gypsum powder and separate paper + process to desired end use particle size

Evaluation & Testing

Resulting recycled gypsum is evaluated and may be sampled and tested per agreed upon protocols for purity, moisture, size, etc.; Protocols differ for recycling (closed and open loop) end uses



Source: Gypsum Association

Recycled GW that meets product performance testing protocols (e.g., purity, free moisture, and particle size) and is free of contaminants can be added into the "stucco preparation" phase of panel manufacturing. At this time, only a relatively limited percentage of recycled gypsum has been shown to effectively replace raw virgin gypsum without compromising the product performance. This can vary by product and manufacturer processes as well.

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GW Recycling Pathway Processes

The pathways and processes for recycling GW clean scrap differ:

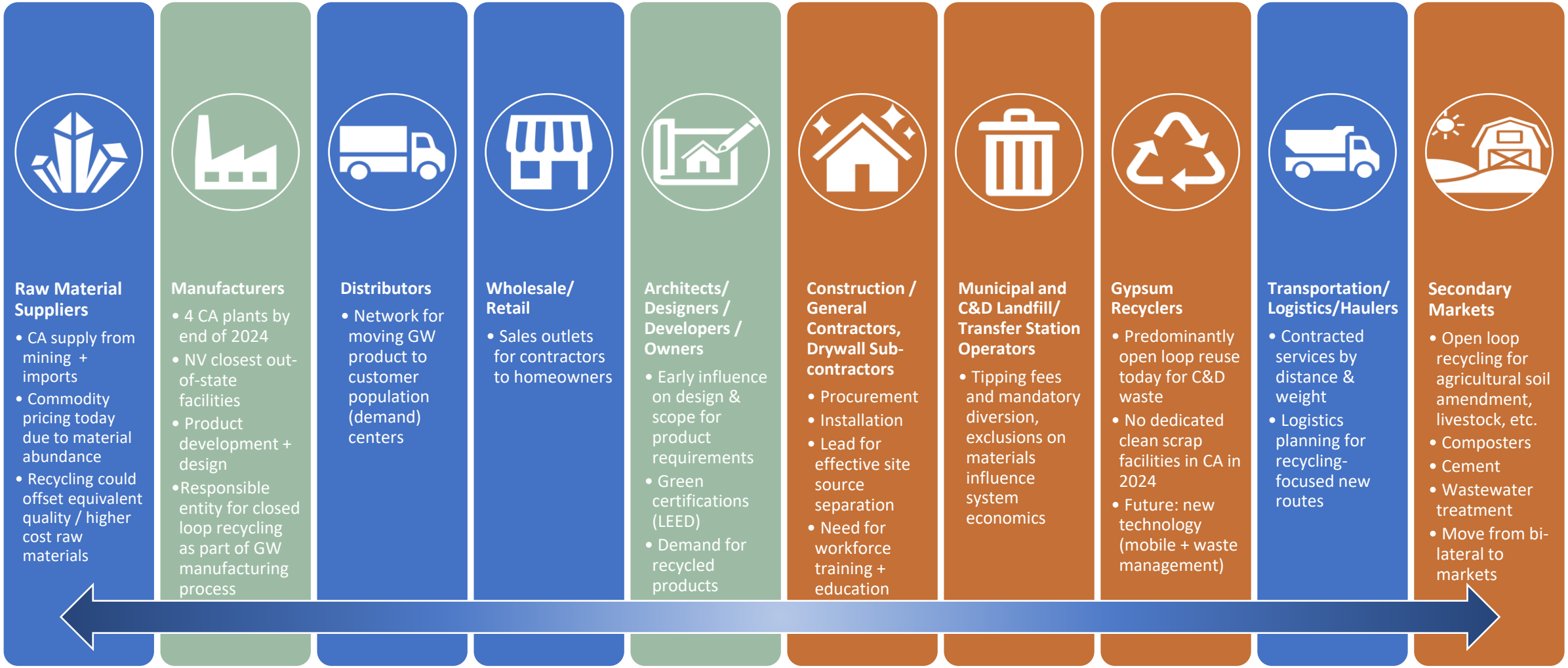
Closed Loop Recycling Pathway

- Incorporating recycled gypsum into new GW products requires additional management and testing processes
  - Product performance
  - Manufacturing equipment performance
- Jobsite source separation for GW is currently not standard/common practice across the building industry
  - Responsibility for onsite separation may vary by jobsite: (general contractor, drywall contractors and installers, haulers, etc.)
  - Workforce education and training is needed for proper handling practices
- Clean scrap GW jobsite source separation is a minimum best practice to achieve viable material recovery
  - Currently, no minimum jobsite guidelines exist for separation of GW for standardized waste acceptance criteria (WAC) for use in processing clean scrap
  - GW manufacturers maintain different chemical acceptance criteria by facility, which would trigger requirements for recycled gypsum material acceptance at the facility level

Open Loop Recycling Pathway

- Agricultural soil amendments and recycled paper
  - Moderately stringent contamination limits to ensure food grade standards met
  - Compost, livestock (bedding / poultry litter) and other applications in addition to direct soil amendment
  - Recycled gypsum prohibited for use in organic farming operations
- Mixing into portland cement
  - Least stringent contamination requirements, but must comply with applicable EPA and product technical specifications
  - Bound into solid state material; may be a future option for demolition GW waste
  - Gypsum material/volume demand unclear, as the amount of material that could be added to cement is limited to less than 5%

GW Recycling Key Stakeholders



Role/Impact on Future of Gypsum Recycling

- = neutral/pass through
- = key role in *early* process changes
- = key role in *later* process changes

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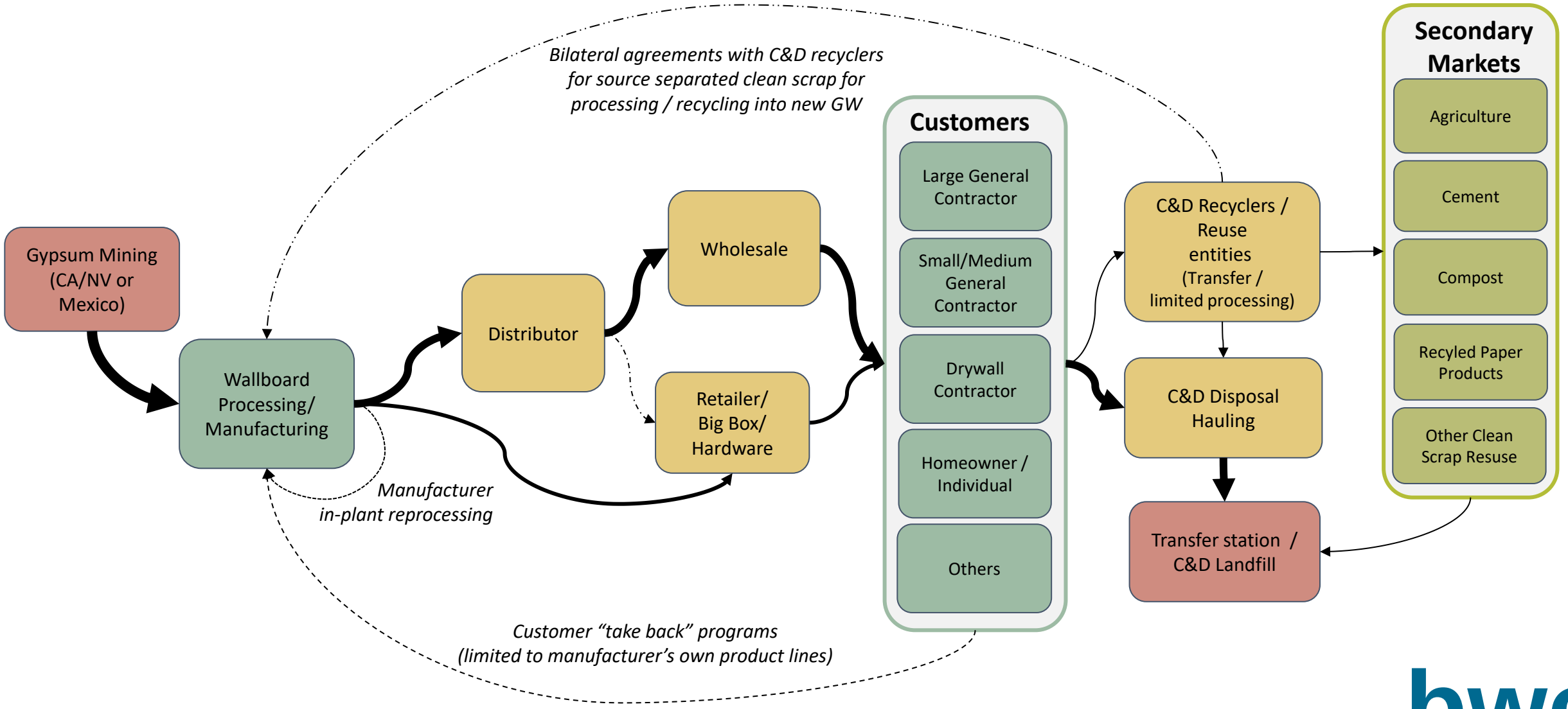
Overview of GW Flows in CA



Line weights and continuity indicative of gypsum material flows (not to scale)

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CA Gypsum Wallboard Industry

Current Snapshot +

GW Recycling Considerations, Choices & Challenges

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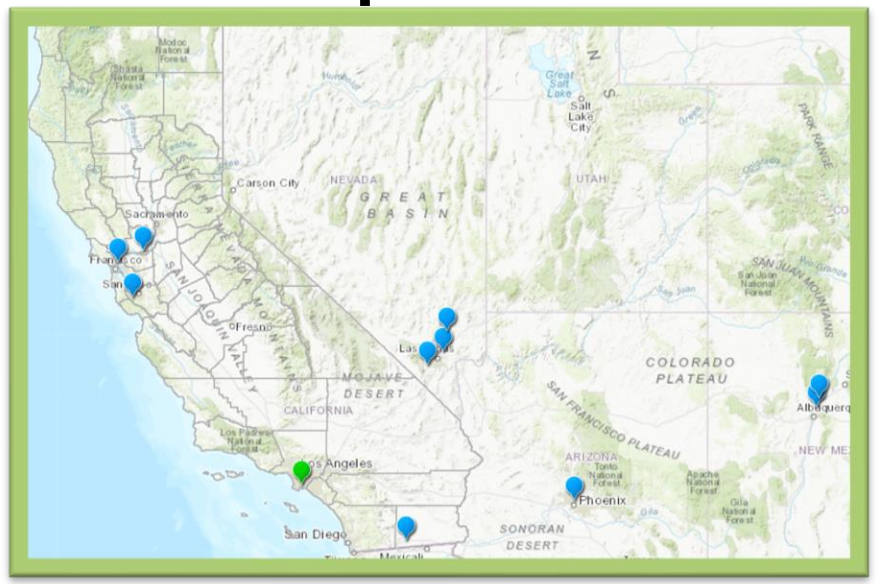
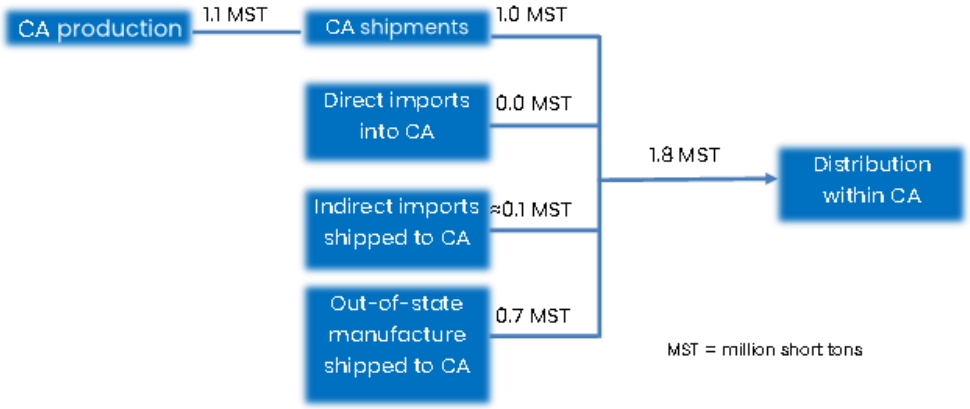
California GW Industry: Current Snapshot

- 4 GW manufacturing plants in state (*blue markers*)
  - Long Beach facility due to close by 2025 (*green marker*)
- Las Vegas, NV and Southwest regional facilities can supply from out-of-state
- A 2023 Gypsum Association material flow study determined that in 2019, 1.8 million short tons of GW were distributed in CA for new construction of new residential and mixed-use multi-family buildings, major remodels, tenant improvement projects, seismic upgrades, and non-residential developments across the state
- Distributor network supplies GW product to CA population centers (demand) as construction activities shift geographically over time
- Facility manufacturing, in-house reprocessing capability, and recycling varies across manufacturing sites, largely influenced by:
  - Raw material sources (on-site mined, shipped, freight-hauled or recycled)
  - Product mix: multiple specialty board product types (SKUs) versus primarily standard GW board production lines
  - Urban space with local permitting constraints vs rural locations with more expansion opportunities
  - Transportation systems: proximity to port shipping, truck or rail freight options
  - Access to clean scrap waste from sources within viable (cost/convenience) hauling distances



GW Manufacturer Facilities (CA & Southwest, US) (Source)



2019 California GW Material Flows- **million short tons (MST)** (Source)

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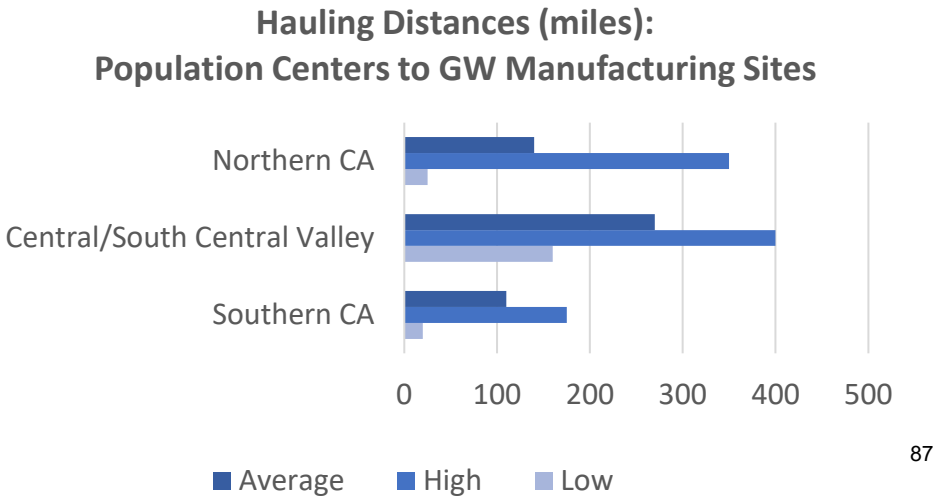
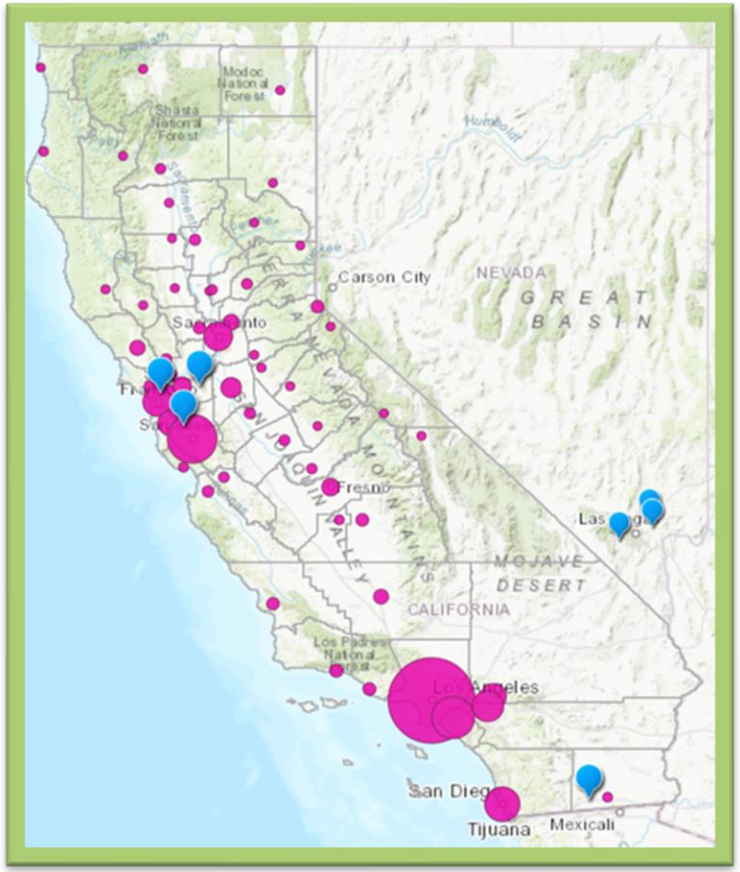
California GW Industry: Current Snapshot (continued)

- The 2023 material flow study, found that GW manufactured for the California markets was distributed in 2019 as follows:
  - ~60% Southern CA
  - ~40% Northern/Central CA
- Clean GW scrap is generated at installation sites where new construction is occurring near population centers. State population centers are shown by indicative size (*pink circles*) relative to manufacturer locations (*blue markers*)
- Average distances from population centers back to current manufacturer sites varies greatly across the state (average >100 miles)





CA Population Centers and Manufacturer Facilities (Source)

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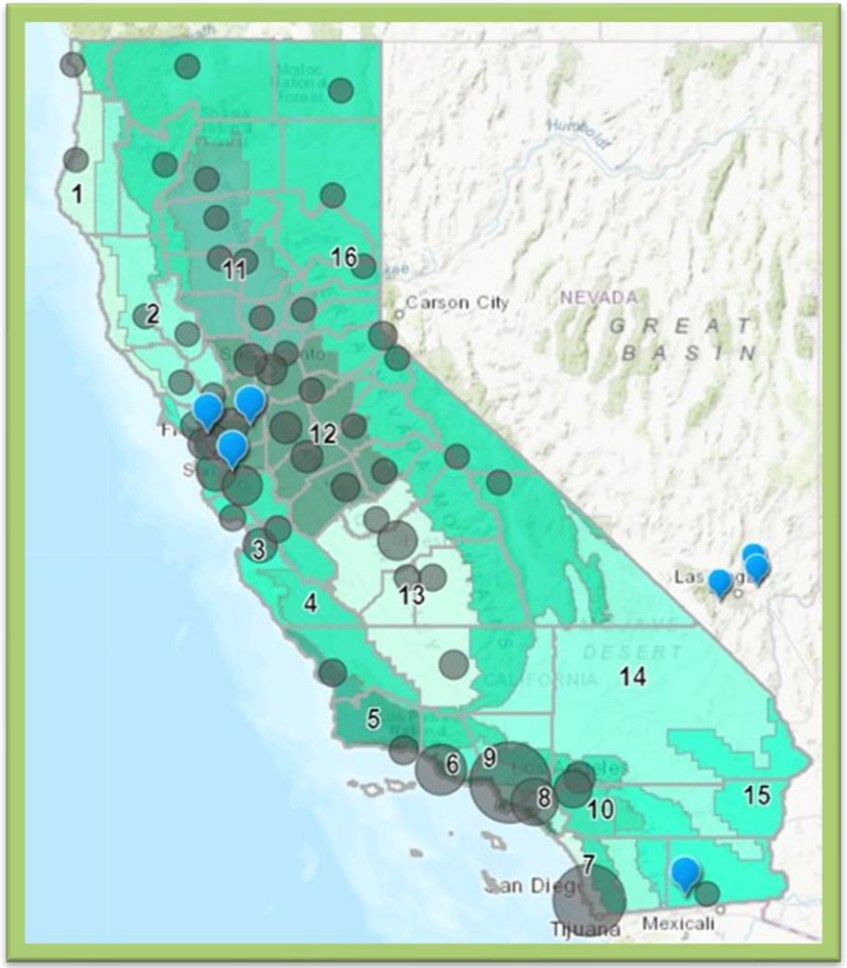
California GW Recycling: Considerations

- Forecasted new construction in CA concentrated in North and South/Central, California and greater San Diego
- California Energy Commission's (CEC) Demand Analysis Office forecasts residential and non-residential new construction to estimate energy usage for new building code updates, delineating CA into 16 climate zones
  - Publicly available data used for statewide planning in other agencies and is updated with forecasted new construction growth centers.
- 9 of the 16 climate zones show significant forecasted new construction (*grey* ***circles***) for 2026 (the date the new building codes will take effect)
  - Remainder are remote, mountainous, or otherwise limited population centers GW distribution, use, and clean scrap generation is anticipated to follow similar distribution patterns across the state
- The high concentration of forecasted construction growth in the southern part of the state indicates that future clean scrap will be generated at significant distances from most of the in-state manufacturing facilities (*blue* ***markers***)



CA Climate Zone Map + Population Centers + GW Manufacturer Facilities (Source)

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California GW Recycling: Considerations

- *Closed loop*: No standalone processing facilities for GW closed loop recycling operate in CA today
  - Majority of clean scrap is landfilled in C&D landfills (*purple circles*)
- *Open loop*: Recycling entities provide services for C&D waste diversion programs and limited closed loop recycling GW services (on a bilateral agreement basis)
  - There are 7 sites in CA that list GW recycling services (*green diamonds*) - concentrated in Northern California
  - Higher likelihood of contamination from mixed construction waste loads
- Aspects of the CA market that impacts recycling
  - Mined raw gypsum rock is the primary source for California GW manufacturing market and is a plentiful, commodity resource
  - Distances from GW manufacturing plants to customers can be significant (>100 miles on average)
    - For closed loop recycling, return trip hauling and freight distances are a major influence on life cycle environmental impacts
    - Transportation / hauling costs for clean scrap vary by origin to destination (landfill, GW recycling) distance
  - Most new construction (and clean scrap source) is occurring near major agricultural regions of the state
  - Cost differential between landfill tipping fees and recycling options varies across regions
  - Open loop recycling contributes to important CA industries
    - Agricultural (gypsum & paper)
    - Portland cement secondary open loop recycling use
  - CA permitting requirements for processing facilities
  - Environmental justice concerns for siting of new or expanded processing facilities

C&D Recycling Facilities Accepting GW + C&D Landfills + Manufacturer Facilities (Source)

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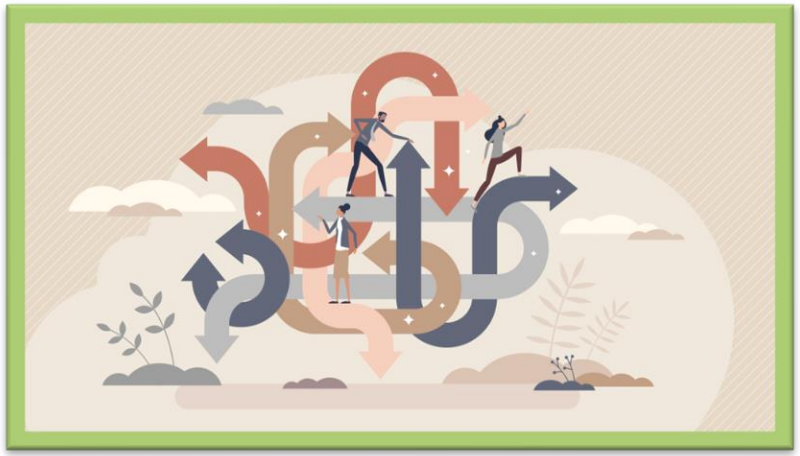
California GW Recycling: Choices + Tradeoffs

Stakeholders across the GW recycling system are faced with numerous choices and trade-offs to determine the best course of action

Manufacturers

- ESG/sustainability goals
- Operational impacts
  - Hauling/freight costs
  - Reduced volume/lower cost raw material purchasing
  - Reliability of input material quality and volume
  - Energy and processing resources
  - Product performance and material management
- Customer support for LEED certification or other project metrics
- Customer take back requests



Key Market Stakeholders

- Customer choice: homeowners /architects
- Designing for reduced clean scrap
- Mandatory C&D waste diversion plans
- Transportation/freight and fuel costs
- Landfill tipping fees/materials exclusions for contractors/haulers
- Recycling processing equipment cost; permit fees for new facilities or added capacity
- Recovery (e.g., jobsite source separation) and processing operating costs

Regulators/Standards Bodies

- Carbon reduction goals
- Affordable housing goals
- Standardization of different pathways for material flow tracking / accountability
- Workforce development and training
- Creating incentives or mandates
- Closed loop and open loop recycling programs
- Supporting transparent market development over bilateral agreements

California GW Recycling: Challenges

- Geographic range
  - High costs of transporting materials:
    - Proximity to source of clean scrap and recycling/reuse markets determines economic viability
  - Environmental trade-offs
    - Achieving high recycling rates for clean scrap may result in higher emissions from fuel and energy use
- Contamination
  - Even with strong site waste management and diversion plans, GW clean scrap can be contaminated during recovery, transit, and processing
    - Moisture, unknown additives, and other mixed debris (metals, plastics, wood) could negatively impact an entire batch of new GW if contaminated materials are mixed with slurry
  - Quality management systems and testing protocols along with waste acceptance protocols will need to be standardized and enforced for widespread adoption of closed loop recycling
  - Workforce education & training and new construction site, transport, and recycling processes (e. g., ASTM guidelines) needed for closed and open loop recycling to scale
- Resource Availability
  - Consistency of recycled product availability for manufacturing
  - How much clean scrap is sufficiently clean to meet agreed upon waste acceptance criteria
  - Potential tension among multiple stakeholders:
    - Efficient building design (building owners/tenants/architects minimizing/eliminating scrap), and end use scrap availability (contractors/installers/recyclers/recycled GW users)

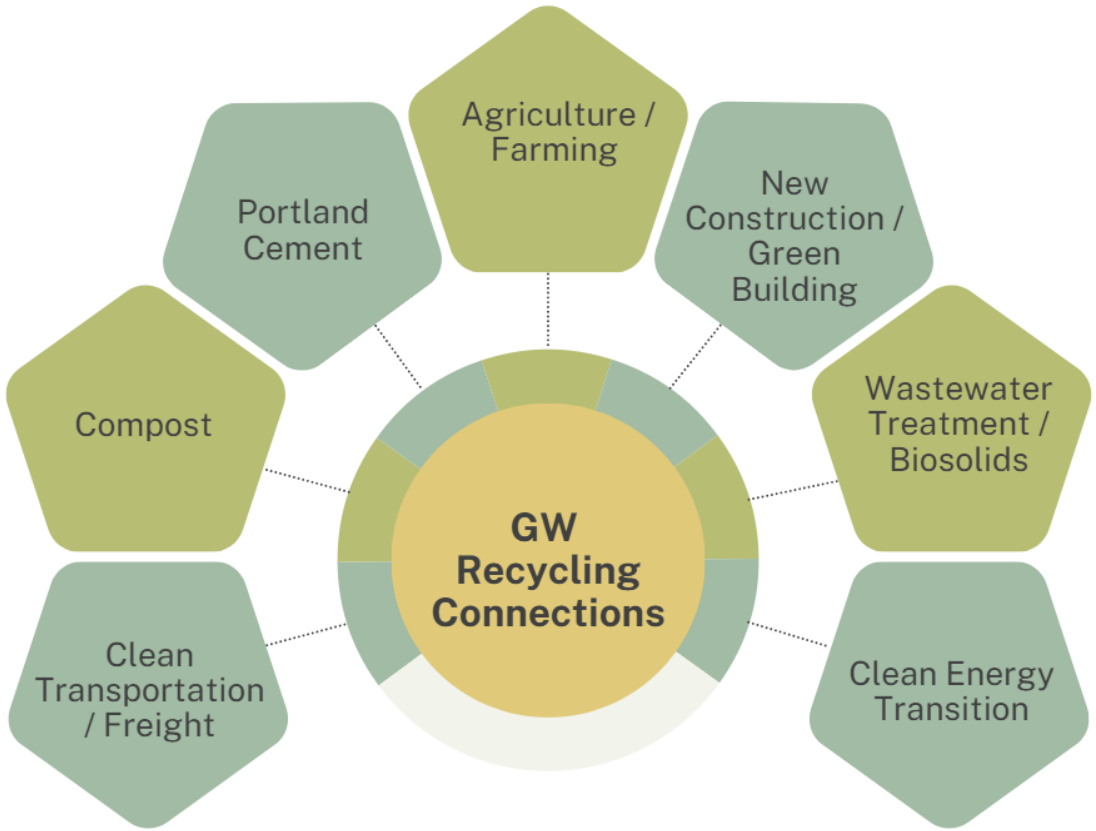
CA Gypsum Wallboard Recycling Assessment

Market Connections

CA GW Clean Scrap Recycling Assessment Overview

- California's history of population growth and associated built environment has led to today's standard industry practices for GW supply to meet non-uniform statewide demand.
- Key factors for assessment of future recycling scenarios for GW clean scrap in CA:
  - Geographic range of GW distribution to population centers from manufacturing sites
  - Links to other CA industries and markets
  - Environmental impacts and trade-offs for transporting gypsum and GW materials
- This assessment examines current recycling practices based up on the 2019 material flow analysis conducted on behalf of the Gypsum Association.

California GW Recycling: Connections



- The technical, economic, and environmental viability and sustainability for GW recycling requires connections among California industries
- Development of these connections will drive opportunities for technically feasible, environmentally beneficial, and cost-efficient recycling scenarios
- Evolving technology, regulations, and business models
  - Fire safety/wildland urban interface (WUI) construction
  - Mobile/technology-enabled processing solutions
  - Clean energy transition
  - Land use/environmental justice
  - Housing policy

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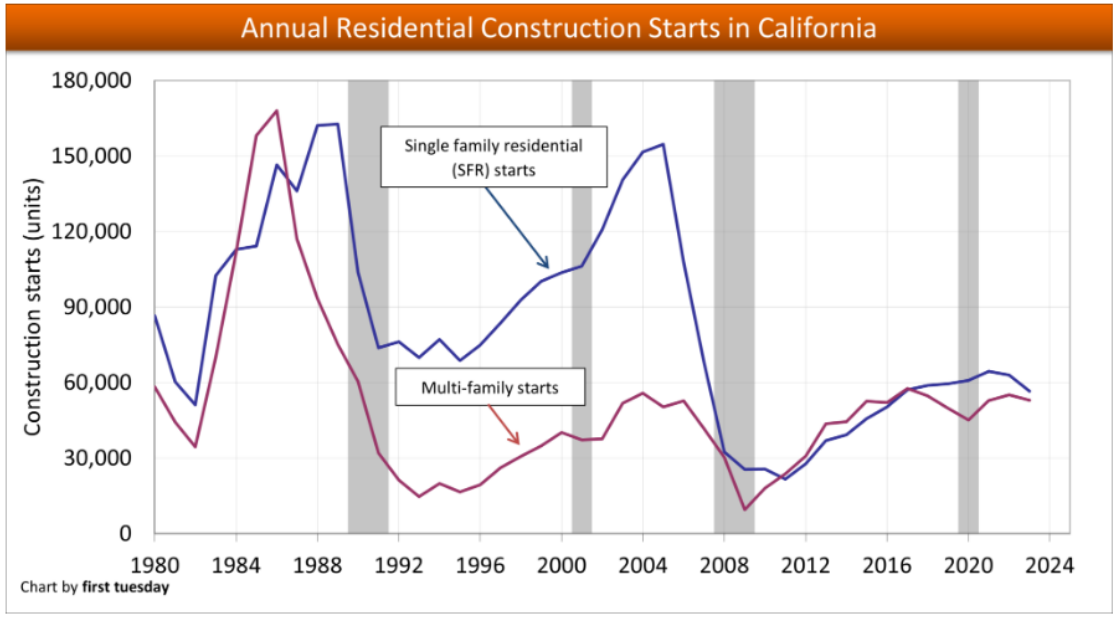
GW Connections: New Construction

- GW product demand directly tied to new construction, major renovation and remodel
- Historical data for new construction starts/permits provides insights from which to base near term forecasts
- Longer-range forecasts vary
  - Year-over-year
  - Location
  - Local or state policies
- Forecasts exclude anomalies (e.g., market downturn, pandemic, wildfires)
- Recycling assessment included California Energy Commission new construction forecast (source)



Historical California Residential New Construction (Source)

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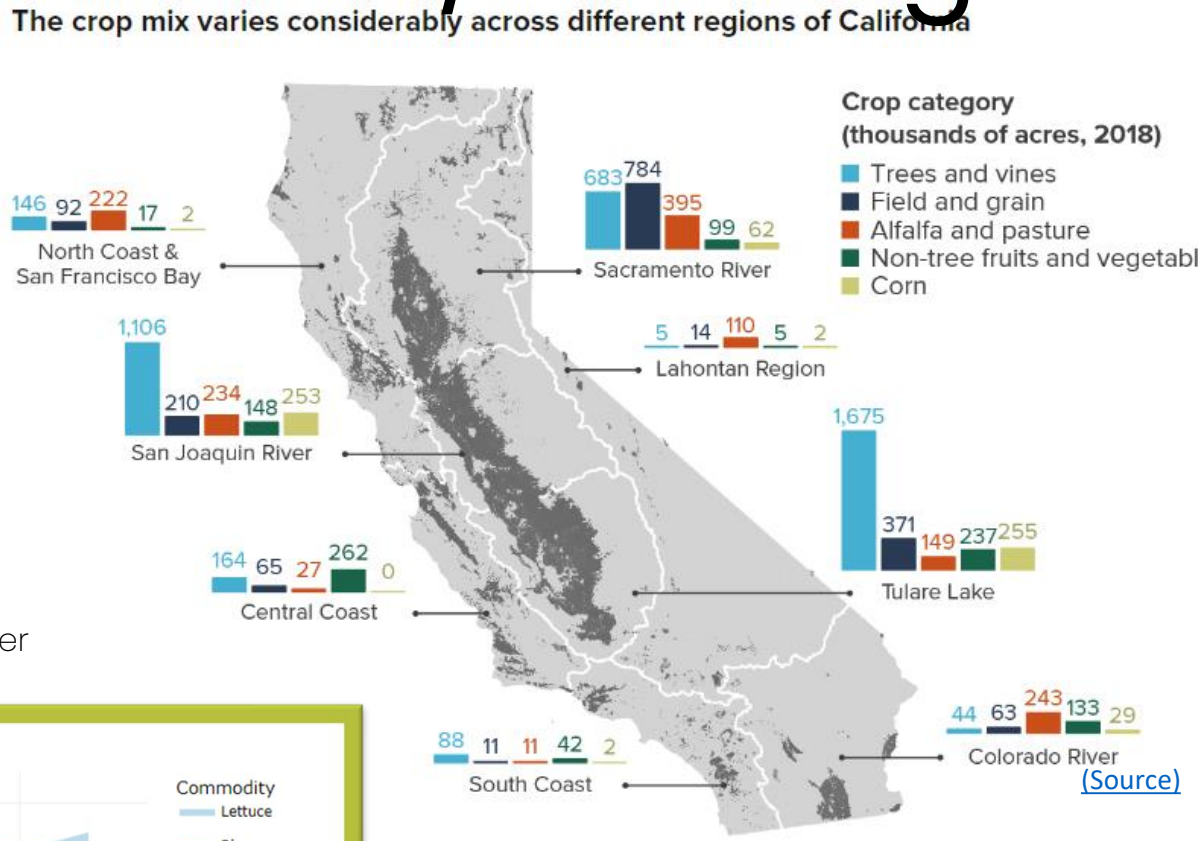
GW Connections: Agriculture/Farming

- CA farmers currently buying/using gypsum products
  - 1.03 million short tons applied to agriculture in 2023 (source)
- Gypsum soil amendment (source)
  - Reclaiming high sodium/low calcium soils – common issues found in Central Valley soils
  - Supplying sulfur to California's sulfur-deficient soils
  - Reducing acidity in soils associated with repeated use of ammonium-based fertilizer
  - Improving water infiltration, root system establishment, and overall nutrient uptake by reducing soil compaction
  - Increasing crop yields
- Agricultural regions adjacent to population centers are used in the assessment to determine hauling distances
- Recycled gypsum is not an allowable soil amendment for organic farming per the National Organic Program (NOP) (Source)



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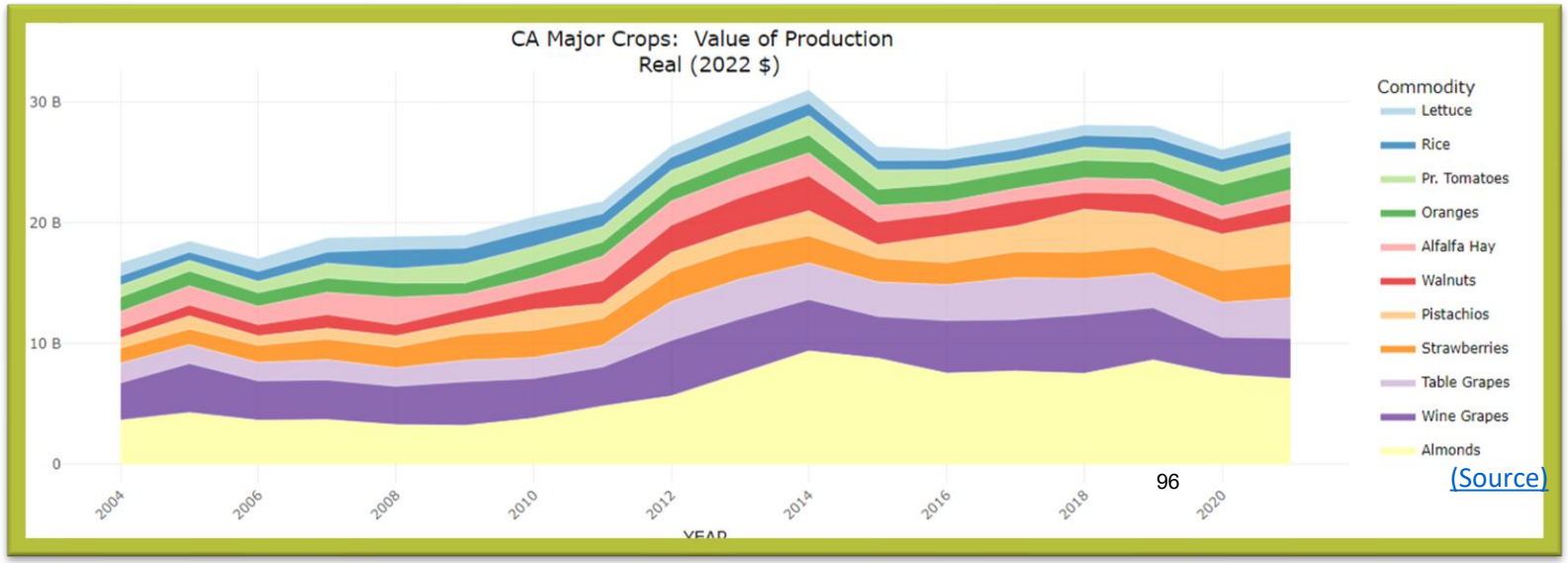

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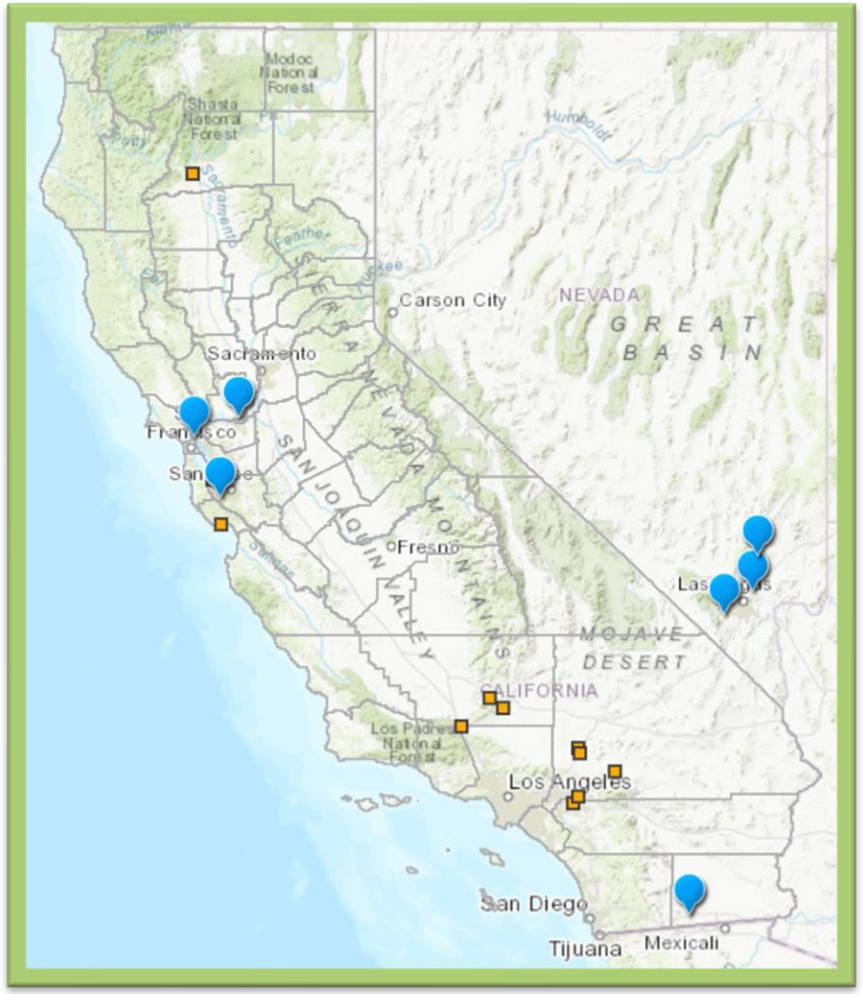
GW Connections: Cement Industry



CA Cement Manufacturers (*gold squares*) + GW Manufacturer Facilities (source)

- Cement production is concentrated in Southern California and recycled gypsum has been used in the production of portland cement (a key component of concrete).
- Cement industry similarly linked to other CA markets (source):
  - New construction and infrastructure
  - Clean transportation and hauling
  - Clean energy transition
- Assessment uses public locations for operational cement plants in CA
- Gypsum in cement manufacturing:
  - *"The general process by which cement is manufactured today entails quarrying and crushing or grinding of the raw materials – commonly limestone or chalk, and clay – which are then combined and passed through a kiln in the form of either a dry powder or a wet slurry. For this reason, cement production is localized around geological resources and cannot be easily relocated. Kiln temperature is more than 1,500°C. The heat fuses the raw materials into small pellets known as clinker. The cooled clinker is combined with gypsum and ground into the fine powder known as Portland cement."*
  - *"Finish Grinding: The nodules of clinker are finely ground in ball mills, ball mills combined with roller presses, roller mills, or roller presses to produce powdered cement. At this stage, a small amount of gypsum is added to control the setting properties of the cement."* (source)

GW Connections: Compost Producers

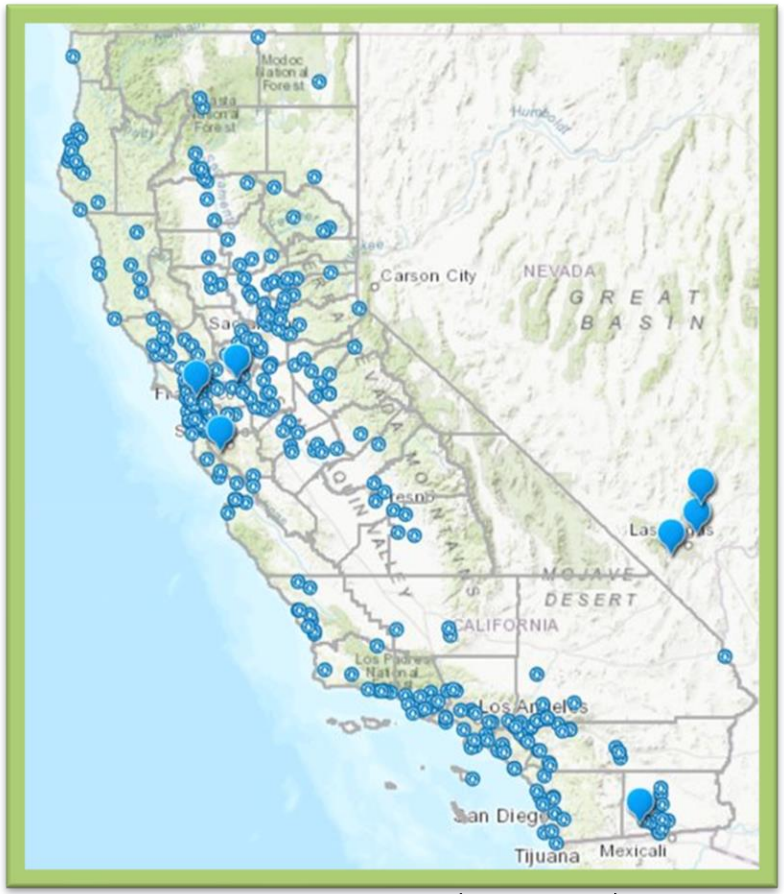
California Composting Facilities (*black stars*) + GW Manufacturer Facilities (source)

- Recycled gypsum blended into commercial compost
  - Bulking agent to absorb excess moisture
  - Increase calcium, sulfur, and carbon
  - Absorb odors
  - Buffering agent and help neutralize acidic compost mixtures
  - Reduce ammonia and nitrogen losses
- Compost with recycled gypsum cannot be used for organic farming
- If composting becomes universal across California, this secondary end-use recycling market could generate significant demand for gypsum clean scrap

GW Connections: California Wastewater Treatment (Biosolids)

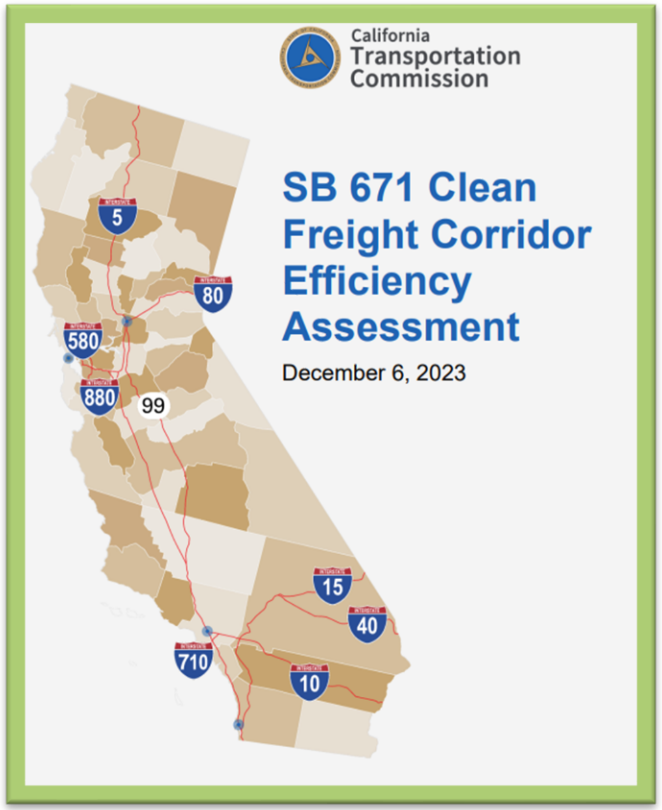
Gypsum is used to absorb various contaminants in wastewater or other bodies of water

- Suspended clay particles that cause turbid water (source)
- Fluoride, commonly found in groundwater (source)
- Pharmaceutical micro-pollutants such as ibuprofen (source)
- Wastewater treated with gypsum typically results in nutrient-rich biosolids providing a low-cost alternative to synthetic fertilizers
    - Concern that biosolids applied to agriculture pose potential human health and environmental threats from toxic substances in wastewater that are carried over to the resulting biosolids (source)
    - USDA prohibits use of biosolids in organic agriculture similar to the prohibition on recycled gypsum (source)



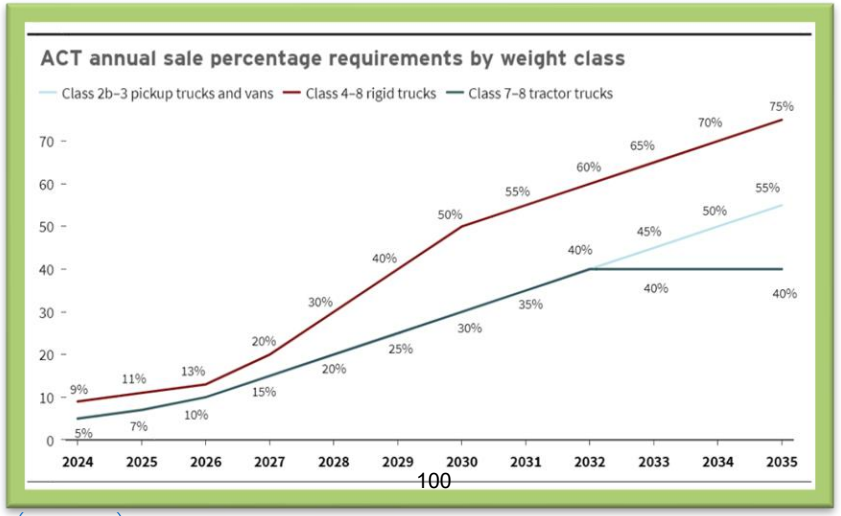
California Wastewater Treatment (*blue circles*) + GW Manufacturer Facilities (Source)

GW Connections: Trucking/Shipping/Rail Freight



(Source)

- Primary environmental impact of GW recycling scenarios is carbon emissions (as well as other air emissions) from GW clean scrap transportation
- Planned adoption of low/zero emission trucking and freight technologies will reduce environmental impacts of recycled GW transport
- The assessment uses current average EPA emissions factors calculated for trucking distances, while noting that CA clean transportation policies will influence this average in the future (source, source)



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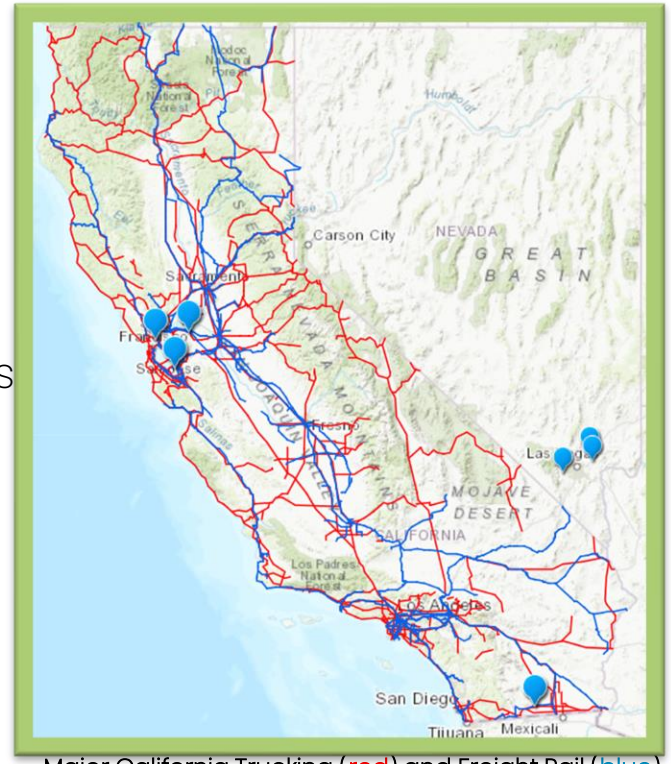

Major California Trucking (red) and Freight Rail (blue) Routes + GW Manufacturer Facilities (Source)

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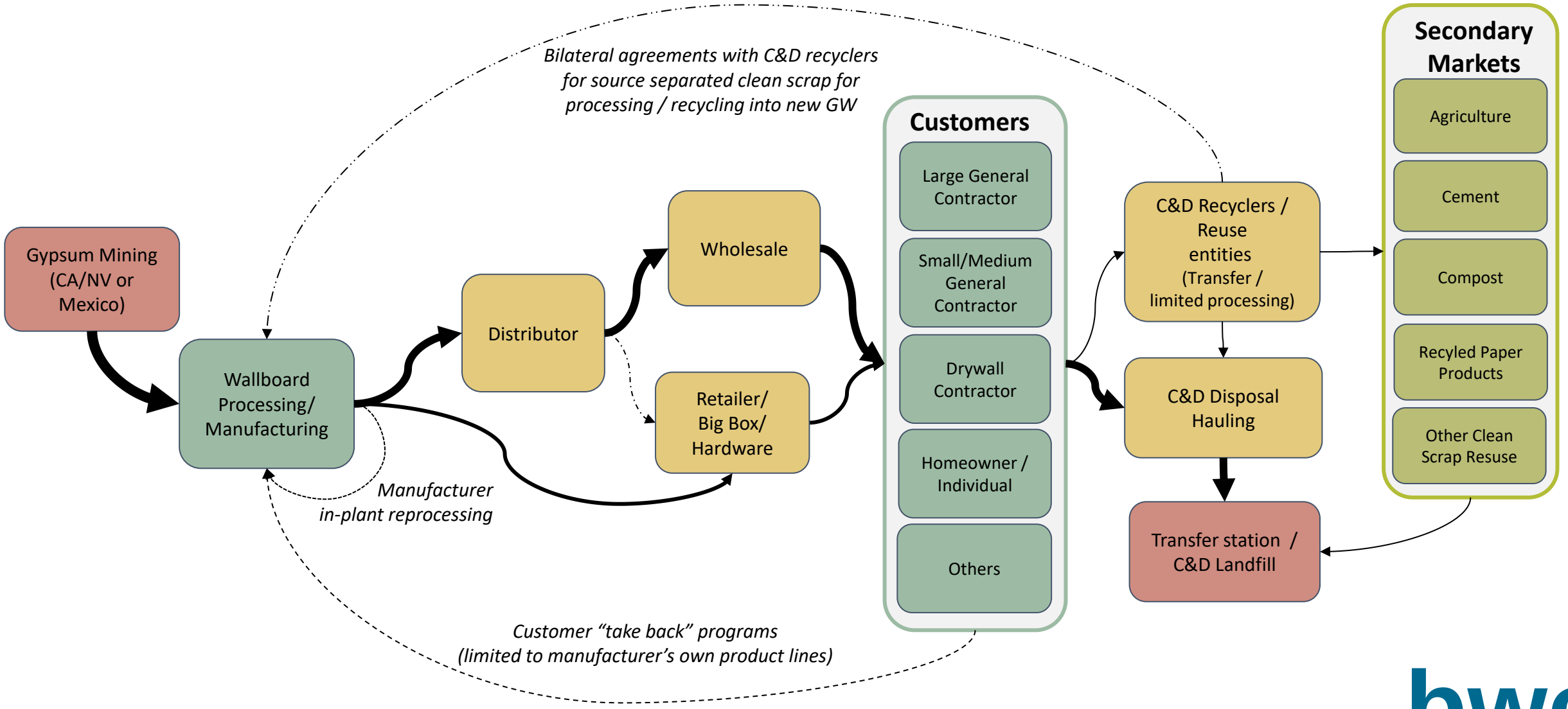
CA Gypsum Recyling Statewide Assessment

CA GW Recycling Statewide Assessment

- Assessing the environmental, economic, and technical impacts of clean scrap GW recycling scenarios in California
  - Environmental
    - Calculating the carbon emissions impacts from truck transport of GW clean scrap from source to disposition
  - Economic
    - Calculating the costs of truck transport of GW clean scrap + landfill tipping fees versus C&D recycling fees
  - Technical
    - Identifying potential recycling for open loop connected end-use markets in addition to closed loop GW recycling plus evolution of recycling and process technology
- Industry drivers
  - Limited current landfill capacity and challenges in siting new landfills
  - Ongoing need to meet new housing, and commercial, industrial, and institutional development demand
  - Mitigating system environmental impacts
- Demolition GW waste is not considered as part of the scope of this assessment due to
  - Higher likelihood of product contamination
  - Dispersed geographic and temporal forecasting of source material

Current GW Material Flow (Revisited)



Line weights and continuity indicative of gypsum material flows (not to scale)

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2019 (Current) Assessment

Assumptions

- 95% Post-Consumer Clean Scrap GW to Landfill
- 4% to Agricultural Secondary Markets
- 1% to Manufacturers
- Current Scenario uses 2023 Material Flow Analysis data
- Only higher scrap volume CA counties included

Disposition	Material Pathway	2019 Tons Clean GW Scrap	Tons CO2e	Transportation Cost ($)	Landfill Tipping Fees ($)	C&D Recycling Fees ($)	Recycling Savings ($)
Landfill	Disposal	133,586	506	7,061,378	15,298,731	-	-
Agriculture	Open Loop Recycling	5,625	95	553,892	-	464,034	165,435
Manufacturer	Closed Loop Recycling	1,406	34	469,524	-	116,009	45,031

Category Key:

- Disposition: Destination for GW clean scrap flow
- Material Pathway: Type of recycling or disposal
- Tons Clean GW Scrap: Short tons (annual basis)
- Tons CO2e: Tons of carbon dioxide equivalent (GHG unit of measurement)
- Transportation Cost: $/mile trucking rate x miles traveled from jobsite to disposition
- Landfill Tipping Fees: $/ton x short tons disposed of at nearest C&D landfill to jobsite
- C&D Recycling Fees: $/ton x short tons recycled at regional facility
- Recycling Savings: Landfill tipping fees - C&D recycling fees

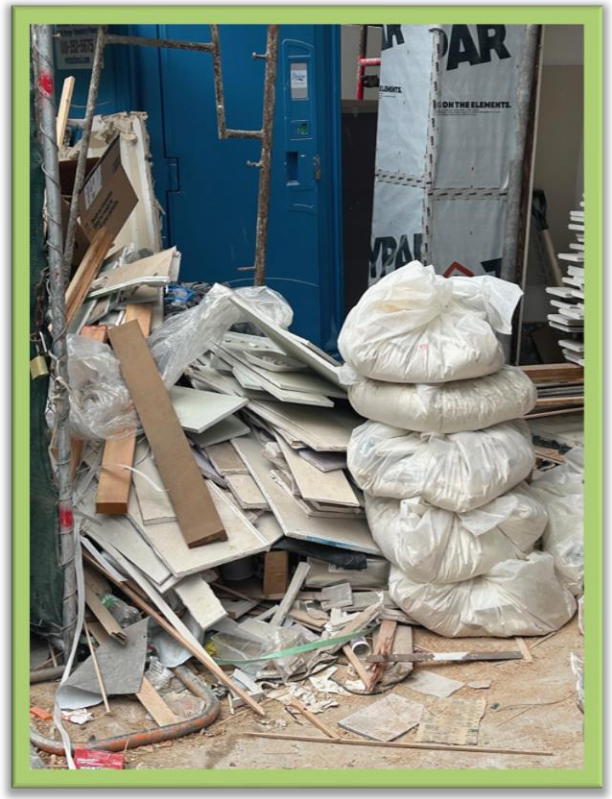
Expanding CA Recycling & Processing Capacity

- Additional processing capacity would be required to achieve increased system recycling of GW throughout the state
  - Expanding capacity of existing C&D recycling facilities already equipped for open loop recycling to secondary customer end-use markets (e.g., agriculture)
  - New, stationary gypsum recycling/processing facility siting
  - Added manufacturer capacity (space and process constraints allowing)
- Business model considerations (for new/enhanced closed loop recycling facilities)
  - Siting close to
    - Clean scrap generation sources
      - Population growth centers
      - New construction sites
      - Rail/freight main lines
    - End-use customer markets:
      - Manufacturer facilities for closed loop recycling
      - Agricultural customers for open loop recycling
      - Portland cement/compost/wastewater for potential future open loop recycling markets
  - Capital costs
    - Processing Equipment
      - Typical range from $1.5M - $2M with CA expected at higher end
      - Additional air handling equipment (for retrofitting existing operations)
    - Mobile site equipment: front-end loaders, trucks, etc.
      - Variable costs by site: processor size, number of vehicles, used/new
      - Diesel vs.. electric powered vehicles
      - Actual prices can range widely: $5,000 - $150,000+

Example Stationary Gypsum Recycling Processing Equipment (Source)

Expanding CA Recycling & Processing Capacity (continued)

- Business model considerations (for new/enhanced closed loop recycling facilities) continued
  - Operational costs
    - Building/storage space (lease/buy)
    - Labor & training
    - Permitting/regulatory requirements
    - Energy and fuel
    - O&M
  - Run-time/shifts/scheduled maintenance
  - Hauling clean scrap from source and to end-use customer (open or closed loop) is the largest ongoing operational cost variable
- Owner/operator models for (private, public, public/private partnerships)
- Potential incentives, subsidies, or permitting paths to encourage increased processing capacity
- Advanced tracking and waste management tools
- Workforce training and development for jobsite source separation
- Mobile gypsum processing equipment is not yet commercially available in U.S.



Jobsite source separation of GW (source: Sydney Miyasaki)

CA GW Recycling:
Statewide Market Investments & Considerations

	Capital Costs	*Operational Costs*	*Environmental Considerations*	*Technology Maturity*	*Additional Considerations*
Manufacturer - Internal Processing	New or expanded processing & air handling systems; material handling equipment	Labor; fuel/energy; O&M	Additional permitting; increased trucking; local environmental justice/land-use	Operational at some manufacturers today	Process changes; space constraints for source separation; potential to reduce costs of raw materials purchases, operations, truck freight, and landfill tipping fees
Centralized, Stationary Dedicated Gypsum Processing	Processing equipment system; material handling equipment	Lease/mortgage; labor; O&M; testing	Additional permitting; increased trucking; local environmental justice/land-use	Available today in US and globally (not CA) for closed loop processing	Site selection within CA; GW scrap availability and truck freight costs
Expanded, Stationary C&D Recycling Facility Processing	Processing equipment & air handling equipment; material handling equipment	Labor; fuel/energy; O&M; testing	Additional permitting; increased trucking; local environmental justice/land-use	Available today in US and globally (not CA) for closed loop processing	Space and siting for source separation; increased landfill diversion
Mobile Processing Units	Mobile units (pricing varies depending on configuration and throughput)	Labor; fuel/energy; storage; O&M; testing	Permitting; hauling	Emerging solution	Mobile processing could be stand-alone business or combined with stationary
Other Technology (e.g., waste tracking platforms)	Minimal	SaaS fees; labor	Potential to reduce impacts from hauling through enhanced management practices	Exists for high value materials; continued emerging solutions	Does not address physical material management
Workforce Education & Training	Minimal	Depends on scale; labor; travel	N/A	Dovetail with existing training	Jobsite source separation is key operational change for successful scale

Key Findings & Conclusions

Key Findings

- Cost-effective recycling of clean scrap GW for landfill diversion is highly dependent on
  - Proximity from the source (construction sites) to recycling processing facility
  - Maintaining consistent jobsite source separation practices
  - Leveraging both closed and open loop recycling pathways
- Environment-effective recycling of clean scrap GW is highly dependent on
  - Minimizing transport distances from sources (construction sites) to recycling processing facilities and then to end-uses of the recycled material
  - Maintaining consistent jobsite source separation practices to maximize clean scrap that meets WAC standards, thereby reducing waste from processing facilities going to landfills
  - Leveraging both closed and open loop recycling pathways to achieve reductions in carbon impacts compared to landfilling
- Any future expansion of either open or closed loop GW clean scrap recycling will require thoughtful consideration and judgement of the trade-offs between cost and environmental factors
  - Differential between landfill tipping fees and C&D recycling fees
  - Hauling distances between jobsite waste generation and recycling/disposal options
  - Continued availability of viable secondary use markets gypsum and improved visibility and accountability.
  - Workforce education and training across stakeholder ecosystem

Conclusions

- The GW ecosystem today is a complex and multi-stakeholder environment with unique recycling options to consider
- The assessment of today's current practices across California indicates that additional modeling of specific potential recycling scenarios to determine the appropriate balance of cost and environmental impacts is a critical next step.
- Areas for policy makers and industry leaders to consider include:
  - Aligning industry stakeholders to best manage recycling across local geographies
  - Considering phased approaches that link to key markets: new construction and transportation
  - Examining paths to cost-efficient increases in recycling processing capacity
  - Maintaining or growing existing open loop recycling for CA agricultural industry
  - Expanding recycling guidelines and waste acceptance protocols
  - Considering environmental justice for future siting of processing facilities
  - Encouraging continuous technological innovation and behavioral best practices in California's C&D recycling ecosystem

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California Gypsum Material Flows for Life Cycle Impact Analysis and Recycling Assessment:

Emerging Research for California Policy Makers

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