Rice Residue: Potential Use Cases in the Sacramento-San Joaquin Delta

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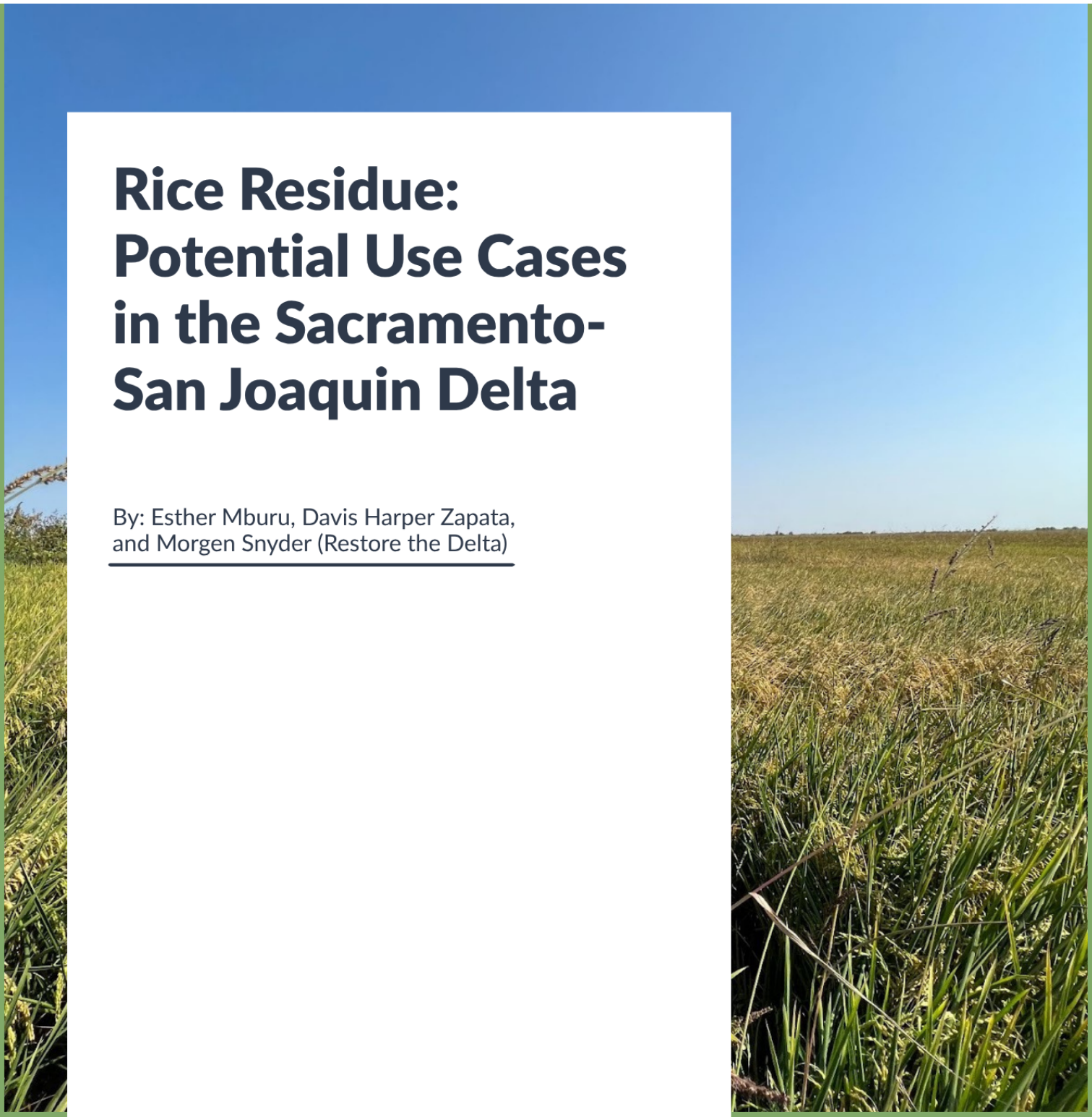

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1. Introduction

1.1 Context of The San Joaquin Delta

The Sacramento–San Joaquin Delta sits at the confluence of California's two great river systems, covering approximately 738,000 acres, of which over 400,000 acres are in active agricultural production. This confluence marks the northwestern boundary of the North San Joaquin Valley region, which is emerging as an ideal location for scaling biomanufacturing given its proximity to large-scale agricultural production and food processing and regional centers of technology innovation in the neighboring San Francisco Bay Area. The Delta's vast waterways connect Northern California to global trade networks, with two inland deepwater ports; five highways; three railroads; and hundreds of miles of natural gas and high-voltage transmission lines, oil and gas wells, and water supply infrastructure (forebays, pumps, and other water control structures).

As the largest freshwater tidal estuary of its kind on the west coast of the Americas, the Delta also provides critical habitat for birds on the Pacific Flyway and for keystone fish species, like the Chinook Salmon, that live in or pass through the Delta. For more than a decade, the State Water Board has recognized that the Delta is in a state of ecological crisis and has promised to update outdated 1995 water quality standards to ensure healthy and thriving Delta waterways.

Formed over roughly 10,000 years by the accumulation of peat and alluvial sediment, the Delta was once a vast freshwater tidal marsh. The Delta's organic soils, which are the peat-rich stretches that define the central and western Delta, formed from centuries of decomposed plant matter under anaerobic, waterlogged conditions. Beginning in the 1850s and largely completed by the 1930s, laborers and reclamation districts built more than 1,100 miles of levees, draining hundreds of thousands of acres of wetland to create farmable islands separated by channels and sloughs.

Today the Delta's fertile peat soil produces an estimated $965 million in agricultural crops annually, making it one of the most productive farming regions in the United States by crop value per acre (Metropolitan Water District of Southern California [MWD], n.d.). This productivity has come with significant costs to land stability and climate, and is now causing a shift in conventional agricultural practices and crop selection.

Once drained for agriculture, these peat soils are exposed to oxygen, triggering carbon oxidation and releasing CO_2. Peat soil oxidation has resulted in significant land subsidence: over time, some Delta islands have sunk by as much as 25 feet below sea level. Subsidence increases stress on vulnerable levee systems and creates ongoing drainage costs for farmers (Deverel et al., 2020; U.S. Geological Survey [USGS], n.d.). Without major levee restoration in the next 25 years, more than $10 billion worth of farmland, homes, businesses and infrastructure, and $2 billion in annual economic activity are at severe flood risk (Delta Stewardship Council, 2021).

In addition to being a structural concern, subsidence has direct consequences for the quality and reliability of water supply in California's north-to-south water delivery infrastructure, which serves over 27 million people across Central and Southern California. Maintaining the integrity of Delta levees and slowing peat oxidation are therefore both local and state-level priorities (Jay Lund, 2021).

1.2 Why Rice? The Case for Flooded Cultivation

Rice has emerged as a strategic defense against subsidence. The controlled flooding of fields creates anaerobic conditions that limit the microbial oxidation of organic material, and consequently inhibit subsidence (Mount, 2005). While most crops cannot grow under flooded conditions, rice is an exception, as it possesses a unique cellular structure that allows oxygen to diffuse through the plant even when roots are submerged.

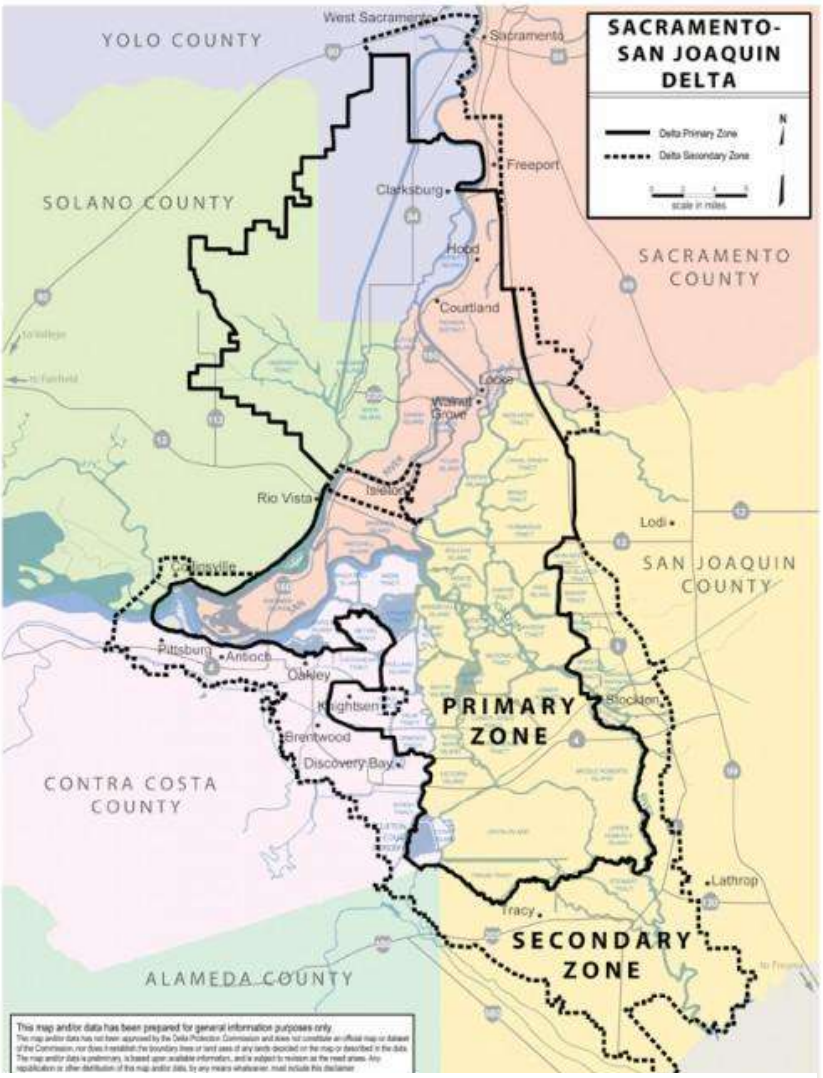

Fig 1: Map of the Sacramento San Joaquin Delta, primary and secondary zones (*Source:* Delta Protection Commission, 2020).

Research conducted at Staten Island (Hydrofocus, Inc.) in the Delta has demonstrated that flooded conditions during rice cultivation can significantly reduce, and in some cases arrest, soil carbon loss. Flooded rice cultivation essentially restores the anaerobic conditions under which peat soils originally formed, keeping carbon in the ground rather than releasing it into the atmosphere. This makes rice farming in the Delta not just an agricultural activity but a potential tool for carbon management, levee protection, and ecosystem restoration for migratory birds on the Pacific Flyway.

California grows approximately 500,000 acres of rice statewide, with 95% concentrated in the

Sacramento Valley. The San Joaquin Delta (Fig 1) is an emerging contributor: from just 3,000 acres in 2017, Delta rice acreage has grown to approximately 15,000 acres in 2024–2025, a fivefold increase in eight years. This rapid expansion reflects both the agronomic fit of rice in the Delta environment and growing recognition of its environmental co-benefits (University of California Agriculture and Natural Resources, 2024).

1.3 What residues does rice cultivation produce, and how are they currently managed?

As rice production expands across the Delta, so does the volume of agricultural residue it generates. Each harvest produces several distinct streams of biomass. Rice straw, the stems and leaves left after the grain is collected, accounts for the largest share by volume. The 2024 San Joaquin County rice harvest generated over approximately 50,000 tons of rice straw, by author's estimation.

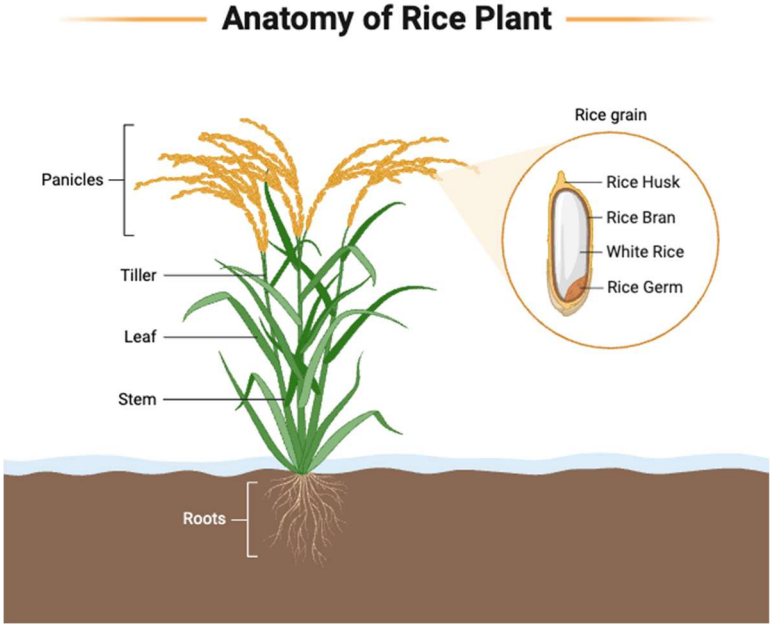

Fig 2: Anatomy of Rice (*Source: Huang, E. 2026*)

Open-field burning was historically the standard method of rice straw disposal in California, but this practice was significantly restricted by the state in 1991 to reduce air pollution (California Air Resources Board, 1991). As of 2025, only 20% of rice straw may be burned, and only where demonstrably necessary for weed control of specific grass species (San Joaquin Valley Air Pollution Control District, n.d.). This puts significant pressure on farmers to find alternative pathways for residue management.

At the same time, California's statewide rice harvest generates approximately 1.5 million tons of straw annually. This is a resource that already supports emerging industries including medium-density fiberboard manufacturing, biofuels, and biogas production. Most of this infrastructure, however, is concentrated in the Sacramento Valley, where the rice industry is mature.

The rice milling process additionally generates three byproduct streams. An ideal milling process produces approximately 20% husk, 8 to 12% bran depending on milling degree, and 68 to 72% milled or white rice depending on variety (IRRI, n.d.-a). The hull (also called the husk) accounts for 20% of paddy weight, and an efficient husker should remove 90% of it in a single pass (IRRI,

n.d.-b). Rice bran is generated when brown rice moves through the whiteners and polishers; 100 kg of paddy rice will generate approximately 5 to 10 kg of bran, which is a mixture of protein, fat, ash, and crude fiber (IRRI, n.d.-c). Broken rice (grain fragments produced during milling) is recovered as a separate stream, though the proportion varies by variety and milling operation.

These byproducts differ from straw in two important ways. First, they are generated at centralized milling facilities rather than dispersed across farm fields, making collection and routing structurally simpler. Second, most already have established markets, with bran and broken rice used in livestock feed and food, and hulls used in energy generation and construction materials (California Rice Commission Rice Co-Products, 2026). The total potential value from these streams is not currently captured, however, as Delta acreage grows, the volumes of these co-products will become increasingly significant (Sanoja-López, 2024).

In the San Joaquin Delta, the rice industry is still in its expansion phase, with no grain mill in the region and limited aggregation or processing infrastructure. Additionally, in contrast to the Sacramento Valley, land and ecosystem conditions in the San Joaquin Delta necessitate significant incorporation of field residues (i.e. straw) as soil amendments to buffer land subsidence, reduce Greenhouse Gas (GHG) emissions, and support habitat for migratory birds.

These factors create both a challenge and an opportunity: the Delta is generating increasing volumes of residue without the infrastructure to use it, but it is also in a position to build that infrastructure correctly from the start, learning from the experience of Sacramento Valley farmers and bioproduct developers.

1.4 Research Questions

This paper investigates four core questions, which structure the findings and recommendations that follow:

1) Feedstock reliability: Does the San Joaquin Delta consistently produce sufficient rice residue in volume, quality, and seasonality to support pilot-scale bioproduct applications?

2) Uses: What bioproduct pathways are currently viable or emerging for rice straw, hulls, bran, and broken rice, and which are the strongest fit for the Delta context?

3) Infrastructure: What processing, aggregation, and logistics infrastructure is currently present in the Delta, what is missing, and what would be needed for regional-scale application?

4) Viability: Under shifting economic, behavioral and policy conditions, what is the broader value-add of investments in rice cultivation and local processing infrastructure across industries, including but not limited to Delta farmers, local industry, and water agencies with vested interest in the Delta?

A secondary aim of this paper is to identify the gaps in current literature and practice that would most benefit from future research, farmer engagement, and institutional investment.

2. Methodology

This paper is based on a desk research approach as well as institutional knowledge from the work that Restore the Delta has done over the years on sustainable agriculture in the Sacramento-San Joaquin Delta region.

Restore the Delta's Sustainable Agriculture Program (SAP) supports sustainable farming practices to ensure the Delta remains farmable for future generations. The program promotes subsidence reduction, soil health improvement, and workforce development while connecting farmers to cost-saving solutions, technical assistance, and community resources. Launched in 2022, SAP began with a farmer survey to better understand Delta farmers' needs, perceptions, and challenges. Outreach reached more than 4,000 individuals, with 17 farms completing the survey. Findings revealed several important themes: high operational costs and labor shortages as persistent challenges, low trust in government support and local agencies, and awareness gaps around carbon sequestration and new practices, as well as widespread support for subsidence reduction efforts.

No primary data collection was conducted beyond limited informal conversations with Delta farmers and logistics experts. The paper additionally draws from Restore The Delta's longstanding institutional knowledge working with farmers over the past two decades.

2.1 Desk Research Approach

Research was conducted by reviewing publicly available sources including peer-reviewed literature, UC Cooperative Extension crop reports, California Energy Commission biomass assessments, industry technical reports, market references, and port and trade data. Sources were selected to answer four questions: the volume and consistency of residue supply, current and emerging bioproduct uses, regional infrastructure gaps, and economic feasibility signals for Delta farmers.

2.2 Source Selection Criteria

Sources were prioritized based on geographic relevance to the San Joaquin Delta or Sacramento Valley rice systems, institutional credibility, and recency (where possible). Where peer-reviewed literature was unavailable for Delta-specific data, UC Cooperative Extension reports and California state agency publications were used as the next best standard. Market signals were drawn from industry reports and company case studies, and are noted as such throughout.

2.3 Limitations

The original methodology was planned for structured farmer interviews. This proved difficult in practice. The farming community is close-knit and cautious about engaging with outside funding partners. The farmers who were approached expressed hesitation rooted in a broader trust deficit between agricultural communities and institutional actors. This gap is noted as both a limitation of this study and a priority area for future engagement.

There is currently no rice processing facility operating in the San Joaquin Delta. All milling data referenced in this paper is drawn from Sacramento Valley operations and applied proportionally to Delta production estimates. A future interview with a Sacramento Valley grain mill operator is recommended to ground-truth these estimates.

Because Delta rice is a rapidly growing industry, some figures – particularly acreage and yield – shift year to year. All data is cited with its source year and should be updated annually as UC ANR crop reports are published.

3. Delta Rice Production & Residue Supply

This section evaluates the amounts, timing, and characteristics of rice residues generated in the San Joaquin Delta. Residue streams include straw, hulls, bran, and broken rice, as they form the foundation of any feedstock strategy. Understanding their quantity, stability, and seasonality is essential to assess whether pilot projects or regional applications are viable in the Delta.

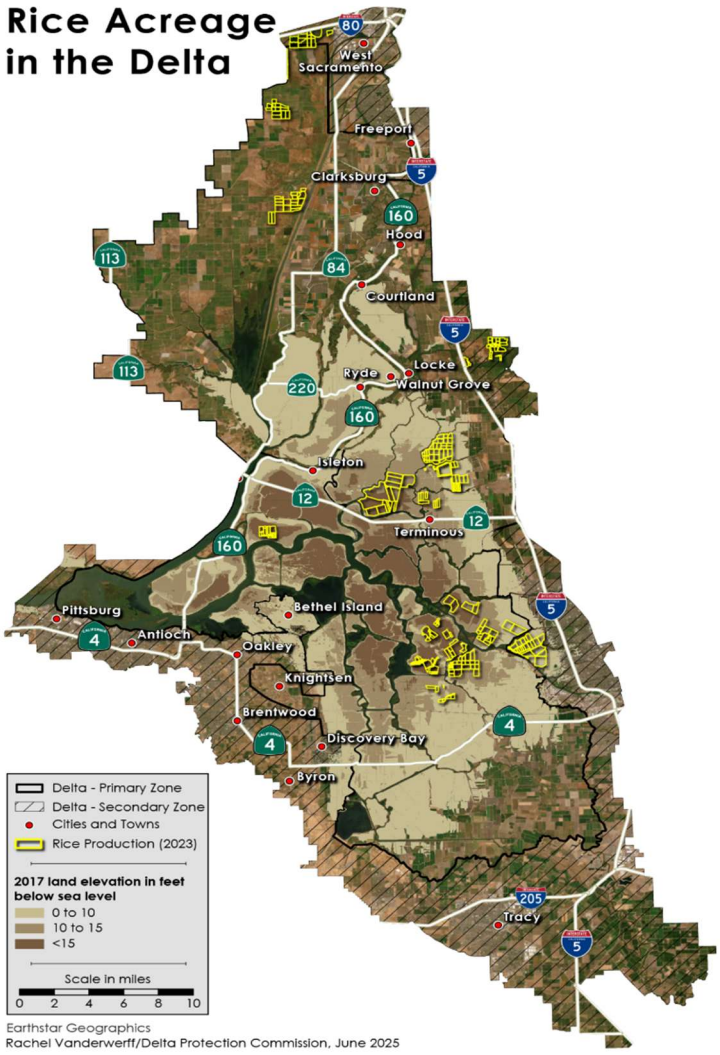

Fig. 3: Rice Acreage in the Delta as of 2023. (*Source*: *Delta Protection Commission, 2025)*

3.1 Rice Acreage & Yield Trends: 1) Does the San Joaquin Delta consistently produce sufficient rice residue in volume, quality, and seasonality to support pilot-scale bioproduct applications?

Production trends and straw estimation:

San Joaquin County has emerged as a significant and rapidly growing contributor to California's Delta rice market, with harvested acreage expanding from 2,700 to 11,600 acres between 2017 and 2024 and production rising from 212,000 to 988,000 cwt (roughly 10,600 to 49,400 short tons) across six NASS annual survey years. Yields remained stable throughout, ranging narrowly from 7,739 to 8,605 lb/acre, suggesting that growth has been driven by acreage expansion rather than productivity gains (USDA, 2017-2024). Using straw-to-grain ratios drawn from Summers et al. (2003) a 1.0:1 baseline reflecting a typical California season and a 1.5:1 planning ceiling reflecting a high-variability year estimated straw volumes for 2024 alone range from

approximately 49,400 to 74,100 short tons(U.S. Department of Agriculture, National Agricultural Statistics Service, n.d.). These figures represent San Joaquin County only, as other Delta counties are partially or fully suppressed in NASS data; a complete Delta-wide picture would require supplemental sources such as CDFA county crop reports or California Rice Commission data (*see* Appendix 2).

Table 1: Production trends and straw estimation[1]

Year	Acres	Yield (cwt/ac)	Yield (tons/ac)	Estimated Straw 1.0:1 (tons)	Estimated Straw 1.5:1 (tons)	Source / Notes
2017	2,700	212,000	10,600	10,600	15,900	NASS Survey
2018	—	—	—	—	—	*San Joaquin suppressed. Other Combined Counties: 6,000 ac, 520,000 cwt (26,000 tons).*
2019	4,300	370,000	18,500	18,500	27,750	NASS Survey. Other Combined Counties also reported: 3,700 ac, 260,000 cwt.
2020	4,600	356,000	17,800	17,800	26,700	NASS Survey
2021	7,000	595,000	29,750	29,750	44,625	NASS Survey
2022	8,561	796,328	39,816	39,816	59,724	*Census only — not annual Survey. CV = 46.6%. Use with caution.*
2023	10,200	860,000	43,000	43,000	64,500	NASS Survey
2024	11,600	988,000	49,400	49,400	74,100	NASS Survey. CV = 9.2%.

This table signals that the San Joaquin Delta consistently generates tens of thousands of tons of grain and a large volume of straw annually. Continued acreage growth further indicates that both residue volume and available feedstock are increasing in scale.

[1] 2022 is excluded because NASS suppressed the annual survey result for San Joaquin County to protect farm confidentiality. The only available figure comes from the Census of Agriculture, a mandatory five-year count that year but with a coefficient of variation of 46.6%, it is not suitable for trend analysis.

3.1.1 Milling Byproducts: Hulls, Bran & Broken Rice

In addition to field residues, rice milling generates three byproduct streams. Byproduct volumes are estimated by applying industry-standard milling ratios (consistent with figures reported by Riceland Foods) to the 2024 San Joaquin County grain tonnage of 49,400 (itself derived from NASS: 988,000 cwt × 0.05) tons: hulls at 20%, bran at 8%, and broken rice at 4%.

Table 2. Estimated milling co-product volumes, 2024, San Joaquin County[2]

Co-Product	% of Grain Weight (Source)	Calculation	Est. 2024 Volume (tons)
Rice hulls	20% (IRRI, n.d.-a; Riceland Foods, n.d.)	49,400 × 0.20	9,880
Rice bran	8–12% (IRRI, n.d.-a)	49,400 × 0.08 to 0.12	3,952 – 5,928
Broken rice	15–25% (IRRI, n.d.-b)*	49,400 × 0.15 to 0.25	7,410 – 12,350

3.1.2 Seasonal & Harvest Considerations

Rice in the San Joaquin Delta is a seasonal crop. Harvest occurs between mid-September and the end of November, concentrating large volumes of biomass generation into a narrow window (Abadam, 2025). This creates several logistical considerations for any residue recovery strategy: limited baling and transport windows before weather conditions affect straw quality, moisture variability affecting storability and end-use suitability, competition for equipment and labor during peak harvest season, and need for aggregation sites near production areas to avoid long transport distances (Kadam et al., 2000).

Milling byproducts, by contrast, are generated more steadily across several months as grain moves through processing facilities. This makes byproduct streams more logistically predictable than field straw, even if volumes are smaller.

Agricultural residue collection is difficult in the Delta due to existing policies and traditional practices.

[2] *(Base: 49,400 short tons grain). Percentages: IRRI (n.d.-a, n.d.-b); Riceland Foods (n.d.). Volumes: authors' calculations.* Broken rice 15–25% = sum of IRRI's separately reported large broken (5–10%) and small broken (10–15%) ranges.*

3.2 Current Residue Management Practices: 2) Uses: What bioproduct pathways are currently viable or emerging for rice straw, hulls, bran, and broken rice, and which are the strongest fit for the Delta context?

After rice is harvested in the San Joaquin Delta, farmers have several options for handling leftover plant material. These decisions affect soil health, field timing, environmental outcomes, and whether residues can realistically be collected for the other uses. Funding programs generally require that certain residues, such as straw, are left on the fields to provide environmental benefits, such as habitat for migrating birds.

This section describes current practices and the tradeoffs involved.

3.2.1 In-Field Retention & Ecological Uses

Public rice conversion incentive programs typically require participating Delta landowners to incorporate post-harvest stubble (i.e. rice straw) and shallow flooding during the fall after harvest, winter, and late winter/spring before planting (Delta Conservancy et. al., n.d.; Bingham, 2026). These management practices are designed to enhance habitat value and food sources for migratory birds in the non-growing season; reduce oxidation and degradation of organic matter in the region; reduce subsidence of peat soils; and reduce greenhouse gas emissions (CDFW, 2026). Farmers may find additional value by leasing flooded rice field acreage to duck hunters, or through the Bird Returns Program, which pays for seasonal flooding to protect shorebirds during key migration periods (Bird Returns, 2026; Heyser, 2025).

Research on Staten Island in the Delta has demonstrated that maintaining flooded conditions including straw incorporation significantly reduces peat oxidation and slows land subsidence (Deverel et al., 2017; Meadows, 2025; Heyser, 2025). Over 4,000 acres of Staten Island have already been converted from corn to rice, with conversion projected to reduce carbon emissions by nearly 600,000 tons by mid-century.

3.2.2 Alternative Uses: Existing & Emerging Markets

While there are some clear established use cases for rice straw in erosion control, construction materials, and livestock bedding, the vast majority of straw accumulated in Delta rice cultivation operations, specifically, should be left on the field after harvest to mitigate subsidence, avoid GHG emissions, and support wildlife habitat (UCANR, 2026; CalFibre, 2026). To that end, this research primarily considers alternative uses of rice milling byproducts: broken rice, rice bran, and rice hulls.

Broken rice has established applications in pet and livestock feed and food industries (e.g. starch, rice flour, processed foods, beer, etc.).

Similarly, rice bran has traditionally been used in feed and food industries (e.g. rice bran oil and its derivatives). That said, it's also been evaluated as a macromolecule source for bioplastic production, due to its high content of starch and proteins, abundance, and low cost (Sanoja-López et al., 2024).

Rice hulls and their combustion byproduct, Rice Husk Ash (RHA), have a range of established and emerging manufacturing applications driven by their unusually high silica content (Barbhuiya, 2025; ScienceDirect, n.d.). Rice hulls originating from Delta farms are predominantly used as a feedstock for electricity generation in direct combustion power plants near milling facilities in the Sacramento Valley (American Commodity Company, 2023). RHA is already used as a partial cement replacement and concrete additive in the construction industry, where it improves workability and reduces reliance on the energy intensive portland cement production. In the advanced materials space, RHA is under active investigation as a feedstock for zeolites, activated carbon, silica gel, and components of lithium-ion batteries and energy storage capacitors (Sulaiman, 2025).

Beyond energy generation, rice hulls also function as effective adsorbents for oils and chemicals, with applications in industrial wastewater treatment (Sanoja-López et al., 2024). One notable commercial use of rice husks involves pyrolytic conversion to biochar for removing metal and organics from water and wastewater, mimicking the function of ion exchange resin beads, a petroleum-based microplastic (Glanris, n.d.).

While most of these pathways are not yet operational at the regional scale in California, the proximity of the San Joaquin Delta to the Port of Stockton and Central Valley construction markets positions the region favorably should aggregation and processing infrastructure develop.

3.3 Infrastructure: What processing, aggregation, and logistics infrastructure is currently present in the Delta, what is missing, and what would be needed for regional-scale application?

On-farm infrastructure has improved considerably as rice acreage has grown. Rice cultivation in the Delta requires significant upfront investments in specialized water management systems, GPS-leveled land, irrigation pipe, gate valves, levee maintenance, and rice boxes (Leinfelder-Miles et. al., 2022). These investments are supported in part by over **$34 million in Nature-Based Solutions grants** from the Sacramento-San Joaquin Delta Conservancy for land leveling and water infrastructure for rice conversion (Heyser, 2025).

After harvest, rice crops are transported by truck to milling facilities in Sacramento County. Once processed and packaged, rice grain products are trucked to the Port of West Sacramento and the Port of Stockton for export into international markets.

Introducing rice milling infrastructure to San Joaquin County, and at the Port of Stockton, in particular, presents a significant opportunity for cost savings and avoiding GHG emissions from

reduced transportation. Such a project could integrate onsite residue management and processing for co-located bioproduct manufacturing, as a cost effective alternative to disrupting current feedstock management practices at existing mills in the Sacramento Valley.

3.4 Viability: Under shifting economic, behavioral and policy conditions, what is the broader value-add of investments in rice cultivation and local processing infrastructure across industries, including but not limited to Delta farmers, local industry, and water agencies with vested interest in the Delta?

Institutional momentum: The Metropolitan Water District's recent move to lease Bacon Island (~5,000 acres) to Lundberg Family Farms for rice cultivation signals growing institutional momentum in the Delta (Metropolitan Water District, 2025).

Behavioral: To sustain reliable feedstock streams from rice cultivation for bioindustrial manufacturing, farmers and landowners require access to clear, trustworthy information on how converting to rice can address rising operational costs and land subsidence. Recent research indicates that Natural Climate Solution projects, akin to rice conversion, that fail to integrate local contexts or meaningfully engage local actors, rightsholders, and other stakeholders may result in inequitable outcomes (Brumberg et al., 2025). Consistent challenges include a lack of opportunity to participate in or influence the implementation due to race, ethnicity, or other dimensions of identity; limited social learning and exchange networks; and difficulty identifying, engaging, or coordinating with relevant actors. These challenges should be addressed to sustain equitable growth of the Delta rice industry, and as part of the pre-development phase for building local rice grain milling and biomanufacturing infrastructure.

Policy infrastructure: The emergence of pro-rice farming policies has seen a substantial rise over the past decade, in conjunction with greenhouse gas reduction goals, habitat restoration, and subsidence reversal efforts. Numerous state agencies have embarked on efforts to encourage a transition to rice farming, including the California Department of Food and Agriculture (CDFA), California Department of Fish and Wildlife (CDFW), the Delta Stewardship Council (DSC), the Nature Conservancy (TNC), and the Delta Conservancy.

The Healthy Soils Program, established in 2015 under Governor Jerry Brown, is a collaborative grant program that promotes sustainable agricultural practices that reduce greenhouse gas emissions (CalCAN, 2026; CDFA, 2026). In 2025, this program recognized the potential for reduction in greenhouse gas emissions in the Delta through rice-cultivation, formally adopting these practices as part of the initiative (Jaquez, 2025).

In 2018, the California Legislature passed AB 2348, the California Winter Rice Habitat Incentive Program, which set up compensation streams for farmers who participate in winter-flooding of rice fields to create habitat for waterfowl and other migrating birds (Cal Ricelands, 2026).

Farmers are required to continuously flood rice fields at 1-12 inches for a minimum of 70 days during the wet season, between October and March. For the 2025-2026 season, there was $860,000 in contracts available to farmers.

Other cross-cutting programs like the nature-based solutions: wetland restoration funding program provided by the Delta Conservancy promotes conservation, climate resilience and restoration in the Delta (Delta Conservancy, n.d.-a; Delta Conservancy, 2023). Eligible projects include rice cultivation due to its ability to reduce subsidence, improve soil health, and create habitat for migrating birds. The original budget allocation, made in 2022, provided $36 million for these projects. With the passage of Proposition 4, additional allocations have become available to grow the existing rice-incentive program under the nature-based solutions program. The bond approved $29 million for projects that reduce the risks associated with climate change, and the first tranche of funding is dedicated to the rice incentive program (Delta Conservancy, n.d.-b).

Overall, the requirements of these programs limit the residue that is removed from the fields. Instead, these programs incentivize farmers to leave certain residue, particularly rice straw, on the fields to decompose over the winter months through flooding, thus creating habitat for migrating waterfowl and shorebird (Heyser, 2025).

The growing breadth of funding programs demonstrates a commitment at the state level to encourage the transition to rice farming, with numerous benefits across environmental, community, and industry perspectives. The Delta Rice Conversion program under the Delta Conservancy originally targeted the conversion of up to 7,500 acres (Delta Conservancy, 2023). With renewed funding streams and continued commitment, this target number is expected to continue to grow.

4. Conclusions & Recommendations

With significant public policy and funding momentum, the San Joaquin Delta is generating a growing and quantifiable volume of rice residues. While the vast majority, by tonnage, of these residues (i.e. straw) is left on the field after harvest for land, climate, and ecosystem benefits, byproducts of rice milling infrastructure present a unique opportunity for regional investment. Rice hulls, the most significant milling byproduct, are emerging as effective adsorbents for oils and chemicals, while rice bran is being evaluated as a feedstock for bioplastic production. Rice grown in the Delta is processed in Sacramento County, and largely exported through the two major ports in the region. The most immediate infrastructure priority is a regional grain mill possibly co-located at the Port of Stockton, which could consolidate milling byproduct streams, reduce transportation emissions, and create a platform for adjacent bioproduct development.

An in-depth economic analysis of residue pathways is a good next step. This should include farm-gate pricing for milling byproducts, infrastructure cost-benefit analysis, and return on

investment estimates for bioproduct pathways identified in this paper so that farmers and potential investors can assess financial viability. Alongside this, a dedicated employment impact assessment for a regional mill and emerging bioproduct industry would strengthen the case for institutional investment. This assessment should also explore cooperative ownership and governance models to ensure equitable distribution of costs and benefits among rice growers, grain mill operators, bioindustrial manufacturing start-up companies, and institutional stakeholders. Future work should also model commodity market volatility for rice co-products, particularly bran and broken rice, to give farmers a more comprehensive picture of revenue reliability. Finally, primary data collection on rice residue management practices specific to the Delta, distinct from Sacramento Valley conditions, should be a priority for the next phase of research.

Section 3.1.1 establishes that supply of feedstock exists and is growing. The demand side, however, remains largely unquantified and undocumented. Beam Circular is well-positioned to address this gap by surveying the start-ups in its network to capture pilot scale feedstock requirements (e.g., volumes, residue types, moisture tolerance, etc.) and providing these figures as baselines for future feedstock matching and infrastructure planning.

4.1 Challenges and limitations of this study

Farmer engagement proved difficult in practice due to longstanding trust deficits between agricultural communities and outside institutional actors, a barrier that is itself a finding worth noting for future work. All milling co-product volumes are extrapolated from Sacramento Valley data rather than Delta-specific operations, as no grain mill currently exists in the region. Market figures for emerging bioproduct pathways reflect global research trends and should not be read as indicators of near-term local market readiness. Production figures cited throughout will also require annual updating as new UC ANR crop reports are published.

Appendicies

Appendix 1

Key Terms and Definitions

Item	Definition
Biochar	A charcoal-like material produced by heating biomass in low-oxygen conditions. One potential end use for rice straw and hulls.
Broken rice	Grain fragments generated during milling, ~4% of grain weight. Established markets in feed and food.
Cwt (hundredweight)	A unit of weight equal to 100 pounds (0.05 short tons). Commonly used to measure rice yields in California.
Feedstock	Raw material used as an input to an industrial or energy conversion process.
Land subsidence	The sinking of the ground surface, caused in the Delta by oxidation and decomposition of drained peat soils.
Rice bran	The thin layer between the hull and the white grain, removed during milling. ~8% of grain weight. Used in animal feed and specialty food products.
Rice hull / husk	The hard outer casing of the rice grain, removed during milling. ~20% of grain weight. High in silica; often used for energy generation.
Rice straw	The stems and leaves of the rice plant remain in the field after grain harvest. The primary residue stream by volume.
Straw-to-grain ratio	Estimated ratio of straw mass to grain mass produced per acre. A ratio of 1.5:1 is used for California rice. (UC ANR, 2010)

Appendix 2: NASS Data

Program	Year	Period	Week Ending	Geo Level	State	State ANSI	Ag District	Ag District Code	County	County ANSI	Zip Code	Region	watershed_code	Watershed	Commodity	Data Item	Domain	Domain Category	Value	CV (%)
SURVEY	2024	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	11,600	8.7
SURVEY	2024	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - ACRES PLANTED	TOTAL	NOT SPECIFIED	11,700	8.3
SURVEY	2024	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - PRODUCTION, MEASURED IN CWT	TOTAL	NOT SPECIFIED	988,000	9.2
SURVEY	2024	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - YIELD, MEASURED IN LB / ACRE	TOTAL	NOT SPECIFIED	8,520	9.2

Program	Year	Period	Week Ending	Geo Level	State	State ANSI	Ag District	Ag District Code	County	County ANSI	Zip Code	Region	watershed_code	Watershed	Commodity	Data Item	Domain	Domain Category	Value	CV (%)
CENSUS	2022	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	FRESNO	019			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	(D)	(D)
CENSUS	2022	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	FRESNO	019			00000000		RICE	RICE, IRRIGATED - ACRES HARVESTED	TOTAL	NOT SPECIFIED	(D)	(D)
CENSUS	2022	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	MERCED	047			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	291	46.6
CENSUS	2022	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	MERCED	047			00000000		RICE	RICE, IRRIGATED - ACRES HARVESTED	TOTAL	NOT SPECIFIED	291	46.6
CENSUS	2022	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	8,561	46.6
CENSUS	2022	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE, IRRIGATED - ACRES HARVESTED	TOTAL	NOT SPECIFIED	8,561	46.6
CENSUS	2022	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	STANISLAUS	099			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	(D)	(D)
CENSUS	2022	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	STANISLAUS	099			00000000		RICE	RICE, IRRIGATED - ACRES HARVESTED	TOTAL	NOT SPECIFIED	(D)	(D)
CENSUS	2017	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	FRESNO	019			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	2,219	(H)
CENSUS	2017	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	FRESNO	019			00000000		RICE	RICE, IRRIGATED - ACRES HARVESTED	TOTAL	NOT SPECIFIED	2,219	(H)
CENSUS	2017	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	MERCED	047			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	1,660	(H)
CENSUS	2017	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	MERCED	047			00000000		RICE	RICE, IRRIGATED - ACRES HARVESTED	TOTAL	NOT SPECIFIED	1,660	(H)
CENSUS	2017	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	2,693	(H)
CENSUS	2017	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE, IRRIGATED - ACRES HARVESTED	TOTAL	NOT SPECIFIED	2,693	(H)
CENSUS	2017	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	STANISLAUS	099			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	(D)	(D)
CENSUS	2017	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	STANISLAUS	099			00000000		RICE	RICE, IRRIGATED - ACRES HARVESTED	TOTAL	NOT SPECIFIED	(D)	(D)
SURVEY	2024	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	11,600	8.7
SURVEY	2023	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	10,200	13.3
SURVEY	2021	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	7,000	8.5
SURVEY	2020	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	4,600	4.7
SURVEY	2019	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	OTHER (COMBINED) COUNTIES				00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	3,700	
SURVEY	2019	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	4,300	
SURVEY	2018	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	OTHER (COMBINED) COUNTIES				00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	6,000	
SURVEY	2017	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	OTHER (COMBINED) COUNTIES				00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	3,300	
SURVEY	2017	YEAR		COUNTY	CALIFORNIA	06	SAN JOAQUIN VALLEY	51	SAN JOAQUIN	077			00000000		RICE	RICE - ACRES HARVESTED	TOTAL	NOT SPECIFIED	2,700	

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