The Digest's 2026 Multi-Slide Guide to Modular Biorefinery Deployment

Where field labour is punishing, prefabrication pays; where it is not, the steel is unrecovered.

Three Ways to Put Steel on a Site

Four distinct routes exist for delivering a biorefinery: stick-built, modular shop-fabrication, large integrated modularization, and conversion of existing assets. Conversion is frequently the most cost-effective but overlooked path. All approaches converge on commissioning a fully operational plant.

Stick-Built Field Construction

Traditional method where all structural steel and equipment are assembled and welded directly on the project site.

Labour-intensive with high reliance on skilled craft labour performing work in often challenging environmental and logistical conditions.

Offers flexibility in design changes but exposes the project to weather delays, safety challenges, and higher field labour costs.

Best suited to sites with abundant skilled labour and accessible conditions where modular transport limits apply.

Shop-Fabricated Modules

Steel and equipment are prefabricated off-site in controlled factory environments, then transported to the site for assembly.

Reduces field labour hours by shifting work to cheaper, more productive shop hours, improving schedule predictability and safety.

Adds costs for extra structural steel, transport logistics, and detailed interface engineering to ensure seamless integration on site.

Limited by transport size and weight restrictions, requiring careful planning for module dimensions and site access.

Modularization of Large Integrated Plants

Involves prefabricating large sections of a complex plant, integrating multiple process units into fewer, bigger modules.

Potential for accelerated construction timelines through high replication and factory learning curves in large projects.

Requires significant upfront engineering coordination and design freeze to manage interfaces across large modules.

Typically suitable for greenfield sites with excellent transport and site infrastructure to handle oversized loads.

Conversion of Existing Assets

A fourth, often-overlooked path involving repurposing or upgrading existing facilities to biorefinery use.

Can drastically reduce capital expenditure by reusing equipment, utilities, and site infrastructure.

Minimizes construction time and risk by avoiding full new builds and leveraging existing operational knowledge.

Highly site-specific and dependent on availability of suitable existing assets, but often the most cost-effective and rapid deployment method.

What Prefabrication Moves, and What It Adds Back

Prefabrication is not an automatic cost discount but a strategic trade. It reduces expensive field labour by shifting work to cheaper shop environments but adds costs in steel, transport, and interface engineering that must be carefully balanced based on site conditions.

Labour Shift: From Field to Shop

- Modular construction relocates labour from the site (field) to controlled fabrication shops, aiming to reduce expensive field labour hours.
- Man-hours decrease from 33.5 million in stick-built field construction to 28.3 million with modular prefabrication.
- Peak site manpower demand drops from approximately 6,000 workers to 3,000, easing on-site resource constraints.
- This shift leverages cheaper, more predictable shop environments, improving labour productivity and reducing weather-related delays.
- Field labour is not eliminated but significantly reduced, highlighting the trade-off in labour allocation rather than a pure cost removal.

Added Costs: Steel, Transport, and Interfaces

- Prefabricated modules require roughly 20% more structural steel to ensure transport durability and modular integrity.
- Additional costs arise from specialized transport frames and logistics to move large modules safely to site.
- Interface engineering complexity increases due to modular connections and the need to integrate modules seamlessly on site.
- Transport constraints such as road width and height limits impose design and cost trade-offs.
- These added costs offset labour savings, making prefabrication a trade-off between labour cost relocation and material plus logistics expenses.

The Number That Decides the Sign

Field labour productivity at the site determines if modularization saves costs or adds premiums. Productivity factors from a modelled LNG plant show modular prefabrication pays only where field labour is scarce or costly. The site decides, not the module.

1.00

Gulf Coast Factor

Baseline productivity at the US Gulf Coast, representing standard field labour conditions with no prefabrication advantage. Modular construction is cost-neutral or a premium here.

1.25

Fabrication Yard Factor

Moderate productivity gain in a controlled fabrication yard, reflecting partial labour relocation from the field.

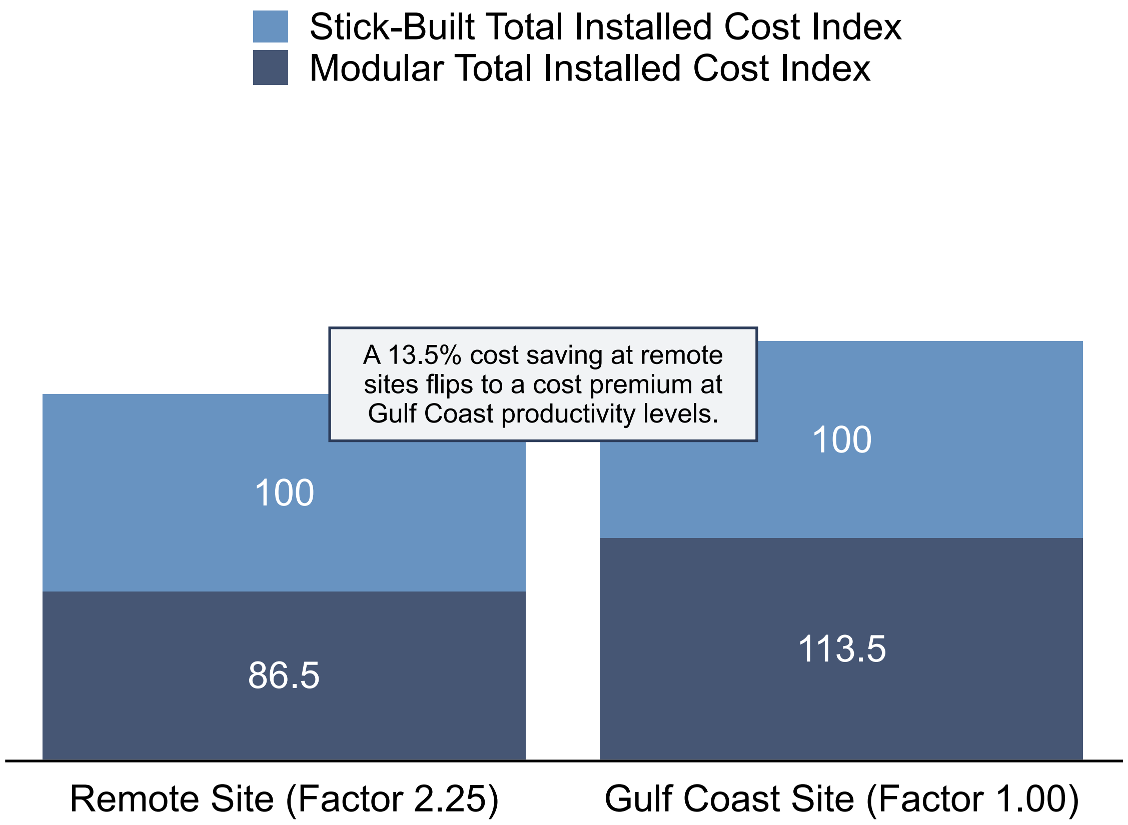
2.25

Remote Site Factor

High field labour penalty in remote locations; prefabrication yields 13.5% cost savings and halves peak site manpower. From a modelled LNG study, not bioeconomy data.

Move the Site, Flip the Answer

Total Installed Cost Comparison: Modular vs Stick-Built by Site Productivity Factor



Cost Impact of Site Labor Productivity

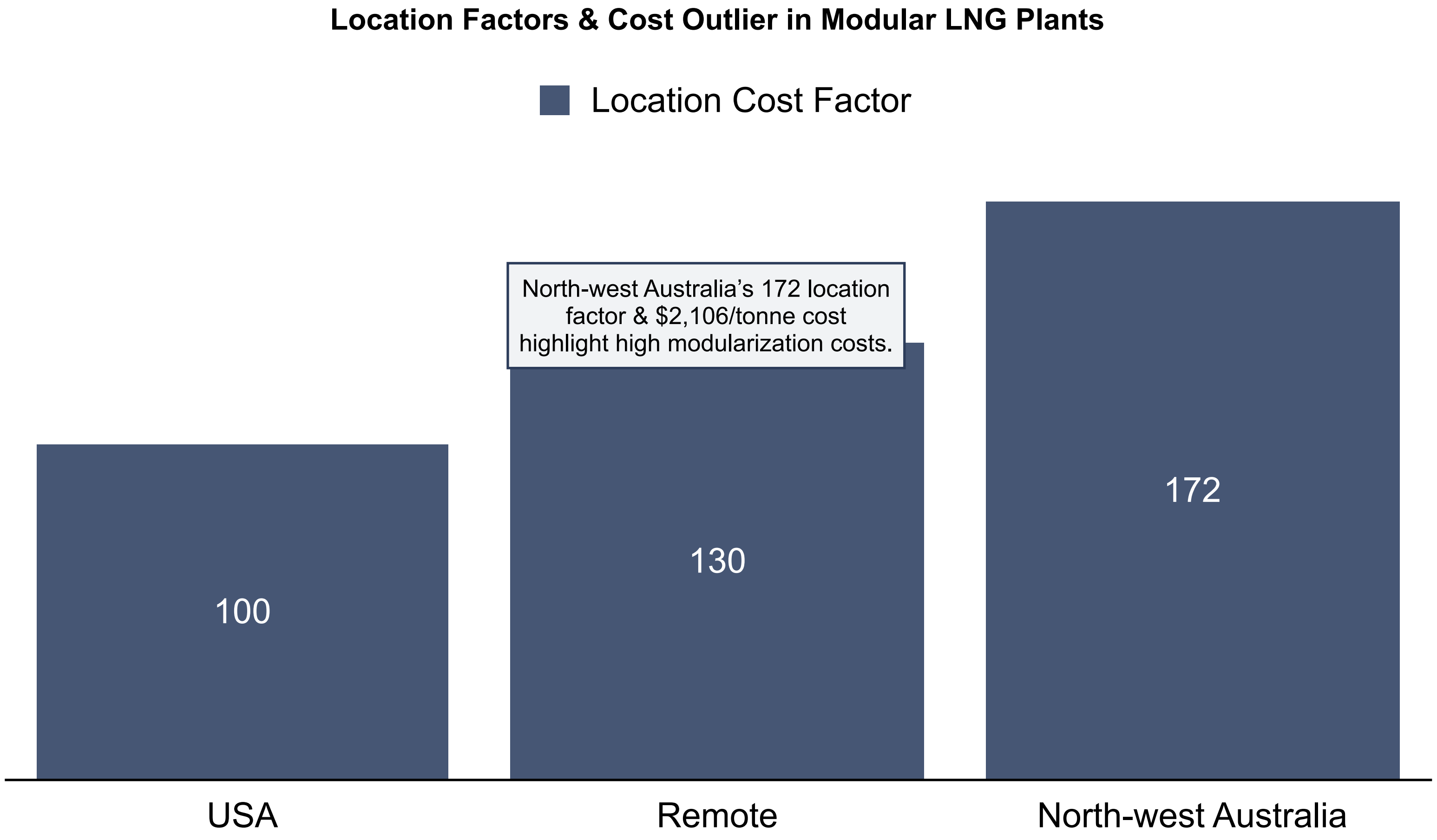
- Modular construction shows a 13.5% installed cost saving compared to stick-built at a remote site with a productivity factor of 2.25.
- At the Gulf Coast site with a productivity factor of 1.00, modular construction becomes a cost premium, reversing the saving.
- The cost difference is driven solely by assumed field labor productivity factors, not intrinsic module costs.
- This modelled data comes from a hypothetical LNG plant study and should not be directly applied to biorefineries without adjustment.
- Understanding local labor productivity is essential for deciding if modular construction offers real capital savings.

Cost Impact of Site Labor Productivity

The cost-effectiveness of modular biorefinery construction hinges critically on site-specific field labour productivity. A modelled LNG plant study shows modular construction yields a 13.5% installed cost saving at a remote site with low labour productivity (factor 2.25), but becomes a cost premium at a high productivity site like the Gulf Coast (factor 1.00). This demonstrates that the location and its labour conditions decisively flip whether modularization saves or adds cost.

The Industry That Modularized Hardest

LNG modularization shows location-driven cost extremes and high steel content raise costs despite labour savings. Modular is fastest but not always cheapest. This is LNG data, not bioeconomy evidence.



LNG Modular Cost & Location Impact

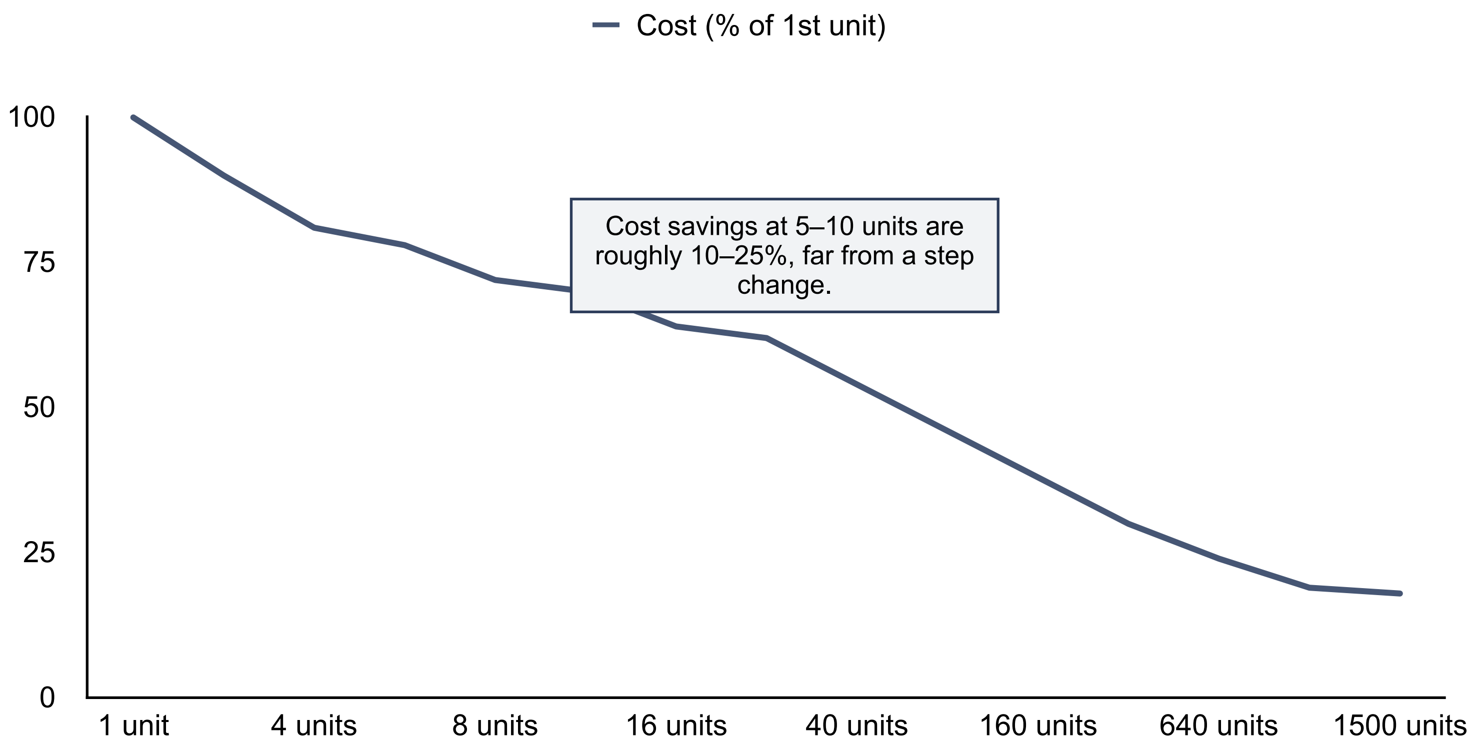
- Location factors vary: USA baseline 100, remote 130, North-west Australia 172, reflecting logistics and labour challenges.
- North-west Australia’s liquefaction cost hits $2,106 per tonne, a clear outlier.
- Structural steel can be 50% of module weight, raising transport & fabrication costs.
- Modularization is fastest but not always the cheapest option, especially in tough locations.
- Data is from LNG benchmarking (Oxford Institute NG137, 2018), not directly applicable to bioeconomy.

The Replication Promise, Priced

Replication Learning Curve Analysis

- Stick-built chemical plants exhibit learning ratios no larger than about 10%, meaning each doubling of units reduces costs by roughly 10%.
- Replicated modular processes have higher learning ratios around 20%, reflecting better cost reductions per doubling but still needing scale.
- A worked case indicates that a three- to tenfold cost reduction demands building approximately 1,500 units, far beyond typical bioeconomy projects.
- At 5 to 10 units—the more realistic scale in biorefineries—the expected savings are roughly 10–25%, not a dramatic step change.
- This evidence tempers expectations for rapid modular cost declines without very large replication volumes.

Learning Curve of Cost Reduction by Number of Units Built



Learning curves show that significant cost reductions through replication require very high unit counts, often beyond typical biorefinery projects. Early replication (5–10 units) yields modest savings of about 10–25%, not transformative cuts. This challenges assumptions of rapid modular cost declines without scale.

Fewer Units, Higher Unit Cost — The Small Modular Reactor Warning

Reducing the number of modules on a fixed site without changing site or licensing scope can sharply increase unit cost. Fewer, smaller units do not guarantee savings if fixed costs remain. This does not reflect on biorefinery module quality.

Overview

- Planned as twelve modules on a fixed site for cost efficiency.
- Site and licensing scope stayed fixed even as module count dropped.
- Fewer modules led to higher unit costs, not savings.
- Highlights risk of downsizing without adjusting project scope.

Problem

- A small modular reactor project was originally planned for twelve modules on a fixed site to maximize scale.
- The project was descoped to six modules, but site, licensing, and balance of plant scope were unchanged.
- Reducing module count increased the target price before escalation, erasing expected savings.
- The project ended near $20,139 per kilowatt and was ultimately terminated due to poor economics.

Solution

- Reducing module count while keeping site and licensing fixed raised unit costs sharply.
- The project failed to achieve economic scale and was terminated for financial reasons.
- Fewer, smaller modules did not bring savings when fixed costs remained unchanged.
- Site and licensing factors, not module quality, drove the cost outcome.

How Much to Discount an Announced Number

Early capital expenditure estimates for pioneer plants typically understate actual costs by about half, necessitating a significant discount for realistic budgeting and risk assessment.

Estimate-Class Progression for Pioneer Plant Costs

Estimate Class	Avg % of Actual Cost	Production Goal Met Within 6 Months
Estimate Class	**Average % of Actual Cost**	**Production Goal Met Within 6 Months (%)**
Research Stage	49%	<50%
Preliminary Estimate	65%	
Detailed Estimate	80%	
Final Estimate	93%	

Estimate Accuracy & Risk

- Research-stage estimates average only 49% of eventual actual costs, reflecting high uncertainty in early planning.
- Cost estimates improve as projects progress, nearing 93% accuracy at final estimate stage.
- Over half of pioneer plants analyzed missed production goals within six months post-startup, indicating operational risk.
- Data is from a measured, ex-post audit of 40 pioneer plants during a high-inflation era (RAND R-2569).

The Road Decides the Module

Key Constraints on Module Size and Transport

- Road transport limits module width to roughly 14 to 16 feet and height to 14 to 15 feet before triggering superload permitting requirements, which add days to weeks of regulatory review.
- Superload permitting delays can extend project schedules by a few days up to a month, impacting overall delivery timelines and costs.
- Modules exceeding road limits require barge or rail transport, which offer fewer size restrictions but depend on site access and infrastructure.
- Structural steel and fabrication shop capabilities generally do not limit module size; instead, transportation logistics and regulatory approvals determine practical module dimensions.
- Planning for site access via water or rail can enable larger modules, potentially reducing onsite assembly time but may introduce logistical complexity.

The maximum size of prefabricated modules is often governed by transport logistics rather than shop fabrication capacity. Understanding road size limits and permitting constraints is critical to optimizing modular biorefinery deployment and avoiding costly delays. Incorporating barge or rail access can circumvent road restrictions, enabling larger modules and more efficient site assembly.

The Path That Beats Both — Montana Renewables, Great Falls

Conversion of existing assets can cut capital costs dramatically. Montana Renewables reused refinery infrastructure, reducing capital by nearly 90%. The cheapest path is often conversion, not stick-built or modular—though reuse depends on asset availability.

Overview	• Sustainable aviation fuel expansion at an existing refinery in Great Falls, Montana. • Conventional options were costly stick-built or modular new construction. • Project team identified asset conversion as a lower-cost alternative. • Conversion leveraged nearby existing hydrotreating and auxiliary units to cut capital and risks.

Problem

- Building new hydrotreating, hydrogen, and naphtha-splitting units from scratch was costly, about $1.2 billion, whether stick-built or modular.
- Constructing these units new posed high financial and schedule risks for the SAF expansion project.
- Site challenges included integration risks, complex construction, and high labor and engineering costs, increasing capex and uncertainty.

Solution

- Montana Renewables restructured to reuse an existing hydrotreater, hydrogen plant, and naphtha splitter next door.
- This cut new capital costs from $1.2 billion to about $137 million, nearly a 90% reduction.
- Reuse minimized construction scope, reduced interface complexity, and shortened the timeline while meeting capacity goals.

What the Operator Must Execute

Successful modular biorefinery deployment hinges on the operator's ability to rigorously manage design freeze, interface ownership, and commissioning. Prefabrication shifts construction challenges but does not eliminate the need for disciplined execution in these three critical phases.

Freeze the Design Before Fabrication Begins

Activities

- Lock the design scope and specifications to prevent costly changes during fabrication.
- Ensure all stakeholders approve the final design to minimize rework risks.
- Establish design baselines early to align shop production and site readiness.

Deliverables

- Finalized and approved design documents ready for fabrication.

Own Interface Scope Through Site Acceptance

Activities

- Define clear responsibilities for module-to-site interfaces including mechanical, electrical, and structural connections.
- Maintain control over scope changes and interface engineering adjustments during installation.
- Coordinate closely with site teams to verify compliance and manage any site-specific deviations.

Deliverables

- Comprehensive interface management plan and documented site acceptance criteria.

Resource Commissioning as a Distinct Phase

Activities

- Plan and allocate dedicated resources for commissioning activities, independent of fabrication completion.
- Recognize that prefabrication does not shorten or remove commissioning; it remains a critical phase requiring skilled labor.
- Implement structured commissioning procedures to ensure system functionality and operational readiness.

Deliverables

- Commissioning plan with allocated resources and documented completion reports.

What We Cannot See

Observation: Borrowed Industry Comparisons

- All quantitative data in this guide originates from industries other than the bioeconomy, specifically LNG, nuclear, and chemical-process sectors.
- No direct, matched-boundary comparisons exist between modular and stick-built biorefineries to validate cost or productivity claims.
- Available figures are modelled or inferred, not from actual built biorefinery projects, limiting their direct applicability.
- This borrowing of data introduces uncertainty when applying findings to biorefinery deployment decisions.
- The absence of measured shop-versus-field productivity studies for biorefineries is a significant evidence gap.

Implications: Treat Capex Savings with Caution

- All stated capital expenditure savings for modular biorefineries lack direct empirical support.
- Without matched-boundary, biorefinery-specific studies, cost-saving percentages remain assumptions.
- Decision-making should not rely solely on modular capex saving claims without site-specific validation.
- Developers and investors must recognize the uncertainty and apply conservative risk adjustments.
- Future research should prioritize direct biorefinery modular vs. stick-built productivity and cost comparisons to close this knowledge gap.

Current cost and productivity claims for modular biorefineries derive from proxy industries and lack direct validation. Until biorefinery-specific studies are conducted, all modular capex-saving figures should be treated as unverified assumptions, urging caution in financial and operational planning.

The Site Test

The choice between stick-built, modular, or conversion deployment hinges on four critical site-specific factors. Assessing local labor costs and availability, site transport logistics, schedule pressures, and realistic replication volumes enables a tailored, economically sound decision. This decision screen channels the developer, operator, or investor toward the optimal construction path based on site realities rather than assumptions about modular cost savings.

	Assess Local Field Labour Cost and Availability	Check Site Access: Barge, Rail, or Road Only	Value Schedule Acceleration Against Capital Cost	Estimate Genuine Unit Count for Replication
Key Activities	• Evaluate skilled craft labour costs specific to the project's geographic location. • Quantify labour availability and scarcity to understand schedule risk and premium rates. • Identify skills gaps that could increase reliance on modular prefabrication to offset local labour constraints.	• Determine if the site allows large module delivery by barge or rail, removing physical size constraints. • Assess road transport limits including width, height restrictions, and superload permitting delays. • Understand transport constraints as a fundamental cap on module size and modularization benefits.	• Quantify the value of reduced field construction time enabled by modular prefabrication. • Balance the premium capital cost of modular steel, transport, and interface engineering against schedule gains. • Evaluate if labour scarcity or project time sensitivity justifies prefabrication despite higher upfront costs.	• Forecast the number of identical modular units realistically buildable given market and project pipeline. • Model cost reductions achievable through replication learning effects, noting diminishing returns. • Adjust expectations for savings if the true unit count is low, mitigating modularization's financial appeal.
Deliverables	• Labour cost benchmark report • Labour availability assessment • Local craft skill inventory	• Transport logistics feasibility study • Road and barge access maps • Permitting requirements overview	• Schedule vs. capital cost impact analysis • Risk-adjusted schedule premium estimate • Schedule compression value proposition	• Replication feasibility model • Order quantity impact report • Learning curve projection

What to Examine Differently

Prefabrication as a Strategic Tool

Prefabrication primarily addresses schedule acceleration and labour scarcity rather than guaranteeing capital cost reductions.

It shifts labor from costly, weather-impacted fieldwork to controlled, efficient shop environments, which can improve project timelines.

The cost benefits vary widely by site-specific conditions and should not be assumed automatic.

Field Labour Productivity is Key

The decisive factor for the economics of modular biorefinery deployment is site field labour productivity, not the module design or fabrication method.

Productivity differences can flip modularization from cost-saving to cost-premium depending on local labour availability and efficiency.

No direct biorefinery studies exist; all current data are borrowed from other industries and must be interpreted cautiously.

Conversion as a Viable Alternative

Before opting for stick-built or modular approaches, evaluate the potential for converting existing assets to meet project goals.

Conversion can dramatically reduce capital expenditure and schedule risk by leveraging existing infrastructure.

This path is often overlooked but can outperform both traditional and modular builds in cost and operational outcomes.

Prefabrication should be viewed as a strategic response to site-specific labour challenges and schedule demands rather than a straightforward capital cost reducer. The true economic impact hinges on the local field labour productivity, which varies by location and project context. Conversion of existing assets deserves serious consideration as it frequently offers a more cost-effective and lower-risk path than either stick-built or modular deployment.

The Closing Decision Test

Skilled Craft Labour Cost and Availability

Assess the local cost of skilled craft labour—this is the key variable driving the economics of modular versus stick-built.

Evaluate labour availability and scarcity, since modular prefabrication gains value where craft labour is punishingly costly or scarce.

Site Access and Transport Constraints

Determine whether the site can accept barge or rail deliveries, which remove physical module size caps and reduce transport risk.

If limited to road transport, factor in module dimension caps (typically 14–16 feet wide and 14–15 feet high) and permitting delays that increase cost and schedule.

Scope of the Quoted Capital Cost

Clarify if the quoted figure includes only equipment or the full installed plant cost with indirects and interfaces.

Beware that different estimates may mask hidden scope gaps or undercount interface complexity, affecting true cost comparisons.

Replication Scale and Unit Count

Estimate how many units will actually be built; benefits from modular replication scale significantly increase beyond 5–10 units.

Test financial resilience of the case if only two units materialize—many modular savings require high volume to justify upfront costs.

Existing Asset Conversion Potential

First consider if an existing asset can be converted or reused, often delivering the lowest capital outlay and risk.

Conversion can outperform both stick-built and modular approaches but depends on site-specific availability and condition.

Before committing to a biorefinery construction architecture, rigorously evaluate local labour economics, transport logistics, project scope clarity, realistic replication volumes, and the opportunity to convert existing assets. These five questions anchor the decision to maximize capital efficiency and schedule certainty.

Thank you