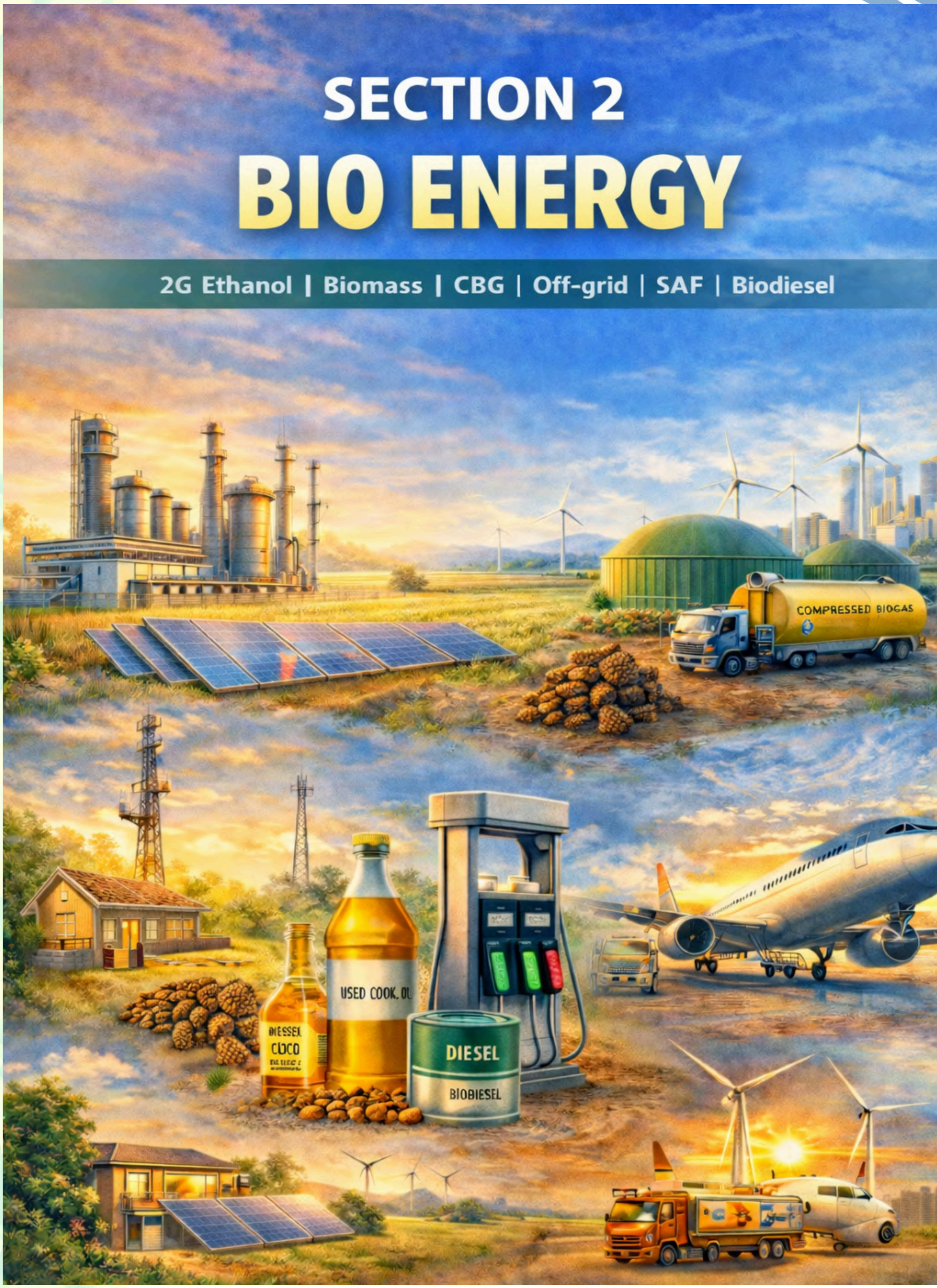

SECTION 2
BIO ENERGY
2G Ethanol | Biomass | CBG | Off-grid | SAF | Biodiesel
COMPRESSED BIOGAS
USED COOK. OIL
DIESEL
BIODIESEL

Section 2

Bio Energy

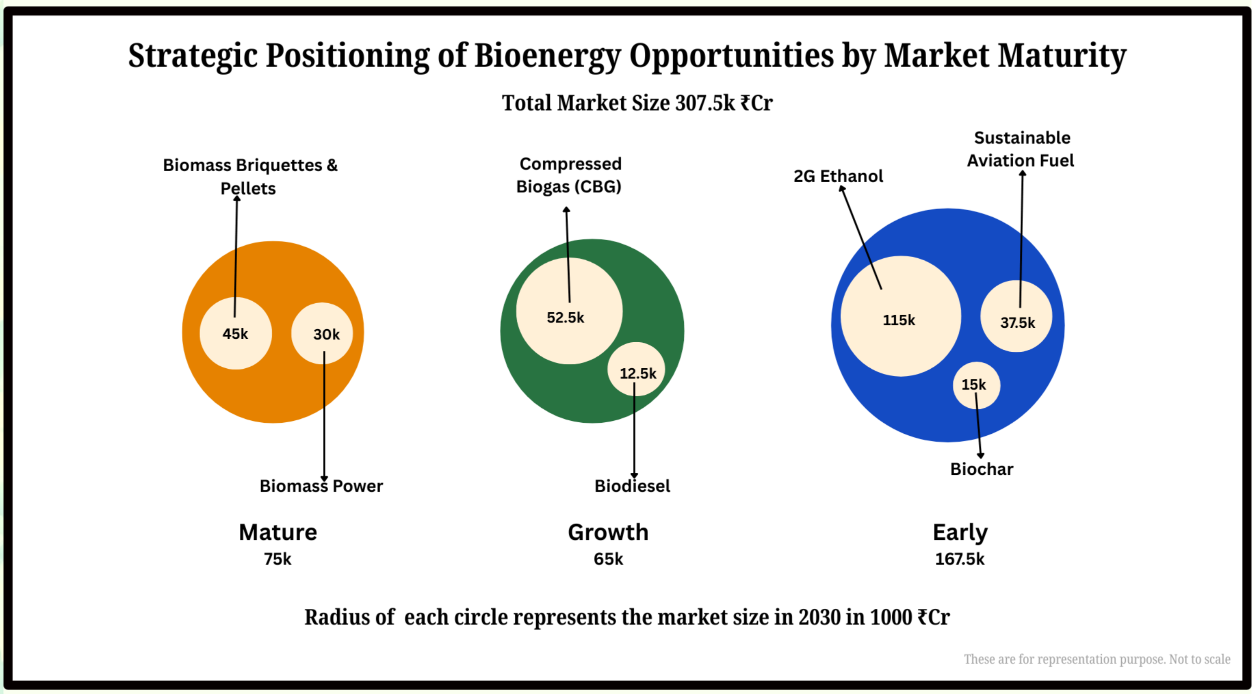
Bio-energy complements solar and wind by providing dispatchable energy, liquid fuels, and circular economy solutions, leveraging India's vast biomass, waste, and agricultural residues.

Market Scale & Policy Push:

- Ethanol Blending Programme (EBP):India achieved 20% ethanol blending in 2025, five years ahead of target, with plans to increase blending to ~30% by 2030
- SATAT scheme targets 5,000+ CBG plants, supporting clean transport fuel and rural income
- Biomass power capacity at 11.6 GW, providing base-load renewable energy

Key Growth Segments:

- **2G Ethanol**: Converts agri-residue into fuel; PSU-led projects scaling up
- **Compressed Biogas (CBG**): Strong traction in transport and industrial fuel replacement
- **Biomass pellets & briquettes**: Rapid coal substitution in industry and power
- **Biodiesel & SAF**: Early-stage but strategically important for aviation and heavy transport



Strategic Trends:

- Shift from waste management to energy monetisation
- Increasing integration with oil & gas, transport, and aviation sectors
- Growing role in energy security and rural economy

Decarbonisation Impact:

These pathways enable direct fossil fuel substitution, delivering immediate CO_2 reduction in sectors where electrification is difficult.

Executive takeaway:

Bioenergy provides alternative fuel-based decarbonisation for India—turning biomass and other waste into strategic assets while strengthening energy security and rural value chains. For investors and corporates, bioenergy is a capital-efficient route to convert biomass and waste streams into dispatchable fuels and circular-economy businesses that support both rural economies and transport-sector decarbonisation.

BIOMASS VALUE CHAIN COMPONENTS

FEEDSTOCK SOURCING

↓

FEEDSTOCK AGGREGATION & LOGISTICS

↙ ↓ ↘

BIOFUELS

PRE-TREATMENT & PROCESSING
(Physical methods/ Sonication/ Alkali/ Acid/ Enzymatic/Sterilization)

↓

CONVERSION TECHNOLOGY
(Anaerobic digestion / Fermentation / Transesterification / Gasification)

↓

FUEL UPGRADING & REFINING
(CBG purification / Ethanol distillation / Biodiesel refining / SAF upgrading)

↓

STORAGE & TRANSPORT

↓

BLENDING / DISTRIBUTION

↓

END USE APPLICATIONS
(Transport | Industry | Aviation | Power | Cooking Gas)

BIOMASS POWER

ENERGY CONVERSION TECHNOLOGY
(Combustion Boilers/Gasification/CHP/ Co - firing/Pyrolysis)

↓

POWER & HEAT GENERATION SYSTEMS
(Steam Turbines/ Industrial Heating)

↓

GRID / INDUSTRIAL INTEGRATION
(Utility Power Supply/Captive Power/Process Heat/Hybrid Renewable Systems)

↓

END USE APPLICATIONS
(Industries | Utilities | SMEs | Thermal Power Plants | Commercial Heating)

BIOCHAR

PRE-TREATMENT & PROCESSING
(collection/ sorting/ drying/ grinding)

↓

PRODUCTION VIA PYROLYSIS
(Slow pyrolysis/ fast pyrolysis/ Gasification/ batch kilns/ continuous kilns)

↓

PROCESSING AND UPGRADING
(cooling/ sieving/ grinding/ leaching/ activation)

↓

BLENDING
(compost/ nutrients/ binders)

↓

END USE APPLICATIONS
(Agriculture | Energy | Water Purification)

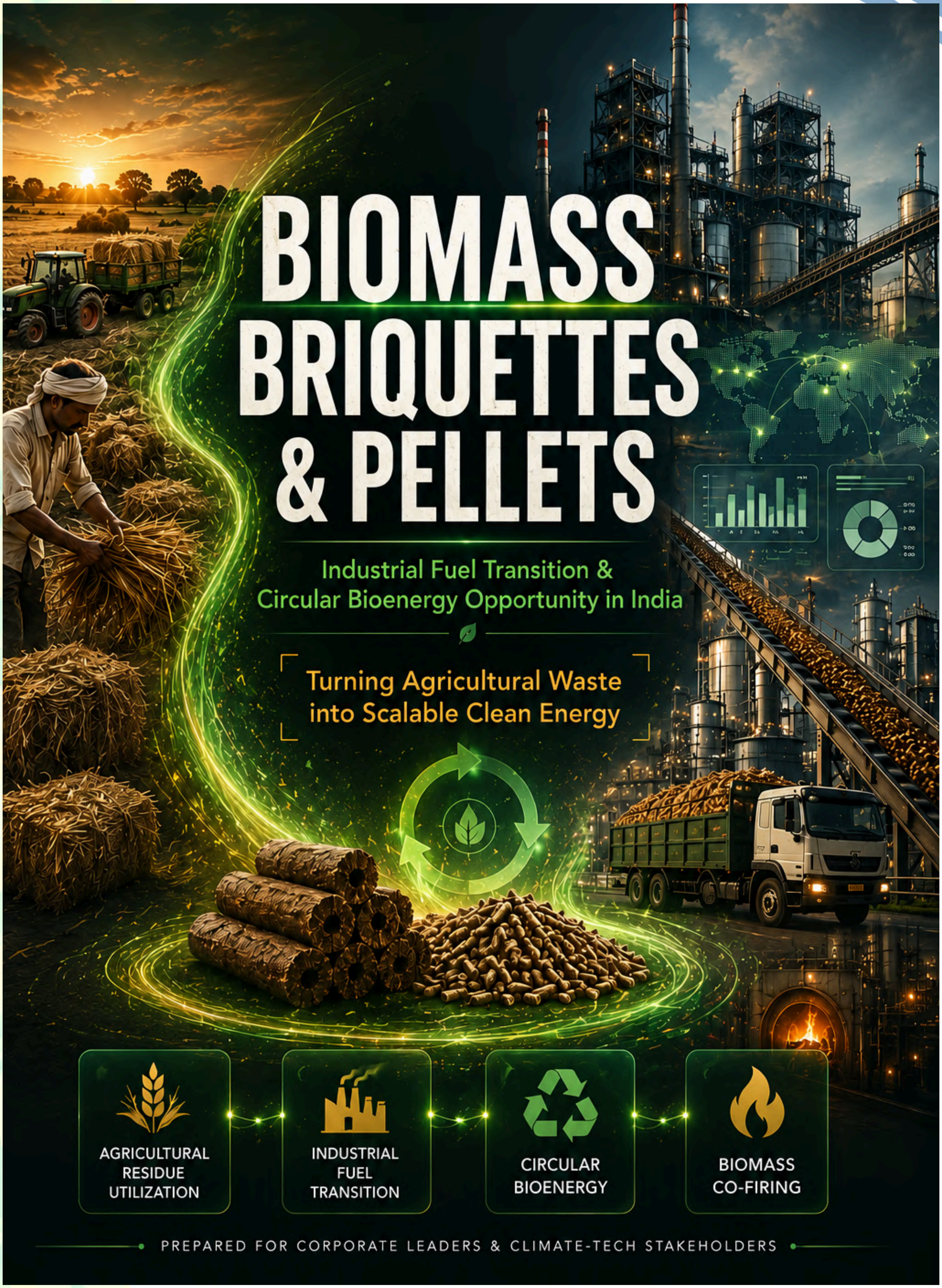
↘ ↓ ↙

SECOND LIFE APPLICATIONS

↓

CARBON & SUSTAINABILITY VALUE STREAMS

(Carbon credits | ESG compliance | Waste management revenue)


BIOMASS
BRIQUETTES
& PELLETS
Industrial Fuel Transition &
Circular Bioenergy Opportunity in India
Turning Agricultural Waste
into Scalable Clean Energy
AGRICULTURAL RESIDUE UTILIZATION
INDUSTRIAL FUEL TRANSITION
CIRCULAR BIOENERGY
BIOMASS CO-FIRING
PREPARED FOR CORPORATE LEADERS & CLIMATE-TECH STAKEHOLDERS

Bio Energy

Biomass Briquettes & Pellets

This section provides key inputs on the Indian Biomass Briquettes & Pellets Opportunities for corporate leaders.

Highlights

- Rapidly growing demand driven by industrial fuel switching from coal/diesel to biomass under ESG pressure and air-quality regulations
- Strong policy tailwinds through mandates on co-firing in thermal plants, pollution control norms, and renewable heat incentives
- Waste-to-value opportunity converting agricultural residues into standardized commercial fuel while addressing stubble burning and rural income gaps
- Scalable distributed manufacturing model allowing cluster-based expansion with relatively low capex compared to large energy infrastructure projects

Key recommendations for corporate leaders include:

- Build reliable feedstock aggregation ecosystems via farmer partnerships and decentralized storage networks
- Standardize product quality and certification to secure industrial buyers and long-term supply contracts
- Target industrial clusters and power co-firing demand at power plants where fuel offtake is significant, concentrated and predictable
- Invest in automation and digital logistics systems to improve yield, consistency, and operating margins

Opportunity Snapshot: Biomass Briquettes & Pellets

Agri residues are converted into solid fuel replacing coal in industrial boilers

Market Signals

- Strong demand from industrial segments shifting from coal to biomass for boilers
- Government push for biomass co-firing in coal power plants
- Annual Market size by 2030: ₹15,000 - 20,000 Cr

What Makes or Breaks It?

- Secured feedstock supply (FPOs/aggregators) at stable pricing
- Proximity to demand centers (≤100 km to reduce logistics cost)
- Long-term industrial offtake

Why It Matters NOW?

- Rising coal prices; need for cost-competitive fuel alternative
- Immediate substitution opportunity with minimal tech change
- Helps address stubble burning and waste management

Well Aligned Opportunity for

- Agri supply chain players (FPOs, aggregators)
- Industrial fuel suppliers and traders
- Local entrepreneurs near biomass clusters

Key Challenges

- Heavy dependency on logistics off feed stock
- Seasonal availability of agri residues
- Price volatility when compared to coal

Business Models

- Tie-ups with industries for long-term fuel supply contracts
- Integrate aggregation + processing + distribution

Explore this opportunity further with EAI

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Introduction and Business Case

Biomass briquettes and pellets are densified biofuels made from crop residues, sawdust, husk, shells and other agri-waste. They provide a renewable and standardised substitute for coal, diesel and furnace oil in industrial boilers, cement kilns and power plants, and also to select commercial & institutional segments like community kitchens etc.

For India, which boasts of a large amount of diverse agri residues, and where stubble burning and fossil imports remain major challenges, briquettes and pellets offer a triple win: lower emissions, reliable industrial fuel and new rural incomes.

Further, co-firing mandates in thermal plants and demand from cement and steel industries for a low carbon heating fuel make this a rapidly scalable opportunity.

Market Potential for Biomass Briquettes & Pellets in India

Year	Estimated Market Size	Key Demand Drivers
2025	₹5,000-7,000 Cr	Biomass co-firing mandates, small-scale industrial use
2030	₹15,000-20,000 Cr	Large-scale industrial substitution, carbon credits, rural clean energy
2040	₹40,000-50,000 Cr	Deep decarbonization in steel, power, cement and rural cooking

Market Segments and Applications

Segment	Applications	Business Model	Key Drivers
Utility-Scale Biomass Power	Coal replacement & baseload power	Long-term supply contracts (10–20 yrs)	Coal phase-out, renewable mandates
Coal-to-Biomass Co-firing	Partial decarbonization of coal plants	Fuel supply + performance guarantees	Fuel supply + performance guarantees
CHP & District Heating	Power + heat for cities & industry	Heat + pellet supply contracts	High efficiency, energy security
Industrial Captive Boilers	Process heat & steam	Long-term fuel supply contracts	Scope-1 emission reduction
Residential Heating (Pellets)	Space heating	Branded retail distribution	Clean heating regulations,

			convenience
Commercial Heating	Hotels, hospitals, campuses	Fuel + boiler O&M contracts	ESG mandates, fuel cost stability
Export-Oriented Industrial Pellets	Overseas biomass power plants	FOB/CIF export contracts	Lack of local biomass, energy security
Integrated Pellet-to-Power	Captive fuel for own plants	Vertical integration	Margin control, supply certainty
Waste & Residue-Based Pellets	Waste-to-energy & circular economy	Tipping fees + pellet sales	Waste disposal pressure
Bioenergy-as-a-Servi ce (BaaS)	Outsourced clean energy	Long-term service contracts	Capex avoidance, ESG reporting

Typical Project Capacities & Investments Required in India

Project *Scale Categories*

Scale	Capacity	Target Market
Micro/Small	1-5 TPD	Local industry, rural stoves
Medium	10-30 TPD	MSMEs, small-scale power/brick kilns
Large	50-100+ TPD	Utility-scale biomass co-firing, exports

Capital Investment Estimates

Capacity	Briquette Plant	Pellet Plant
5 TPD	₹20-30 lakhs	₹40-50 lakhs
10-15 TPD	₹50-75 lakhs	₹80 lakhs - ₹1.2 Cr
30 TPD	₹1.5-2 Cr	₹2.5-3 Cr
100 TPD	₹4-6 Cr	₹7-10 Cr

Underlying Technologies & Processes

Pre-processing (Common to Briquettes & Pellets)

Step	Description
Raw Material Collection	Paddy straw, sawdust, bagasse, groundnut shells, cotton stalks, etc.
Chipping/Crushing	Reduces size of biomass to 5-10 mm using chippers or hammer mills
Drying	Moisture content is reduced to <12% using rotary or flash dryers
Sieving/Screening	Removes stones, metal pieces and oversized particles

Briquetting Technology

Mechanical Piston Press (Most Common in India), Screw Press & Hydraulic Press (Less Common)

Pelleting Technology

Flat Die Pellet Mill, Ring Die Pellet Mill

Key Challenges

Challenge Area	Key Issues	Business Impact	India Specific	Strategic Implications
Feedstock Supply Chain & Price Volatility	Seasonal agri-residue availability, competing uses (fodder, ethanol, biomass power), logistics costs	Raw material price fluctuations reduce margins; inconsistent supply affects production	Fragmented agriculture system; dependence on crop cycles (rice straw, mustard husk, etc.)	Develop localized sourcing networks, farmer partnerships, and long-term supply contracts
Demand Stability & Offtaker Dependence	Limited long-term contracts; demand linked to industrial fuel switching and coal co-firing policies	Revenue unpredictability impacts financing and scaling	Strong demand potential from thermal power plants (biomass co-firing), brick kilns, SMEs	Secure PPAs or fuel supply agreements with utilities and industrial users

Pricing Competition with Coal & Fossil Fuels	Biomass pellets must compete with subsidized or cheaper coal	Profitability sensitive to fuel price fluctuations	Government mandates for biomass co-firing help but enforcement varies	Position as ESG-driven solution; leverage carbon credits and policy incentives
Operational & Quality Challenges	Moisture content variation, equipment wear, inconsistent pellet/briquette quality	Increased maintenance costs; customer rejection risks	Lack of standardized quality control among smaller producers	Invest in preprocessing, drying systems, and quality certification
Logistics, Regional & Infrastructure Constraints	High transportation costs due to low energy density; limited storage infrastructure	Reduced profitability especially for long-distance transport	Biomass concentrated in certain regions (Punjab, Haryana, UP, Maharashtra)	Site plants close to feedstock sources and major industrial clusters

Prominent Players in the Indian Market

Company / Entity	Project Details
PRESPL (Punjab Renewable Energy Systems Pvt. Ltd.)	India's leading biomass supply chain company; aggregation, baling and supply of briquettes/pellets to NTPC, state GENCOs and industries.
Ecostan Biofuel	Manufactures biomass briquettes, pellets and the machinery required to produce those
NTPC Ltd.	Large-scale procurement of biomass pellets for co-firing; floated tenders for millions of tonnes annually.
Sanron Fuel	Biomass briquette & pellet manufacturer

Innovation Perspectives

Innovation	Business Opportunity	For Senior Management
Coal-to-Biomass Conversion Fuel Platforms	Long-term fuel partnerships with utilities	Coal plants need fast decarbonization
Integrated Pellet-to-Power / Fuel-to-User Models	Margin capture + fuel security	Fuel volatility is top risk

Industrial Heat-as-a-Service (HaaS)	Selling heat, not fuel	Industries avoiding capex
Residue Aggregation & Preprocessing Platforms	Multi-customer biomass supply hubs	Feedstock fragmentation
Export-Grade Pellets for Asia	Entry into high-credit Asian markets	Asia lacks domestic biomass
Waste + Biomass Hybrid Pelletization	Tipping fees + pellet sales	Waste disposal pressure
Premium Low-Ash / Low-Carbon Pellets	ESG-premium fuel segment	Carbon disclosure tightening
Decentralized Modular Pellet Plants	Rapid replication near residue hubs	Logistics is cost driver
Digital Feedstock & Quality Optimization	Predictive modeling and production optimization	Higher yield, lower rejection
Pellets as a Bio-Platform Feedstock	Entry into advanced bioeconomy	High energy density and lower carbon footprint.

Concentric & Satellite Opportunities

- Residue aggregation & preprocessing networks: FPO- and startup-led collection, drying and shredding hubs near paddy, sugarcane and sawmill belts.
- Pellet & briquette machinery manufacturing: Localised production of compact presses, grinders and dryers adapted for Indian feedstocks and moisture levels.
- Industrial fuel supply contracts: Long-term PPA-style models supplying briquettes/pellets to cement, textile and food-processing industries.
- Quality testing & certification services: Labs verifying calorific value, ash content and emissions compliance to standardise the market.
- Co-firing infrastructure at TPPs: Retrofitting and logistics services enabling 5-10% biomass co-firing in coal plants under mandated targets.
- Rural entrepreneurship clusters: Decentralised briquetting units offering local employment and income diversification for farmers.
- Innovative biomass consumer products: Satellite spin-offs using densified biomass for clean cooking stoves, BBQ fuels and heating pellets for domestic markets.

Key Takeaway for Senior Management

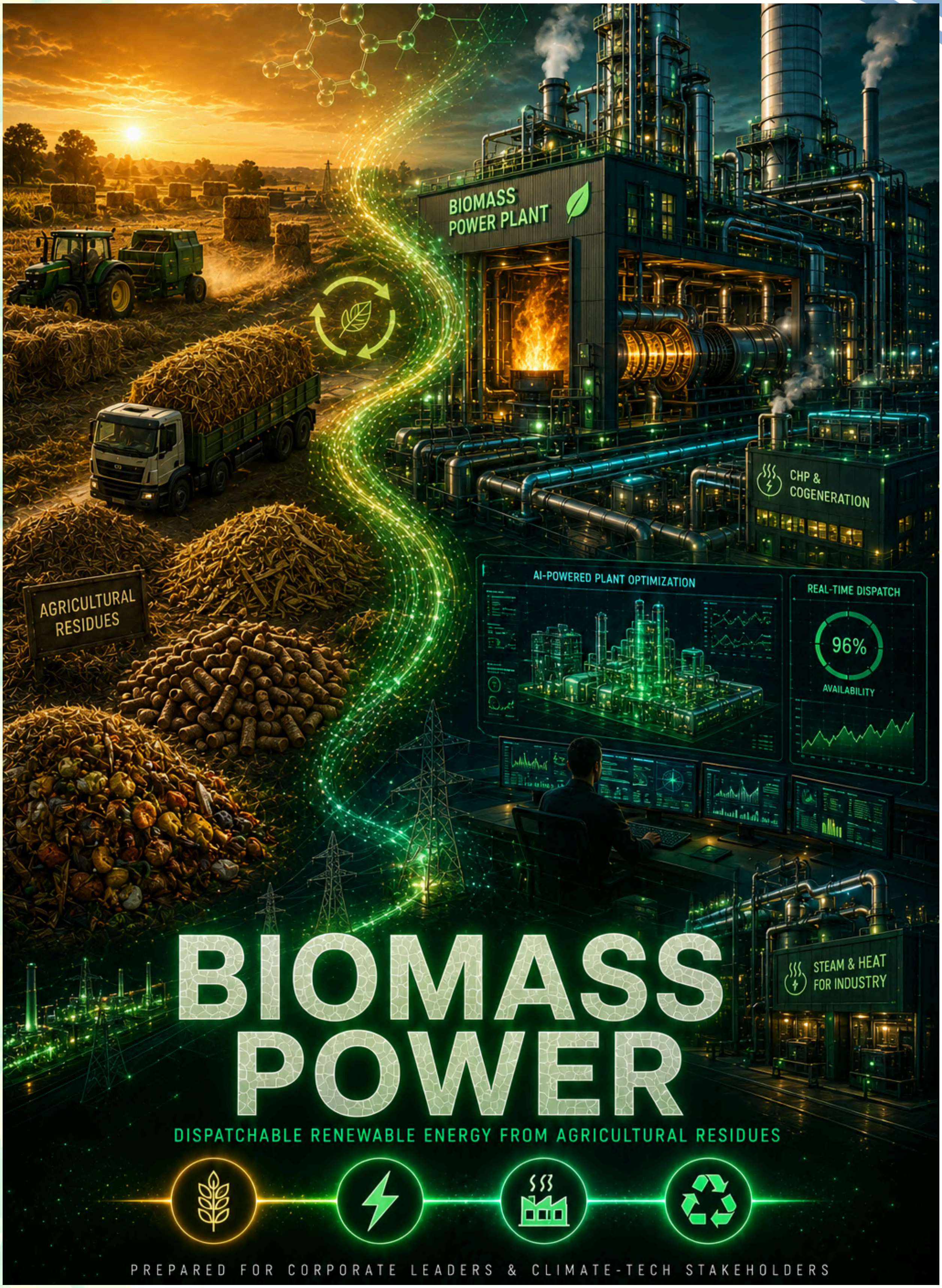
Takeaway	Details
Feedstock control is the primary strategic moat	• Briquette/pellet businesses are fundamentally logistics platforms, not simple manufacturing plants • Profitability depends on aggregation reliability, along with and price and quality control • ***Examples**:* baling hubs, decentralized farmer contracts, pellet storage silos, moisture-controlled warehouses • **Innovation focus:** AI-driven feedstock mapping, smart aggregation routing, quality sensors • **Competitive advantage:** proprietary biomass sourcing & logistical ecosystems create defensible supply chains competitors cannot easily copy
Quality standardization determines long-term buyer lock-in	• Industrial users demand consistent calorific value, ash content, and combustion performance • ***Sub-components**:* pellet density control, binder optimization, emissions compliance, certification frameworks • **Innovation focus:** automated quality monitoring and batch traceability • **Competitive advantage:** premium-quality suppliers secure long-term industrial contracts over price-driven competitors
Cluster-based platforms outperform isolated plants	• Economics improve when production is located near both feedstock sources and industrial demand centers • ***Examples**:* agro-industrial corridors, thermal plant co-firing zones, manufacturing clusters • **Innovation focus:** shared logistics infrastructure and regional aggregation networks • **Competitive advantage:** reduced logistics cost per ton and scalable platform deployment
Digital logistics and automation unlock hidden margins	• Transportation, drying efficiency, and inventory management materially affect IRR • ***Examples**:* automated pellet lines, IoT moisture sensors, predictive maintenance • **Innovation focus:** digital supply-chain orchestration and plant analytics • **Competitive advantage:** lower O&M cost and higher throughput than manual competitors
Industrial fuel transition is creating a structural demand shift	• ESG mandates, pollution control norms, and coal substitution policies are pushing industries toward biomass fuels • ***Examples**:* thermal co-firing mandates, industrial boiler

	conversions, green procurement standards. ● **Innovation focus:** hybrid fuel systems and combustion optimization ● **Competitive advantage:** early positioning as a preferred industrial fuel partner

Next Steps for Corporate Leaders

Biomass briquettes and pellets are seeing accelerated adoption as industries seek lower-carbon heat substitutes for coal, FO, HSD, and other fossil fuels without major boiler or burner modifications. Demand is being driven by industrial decarbonization commitments, co-firing policies in thermal power plants, and increasing carbon cost visibility. Supply chains continue to formalize through aggregation platforms, densification plants, and quality standardization — though seasonal agri-residue availability and logistics remain key determinants of delivered cost and reliability.

This could be an attractive climate tech opportunity for industries and firms in specific sectors and industries keen on catering to this fast growing market.


BIOMASS
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Bio Energy

Biomass Power

This section provides key inputs on the Indian Biomass Power Opportunities for corporate leaders.

Highlights

- Firm renewable energy opportunity providing dispatchable baseload power, unlike intermittent solar/wind, making it valuable for grid stability and RTC clean energy needs
- Waste-to-value ecosystem converting agricultural residues and organic waste into energy while addressing pollution and rural income challenges
- Policy and ESG tailwinds through renewable purchase obligations, waste management mandates, and carbon reduction incentives
- Cluster-driven scalability in regions with high biomass density, enabling repeatable plant deployment and logistics efficiency

Key recommendations for corporate leaders include:

- Secure long-term biomass supply chains through farmer networks, aggregation hubs, and logistics partnerships to stabilize plant utilization
- Invest in efficient combustion and biomass gasification technologies to enhance yield and reduce operational downtime
- Strive for long-term, reliable PPAs to create predictable revenue streams and attract infrastructure capital

Opportunity Snapshot: Biomass Power

Generate electricity by burning biomass - agri residues, bagasse, pellets

Market Signals

- Policy support via feed-in tariffs and renewable purchase obligations (RPOs)
- Strong presence in sugar mills (bagasse-based cogeneration)
- Annual Market size by 2030: ₹25,000 - 28,000 Cr (Including bagasse based power generation) and ₹4,000-4,500 Cr (Excluding bagasse based power generation)

What Makes or Breaks It?

- Secured feedstock supply (≥70–80% capacity linkage within ~100 km)
- High plant efficiency (boiler + turbine performance)
- Long-term PPAs with DISCOMs or captive users

Why It Matters NOW?

- Provides firm, dispatchable renewable power (unlike solar/wind)
- Need to manage agri residues in a more sustainable manner

Well Aligned Opportunity for

- Sugar mills and agri-processing companies
- Independent power producers (IPPs)
- Industrial players with captive power needs

Key Challenges

- Feedstock supply inconsistency (seasonal + fragmented sourcing)
- Lower plant load factors (PLF 60–70%) vs conventional power

Business Models

- Bagasse-based cogeneration in sugar mills
- Independent biomass plants near agri clusters
- Captive power plants for industrial use

Introduction and Business Case

Biomass power plants convert agricultural residues, forestry waste and agro-industrial by-products into electricity through direct combustion or gasification. For India, biomass power offers a reliable renewable source that complements solar and wind while also tackling stubble burning and rural waste management.

With a strong policy push for co-firing, RPO compliance and waste-to-energy integration, biomass power supports energy security, emission reduction and farmer income generation while supplying firm renewable electricity to the grid.

While the biomass power generation sector has faced feedstock and economic challenges in the past decade, given the large potential the sector presents, select industries can expect significant business opportunities.

Market Potential for Biomass Power in India

Year	Installed Capacity (GW)	Market Size (₹ Cr)	Drivers
2025	12-13 GW	20,000-22,000	Existing grid-connected plants, co-firing mandates, industrial captive use.
2030	18-20 GW	25,000-28,000	Expansion driven by agri-residue utilisation, hybrid RE + biomass PPAs.
2040	25-28 GW	40,000-45,000	Firm RE demand; carbon markets; integration with bio-CNG and biochar co-products.

Market Segments and Applications

Segment	Applications	Business Model	Key Drivers
Utility-Scale Baseload Power	Grid-connected renewable electricity	Long-term PPAs with utilities/governments	Baseload renewable need, coal replacement
Coal-to-Biomass Conversion	Decarbonizing existing coal plants	Asset repurposing + regulated returns	Fast decarbonization, low incremental capex
Combined Heat & Power (CHP)	Power + heat for cities/industry	Heat contracts + power PPAs	Higher efficiency (70–85%), stable cash

			flows
Industrial Captive Power & Steam	Energy for cement, paper, chemicals	Long-term industrial offtake contracts	Industrial decarbonization pressure
District Heating Networks	Urban heating using biomass CHP	Urban heating using biomass CHP	Cold climates, energy security
Waste-to-Biomass Power	Power from organic MSW & RDF	Tipping fees + power sales	Waste management + energy convergence
Biomass Pellet Manufacturing	Fuel supply for power plants	Integrated fuel supply contracts	Supply-chain control, margin protection
BECCS (Carbon-Negative Power)	Power + carbon removal	Power + carbon credit monetization	Net-zero & negative emissions demand
Rural / Distributed Biomass Power	Power for agri & rural clusters	Mini-grids + anchor customers	Residue availability, energy access
Energy-as-a-Service (EaaS)	Outsourced clean energy for clients	Long-term service contracts	Opex model preference, ESG goals

Typical Project Capacities & Investments Required in India

Project Type	Typical Capacity	Indicative CapEx (₹ Cr/MW)	Notes
Small-scale biomass gasifier plants	0.5-5 MW	6-8	Village/cluster scale; often rice mills, sugar units; decentralised power + heat.
Medium-scale combustion plants	5-25 MW	5-7	Grid-connected; based on direct combustion of residues (paddy straw, bagasse).
Large-scale biomass/biomass-cofiring plants	30-50 MW	4.5-6	Independent biomass plants or coal plants with cofiring lines.
Cogeneration at sugar mills	20-100 MW	4-5	Bagasse-based; captive with grid export.
Biomass + Waste-to-Energy hybrid plants	10-20 MW	6-9	Combines crop residues with MSW/RDF for urban-industrial applications.

Underlying Technologies & Processes

Element	Options	Key Traits
Feedstock	Paddy straw, bagasse, husk, shells, forestry residues	Region-specific, seasonal; aggregation critical.
Conversion	Direct combustion (boilers + steam turbines)	Mature, proven, scalable for 5-30 MW units.
	Gasification (biomass → syngas → power)	Suited for smaller, decentralised plants; flexible fuels.
Co-firing	5-10% biomass pellets with coal in TPPs	Policy-mandated; large volume demand.
Cogeneration	Bagasse-based power in sugar mills	Common in India; improves efficiency.
Advanced integration	Biomass + CBG + biochar plants	Multi-product hubs improve margins.

Key Challenges

Challenge Area	Key Issues	Business Impact	India Specific	Strategic Implications
Feedstock Supply Chain & Price Volatility	Seasonal availability of agri-residue, competing demand (fodder, biofuel, industry), logistics challenges	Fuel cost variability reduces margins; plant load factor instability	Fragmented agriculture ecosystem; biomass collection networks still developing	Long-term supply contracts, decentralized aggregation models, and local sourcing critical
Offtaker Risk & DISCOM Financial Health	Delayed payments, tariff disputes, renegotiation risks	Cash flow constraints impact financial viability	Many state DISCOMs financially stressed; payment delays common	Diversify offtake via C&I PPAs, captive use, or hybrid energy models
High Operational Complexity &	Fuel quality variation,	Increased O&M costs; reduced	Technology adaptation	Invest in fuel preprocessing and

Maintenance	handling issues, boiler fouling, downtime risks	efficiency	required for mixed Indian biomass types	robust plant design to maintain uptime
Policy & Regulatory Uncertainty	Tariff structures vary by state; evolving renewable policies; limited incentives compared to solar/wind	Uncertain long-term revenue projections	Biomass often overlooked versus solar/wind in policy prioritization	Need stable policy framework and stronger REC/carbon credit monetization
Capital Requirement & Project Financing	Moderate-to-high capex with perceived technology and fuel risks	Financing costs higher; investor hesitancy	Lenders cautious due to historical underperformance of some projects	Structured financing, blended finance, and integrated waste-to-energy models improve bankability

Innovation Perspectives

Innovation	**Business Opportunity**	**For Senior Management**
Coal-to-Biomass Conversion Platforms	Fast-track decarbonization of existing fleets	Utilities under pressure to decarbonize
Biomass CHP + Industrial Heat Clusters	Anchor long-term industrial offtake	Industry struggling with Scope-1 emissions
Waste + Biomass Hybrid Plants	Dual revenue (tipping + power)	Waste crisis + energy demand
Integrated Fuel-to-Power Models	Control of cost & quality of biomass	Fuel volatility is main risk
BECCS (Carbon-Negative Power)	Selling power + carbon removal	Net-zero turning into net-negative
Energy-as-a-Service (EaaS)	Opex-based contracts with industry	Clients avoiding capex
Digital Biomass Yield Optimization	3–7% efficiency gains	Biomass quality variability
Decentralized Modular Biomass Plants	Rapid replication near residue hubs	Feedstock is geographically dispersed

District Heating & Cooling Platforms	Long-tenure urban energy concessions	Cities decarbonizing heating
Biomass + Biofuels Convergence	Closed-loop, low waste biomass + biofuel plants.	Fuels & chemicals growing faster than power

Concentric & Satellite Opportunities

- Agri-waste supply & logistics networks: Organised residue aggregation systems ensuring year-round feedstock through FPOs and rural entrepreneurs.
- Biomass power EPC & O&M firms: Specialist service providers for combustion, gasification and co-generation plants adapted to regional feedstocks.
- Ash & byproduct utilisation ventures: Concentric businesses converting biomass ash into construction additives, fertilisers, or ceramic materials.
- Distributed biomass microgrids: Decentralised plants powering rural MSMEs, cold chains and community facilities under pay-per-use models.

Key Takeaway for Senior Management

Takeaway	Details
Feedstock logistics determine profitability more than plant efficiency	• The economics of biomass plants are driven by aggregation, storage, transport, and moisture control • ***Examples****:* pelletization hubs, decentralized collection centers, seasonal buffer storage • **Competitive advantage lever:** proprietary biomass supply ecosystems reduce price volatility and plant downtime • **Innovation focus:** digital biomass marketplaces, AI logistics routing, feedstock quality sensors
Dispatchable, firm renewable power is a premium asset class	• Biomass provides firm power that complements intermittent solar/wind portfolios, and if structured well, can attract high quality capital • ***Examples****:* RTC tenders, grid balancing contracts, industrial captive supply • **Competitive advantage lever:** positioning biomass as grid-stability infrastructure commands higher valuation than pure generation • **Innovation focus:** hybrid dispatch optimization, integrated storage, smart grid participation • **Competitive advantage:** firms that position biomass as grid-stability infrastructure command premium valuation and long-term PPAs

Operational efficiency shapes lifecycle returns	• Operational performance and efficiency have significant impact on project returns • ***Sub-components****:* boiler efficiency, gas cleanup, ash handling, emissions control • **Competitive advantage lever:** optimized plant engineering increases uptime and lowers O&M costs • **Supporting statement:** operational efficiency compounds over plant life
Cluster-based deployment reduces structural cost	• Regional biomass availability density determines scalability • ***Examples****:* locating plants near agro belts, sugarcane zones, rice straw clusters • **Competitive advantage lever:** regional platform strategy lowers logistics cost per ton; distributed plants outperform centralized mega-facilities • **Innovation focus:** optimized logistics infrastructure and multi-plant portfolio management • **Competitive advantage:** regional platforms lower cost per ton and accelerate scaling
Digital plant intelligence is an underutilized moat	• Real-time fuel analytics and predictive maintenance improve reliability • ***Examples****:* moisture sensors, combustion analytics, AI maintenance scheduling • **Competitive advantage lever:** digital optimization increases uptime and IRR • **Supporting statement:** small efficiency gains materially affect cash flow

Next Steps for Corporate Leaders

Biomass power is gaining renewed attention as corporates explore firm renewable energy options and industrial users seek dispatchable alternatives to fossil-based heat and power. Modern combustion, gasification, co-firing, and CHP configurations are improving efficiency and emissions performance, while digital supply chain platforms strengthen feedstock visibility. Policy incentives, carbon markets, and residue management goals are driving interest, though biomass economics remain tightly linked to logistics, seasonal availability, and competing industrial uses.

This could be an attractive climate tech opportunity for industries and firms in specific sectors and industries keen on catering to this market.

2G
ETHANOL
ADVANCED
BIOREFINERY
ENZYMATIC
CONVERSION
AGRICULTURAL
RESIDUES
RENEWABLE
FUEL
LOW-CARBON FUEL
2G
ETHANOL
AGRICULTURAL RESIDUES • CIRCULAR FUELS • ADVANCED BIOREFINERIES
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Bio Energy

2G Ethanol

This section provides key inputs on the Indian 2G Ethanol Opportunities for corporate leaders.

Highlights

- Strong policy-driven growth opportunity anchored in India's ethanol blending targets, waste-to-fuel mandates, and government support for advanced biofuels
- Feedstock advantage from agricultural residues, enabling waste valorization while addressing stubble burning and rural income challenges
- Strategic decarbonization role in hard-to-electrify transport aligned with energy security goals
- Technology maturation phase, with early commercial plants demonstrating viability but leaving room for efficiency and scale innovation

Key recommendations for corporate leaders include:

- Secure long-term feedstock aggregation models through farmer networks, cooperatives, and logistics platforms to ensure plant utilization
- Invest in proven technology partnerships while building in-house process optimization capability to reduce operational risk
- Design integrated business models linking ethanol production with co-products (biogas, lignin power, chemicals) to enhance plant economics
- Structure projects with blended financing (policy incentives + private capital) to manage early-stage technology risk

Opportunity Snapshot: 2G Ethanol

Produce ethanol from agri residues instead of food crops using advanced biochemical processes

Market Signals

- India targeting 20% ethanol blending (E20) by 2025–26
- Push for 2G ethanol to avoid food vs fuel conflict
- Annual Market size by 2030: ₹60,000 - 70,000 Cr

What Makes or Breaks It?

- Consistent feedstock supply (from within 100 km)
- Technology performance (yield optimization, uptime >80%)
- Long-term offtake agreements with OMCs (price assurance)

Why It Matters NOW?

- Excess agri residue (stubble) causes feedstock availability also helps in pollution mitigation
- Government-backed pricing and offtake by OMCs

Well Aligned Opportunity for

- Oil marketing companies (OMCs)
- Large agri-processing and sugar companies
- Industrial players with strong capex capacity

Key Challenges

- High capex (₹800–1,200 Cr per plant)
- Complex technology with low conversion efficiency
- Feedstock collection and logistics at scale

Business Models

- Set up plants under OMC-backed or government-supported programs
- Partner with tech providers for process efficiency
- Integrate feedstock aggregation (FPOs, agri networks)

Explore this opportunity further with EAI

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Introduction and Business Case

2G ethanol is an advanced biofuel produced from non-food lignocellulosic biomass such as agricultural residues, forestry by-products and municipal solid waste. Unlike 1G ethanol, which relies on food crops, 2G ethanol eliminates the food-versus-fuel conflict while addressing India's key challenges in energy security, environmental sustainability and rural development.

By converting agri-waste into a renewable, domestically produced fuel, it reduces dependence on imported crude oil, mitigates waste disposal challenges including stubble burning and associated air pollution, lowers greenhouse gas emissions, and creates new income opportunities for farmers.

While the sector is currently (as of 2026) facing teething technology & economic challenges, one can expect rapid growth once these challenges are taken care of, given the significant demand from the passenger and light vehicle commercial transport sector, a good portion of which will rely on liquid fuels for the next few decades.

Market Potential for 2G Ethanol in India

Current gasoline demand: 4000 crore liters (2025), expected to be about 5000 crore liters by 2030 and 6000 crore liters by 2035

Year	Estimated Market Value (₹ Cr)	Total Ethanol Blend Demand (transport)	Ethanol Blend Estimate (% of total gasoline demand by volume)
2025	₹35,000-₹40,000	600-800 crore litres	15-20%
2030	₹60,000-₹70,000	1,000-1200 crore litres	20-25%
2040	₹100,000-₹130,000	1,500-1800 crore litres	25-30%

Market Segments and Applications

Segment	Applications	Business Model	Key Drivers
Transportation fuel – gasoline blending	Ethanol blended with petrol (E10–E20+)	Long-term offtake contracts	Core demand driver globally
Aviation fuel intermediates (SAF pathways)	Alcohol-to-jet (ATJ) feedstock	Long-term supply agreements	High-growth future market
Industrial chemicals & solvents	Green ethanol for chemicals	B2B supply contracts	Higher margins than fuel

Bio-based plastics & materials	Ethanol-to-ethylene, biopolymers	Strategic supply partnerships	Decarbonization of materials
Waste-to-energy & circular economy	MSW-to-ethanol pathways	Tipping fee + ethanol sales	ESG and circularity premium
Oil & gas decarbonization	Scope-3 emission reduction	Strategic supply deals	Transition fuel relevance
Hydrogen & e-fuels intermediates	Reforming to H_2 or e-fuels	Future offtake MoUs	Long-term optionality
Bio-refinery integrated platforms	Multi-product biorefineries	Platform ownership	Margin diversification
Power & CHP co-products	Lignin-based power & steam	Internal consumption	Improves plant economics
Low-carbon fuel compliance markets	Emission reduction credits	Ethanol + carbon credits	ESG compliance and carbon offsets.

Typical Project Capacities & Investments Required in India

Capacity	Feedstock Required	Estimated Capital Investment
100 KLPD	300 tons/day	₹300-₹450 crore
200 KLPD	600 tons/day	₹625-₹750 crore
500 KLPD	1,400-1500 tons/day	₹1,500- 1,750 crore

Underlying Technologies & Processes

Technology	Type	Used by	Description
Praj Enfinity	Enzymatic	IOCL, HPCL	Indian-developed process using pre-treatment + enzyme hydrolysis
Clariant Sunliquid®	Enzymatic	Pilot projects	Swiss technology - integrated enzymatic hydrolysis
Shell-Iogen	Enzymatic	Raízen Energia	Biochemical process - enzymatic hydrolysis + fermentation
Sekab CelluApp®	Enzymatic	Proposed	Swedish modular process for small-scale 2G plants

Prominent Players in the Indian Market

Company / Entity	Project Details
Indian Oil Corporation (IOCL)	Panipat, Haryana — 100 KL/day 2G ethanol plant using rice straw; among India's first large-scale commercial units.
Hindustan Petroleum (HPCL)	Bhatinda, Punjab — 100 KL/day biorefinery based on paddy straw; targets stubble burning reduction.
Bharat Petroleum (BPCL)	Bargarh, Odisha — 100 KL/day project using agri-residues (rice straw, bamboo).
Numaligarh Refinery Ltd. (NRL)	Assam — 60 KL/day 2G ethanol plant, one of the first bamboo-based biorefineries globally.
Praj Industries	India's leading technology licensor and turnkey provider for 2G ethanol; partner for IOCL, BPCL, HPCL projects.

Innovation Perspectives

Innovation	Business Opportunity	For Senior Management
Integrated 2G Ethanol + SAF Platform	Entry into **Sustainable Aviation Fuel** value chain	India's aviation fuel demand growing at ~8–10% CAGR
Agri-Residue Aggregation as a Business	"Biomass-as-a-Service" for multiple 2G plants	India's biggest bottleneck is feedstock logistics
India's biggest bottleneck is feedstock logistics	Faster replication near residue clusters	India's residue is geographically fragmented
Digital Twin & AI Yield Optimization	3–5% yield improvement = major EBITDA upside	Feedstock quality highly variable in India
2G Ethanol → Bio-Chemicals Pivot	Entry into ₹30,000+ Cr green chemicals market	FMCG & plastics players seeking green inputs
Enzyme & Yeast IP Localization	Reduce import dependence, tailor to Indian biomass	Enzymes are a major cost driver
Energy Self-Sufficient 2G Plants	Net-zero or energy-positive ethanol	Power costs volatile in India
Co-Product Monetization (Beyond Ethanol)	Converts cost center into revenue streams	India imports specialty chemicals

Key Challenges

Challenge Area	Key Issues	Business Impact	India Specific	Strategic Implications
Feedstock Supply Chain & Logistics	Collection of agri-residue (rice straw, wheat straw), seasonal availability, storage losses	High logistics cost reduces margins; inconsistent feedstock impacts plant utilization	Fragmented farming ecosystem; biomass aggregation still evolving	Long-term farmer contracts, local aggregation hubs, and digital supply tracking essential
High Capital Intensity & Technology Risk	Expensive pre-treatment and enzymatic technologies; complex plant design	Long gestation periods; high financial risk for investors	Early-stage commercializati on in India; limited proven large-scale operations	Strategic partnerships with technology providers; phased scaling reduces risk
Operational Complexity & Yield Optimization	Biomass variability affects conversion efficiency; enzyme cost and process stability	Lower yields directly impact project economics	Limited domestic experience operating commercial-scal e 2G plants	Continuous process optimization and skilled workforce development required
Policy Dependence & Offtake Structure	Reliance on ethanol blending mandates and Oil Marketing Company (OMC) procurement	Policy changes can affect pricing and demand certainty	Govt supports through E20 blending targets and viability gap funding	Secure long-term offtake agreements; diversify into bio-chemicals or SAF markets
Timing, Regional & Infrastructure Challenges	Biomass availability concentrated in certain states; logistics infrastructure gaps	Higher transportation costs; location-specific viability	Strong opportunities in Punjab, Haryana, UP due to stubble burning issues	Careful site selection near feedstock sources; integrated logistics planning critical

Concentric & Satellite Opportunities

- Agri-residue aggregation networks: Scalable FPO- and startup-led logistics models for baling, collection and moisture-controlled transport of crop residues.

- Bio-refinery EPC & technology services: Localized turnkey solutions for pre-treatment, enzymatic hydrolysis and distillation tailored to multi-feedstock Indian residues.
- Enzyme & biotech inputs manufacturing: Indigenous R&D and production of cellulases and yeasts to replace imported biologicals, driving cost reduction.
- Byproduct valorization (lignin, CO_2, ash): Conversion into bioplastics, animal feed, or carbon materials, turning waste streams into parallel revenue lines.
- Bio-CBG and green hydrogen hybrids: Integration of ethanol plants with biogas or electrolyser systems for circular energy parks.
- Rural energy & chemical hubs: Village-level refineries supplying ethanol, power and fertilizer locally, modelled after Brazil's bio-cluster zones.
- Digital traceability & carbon credit platforms: Blockchain-verified emissions reduction and sustainable feedstock sourcing for export-grade compliance.
- Sustainable consumer product lines: Satellite evolution into low-carbon chemicals, bioplastics and green solvents derived from ethanol intermediates.

Key Takeaway for Senior Management

Takeaway	Details
Feedstock logistics are a key determinant of success	• Plant economics are dominated by residue aggregation, transport, and storage reliability • ***Examples****:* rice straw collection networks, baling infrastructure, seasonal feedstock contracts • **Competitive advantage lever:** companies that build proprietary aggregation ecosystems outperform those focused only on plant engineering
Integration drives profitability, not ethanol yield alone	• 2G plants become viable when co-products are monetized • ***Sub-components****:* lignin-based products, green chemicals, steam recovery • **Competitive advantage lever:** integrated biorefinery models create diversified revenue streams • **Supporting statement:** Standalone ethanol margins are volatile; integrated plants stabilize IRR
Policy alignment is as critical as process efficiency	• Revenue certainty depends on blending mandates, offtake agreements, and incentives • ***Examples****:* OMC procurement frameworks, viability gap funding & capital subsidies, carbon credits • **Competitive advantage lever:** regulatory intelligence and policy positioning accelerate scaling • **Supporting statement:** 2G ethanol is policy-shaped infrastructure, not a pure commodity market
Operational uptime is a	• Enzyme performance, pretreatment efficiency, and

hidden value driver	maintenance discipline determine real output ● ***Examples****:* enzyme cost optimization, pretreatment chemistry tuning, predictive plant maintenance ● **Competitive advantage lever:** digital plant analytics increase yield and reduce downtime ● **That is:** Small uptime improvements materially change plant IRR
Cluster-based deployment beats isolated mega-projects	● Geographic feedstock density determines scalability ● ***Examples****:* Punjab/Haryana straw belts, sugarcane residue zones, agro-industrial clusters ● **Competitive advantage lever:** regional platform strategy reduces logistics cost per ton ● **That is:** distributed plants outperform centralized mega-facilities in feedstock-heavy industries

Next Steps for Corporate Leaders

2G ethanol is progressing from demonstration to early commercial scale as bio-refineries leverage crop residues, agro-waste, and lignocellulosic feedstocks to produce low-carbon liquid fuels for transport and industrial blending.

Policy support, blending mandates, carbon accounting, and circular bioeconomy strategies are driving interest, while technology & feedstock uncertainties, high enzyme & operational costs, and challenging offtaker interest owing to high cost of the product are affecting commercial viability.

As corporates target Scope 1 and fuel-related Scope 3 emissions reductions, 2G ethanol could offer a viable pathway in future to displace fossil fuels without engine or infrastructure change if the key technology & economic challenges are taken care of.

This could be an attractive climate tech opportunity for industries and firms in specific sectors and industries keen on catering to this market.


COMPRESSED BIOGAS (CBG)
India's Circular Bioeconomy & Clean Fuel Opportunity
BIOGAS
CLEAN ENERGY
BETTER FUTURE
CBG FUEL FOR A CLEANER INDIA
CBG
ORGANIC WASTE
CBG
GREEN PIPELINE
Waste-to-Energy
Clean Fuel Transition
Circular Bioeconomy
Prepared for Corporate Leaders & Climate-Tech Stakeholders

Bio Energy

Compressed Biogas (CBG)

This section provides key inputs on the Indian Compressed Biogas (CBG) Opportunities for corporate leaders.

Highlights

- Strong policy-backed growth opportunity under India's SATAT program and gas blending ambitions, positioning CBG as a strategic domestic fuel source
- Multi-feedstock flexibility (agri residues, municipal waste, press mud, manure) enabling circular waste-to-energy ecosystems
- Growing demand from transport and industry as a low-carbon substitute for CNG/LNG and fossil gas
- Co-product economics (organic fertilizer, digestate, carbon credits) improving overall plant viability

Key recommendations for corporate leaders include:

- Secure long-term feedstock ecosystems through options such as contract farming, farmer partnerships, and municipality contracts for waste aggregation
- Develop integrated offtake partnerships with OMCs, transport fleets, and industrial users for revenue certainty
- Design projects as circular economy platforms to monetize fertilizer, carbon credits, and waste management services

Opportunity Snapshot: Compressed Biogas (CBG)

Converts organic waste such a MSW/ agricultural waste into natural gas substitute

Market Signals

- Strong policy push via SATAT, blending mandates
- Demand led by OMC's, transport fleets, and industry fuel substitution.
- Annual Market Size by 2030: ₹7000-10000 Cr

What Makes or Breaks It?

- Feedstock Aggregation within 50-100 km radius ensuring plant utilization
- Offtake Partnerships with OMCs/CGD/ industrial buyers
- Operational Efficiency in digestion, purification and uptime (>85-90%)

Why It Matters NOW?

- Circular economy focus and push for W2E (waste-to-energy)
- Rising LNG/CNG prices, improving CBG competitiveness
- Govt. incentives + OMC demand accelerating adoption

Well Aligned Opportunity for

- Agri Supply chain players with feedstock access (FPOs, aggregators, mills)
- Fuel distribution players (CGD companies, OMC linked distributors)
- Industrial fuel consumers (cement,ceramic, chemicals), seeking fuel substitution

Key Challenges

- Aggregation & logistics inefficiency due to fragmented feedstock supply
- Long Payback Period (7-9 years), high upfront capex

Business Models

- Cluster-based projects (near feedstock/biomass zones)
- Long-term supply & offtake (FPO's +OMCs/CGD)
- Integrated model (gas + bio-fertilizer + carbon monetization)

Explore this opportunity further with EAI

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Introduction and Business Case

Compressed Biogas (CBG) is produced by purifying biogas derived from agricultural residues, animal waste, press mud, MSW and sewage sludge, such that the resulting gas matches natural gas quality standards.

CBG offers a clean, renewable substitute for fossil-based natural gas, directly usable in vehicles, city gas networks and industries. For India, CBG addresses stubble burning, waste disposal and fossil imports, while providing farmers with income streams. To this end, the central government had come up with the ambitious SATAT initiative some years back.

With strong policy tailwinds, and combined with its potential to improve energy security and rural economies, CBG can be expected to comprise a critical component of India's bio-economy.

Market Potential for Compressed Biogas in India

Year	Market Size (₹ Cr)	Capacity Outlook	Drivers
2025	1300-1500	~200-250 kT	Initial SATAT plants operational; OMC offtake contracts.
2030	7,000-10,000	~1000-1500 kT	Scale-up with 5,000+ SATAT plants; CGD blending.
2040	45,000-60,000	~5000 - 7000 kT	Mass adoption in transport, CGD grids and industry.

Market Segments and Applications

Segment	Applications	Business Model	Key Drivers
Utility-scale biomethane production	Grid injection, Bio-CNG for mobility, industrial gas substitution	Own–operate–integrate	Decarbonization of gas portfolios
Landfill & waste-based RNG	Bio-CNG for transport fleets, pipeline RNG	Asset-heavy ownership + offtake contracts	Low-carbon fuel credits
Biomethane production platforms	Industrial fuel switching, grid gas, mobility fuels	Platform acquisition + long-term PPAs/offtake	EU Fit-for-55, energy security, Scope-1 & 3 reductions
Renewable gas	Grid-injected	Utility-style ownership	Gas decarbonization

utilities	biomethane, municipal gas supply	+ regulated sales	commitments by cities & utilities
Residue-based BioCNG & BioLNG	Transport fuels (Bio-CNG/Bio-LNG), industrial users	Integrated producer + fuel marketer	Agricultural waste utilization; transport fuel decarbonization
Biogas & biomethane infrastructure	Bio-CNG plants, upgrading systems, bio-LNG	EPC + O&M + selective asset ownership	Global demand for turnkey biomethane projects
Transport fuel retail	Fleet Bio-CNG (trucks, buses), refuse vehicles	Fuel offtake + station infrastructure	Fleet ESG targets; LCFS & carbon credit monetization
Dairy & organic waste RNG	Bio-CNG, pipeline RNG, transport fuels	JV-led project development + integration	Methane abatement + ultra-low CI fuels
Biomethane project pipeline	Grid biomethane, future Bio-CNG mobility	Equity stakes + project pipeline build-out	Iberian biomethane policy push; gas decarbonization

Typical Project Capacities & Investments Required in India

Project Type	Feedstock	Typical Size	Output	Indicative CapEx (₹ Cr)
Cluster CBG (entry)	Cattle dung + agri residues	2-5 TPD CBG	700-1,800 kg/day	12-25
MandI/Agri-hub CBG (standard)	Press-mud/bagasse, straw, F&V waste	10-15 TPD CBG	3,500-5,000 kg/day	35-60
Large CBG (industrial)	Mixed residues + segregated OFMSW	30-50 TPD CBG	10,000-17,000 kg/day	80-140
MSW-to-CBG (urban)	OFMSW (source-segregated)	10-20 TPD CBG	3,500-7,000 kg/day	40-80
Integrated bio-fert line	Digestate processing	50-150 TPD wet digestate	30-60 TPD bio-fert	6-15

Underlying Technologies & Processes

Element	Options	Key Traits
Feedstock	Agri residues, dung, press-mud, MSW, sewage sludge	Abundant, region-specific; moisture & collection critical.
Conversion process	Anaerobic digestion → raw biogas	Proven, scalable; yields biogas + digestate (bio-fertilizer).
Purification & upgrading	PSA, water scrubbing, membrane separation	Removes CO_2, H_2S, moisture; produces >95% pure methane.
Compression & storage	CBG compressed to 200-250 bar	Matches CNG specs; allows transport and retail.
By-products	Digestate → biofertilizer; CO_2 → industrial use	Adds revenue streams and circularity.
Distribution	CGD pipeline injection, cascades, bottling plants	Ensures end-user access in transport & industry.

Key Challenges

Challenge Area	Key Issues	Business Impact	India Specific	Strategic Implications
Feedstock Supply Chain & Aggregation	Collection of agri-waste, municipal waste, or organic feedstock; seasonal variability; logistics complexity	Inconsistent feedstock reduces plant load factor and impacts revenue stability	Fragmented waste streams; dependence on local ecosystem (farms, mandis, municipalities)	Long-term feedstock agreements, decentralized collection hubs, and strong local partnerships needed
Capital Intensity & Financing Risk	High upfront capex for digestion, upgrading systems, compression units, and infrastructure	Long payback periods; investor risk perception due to operational complexity	SATAT scheme supports projects but financing challenges remain	Structured financing, subsidies, and JV models improve bankability
Offtaker Agreements & Pricing Structure	Dependence on Oil Marketing Companies (OMCs) or local	Revenue predictability tied to policy-driven procurement	SATAT provides offtake assurance but contract	Diversify customers (transport, industrial fuel,

	gas demand; pricing uncertainty		execution varies	CGD networks)
Operational Complexity & Technology Reliability	Feedstock quality variability, biological process sensitivity, gas upgrading efficiency	Operational downtime increases costs; affects project economics	Limited skilled manpower and technical expertise in some regions	Invest in robust technology, automation, and experienced operators
Policy, Infrastructure & Regional Constraints	Pipeline access, gas bottling logistics, local regulatory approvals, land availability	Slower project timelines; increased logistics costs	CGD network expansion uneven across states; regional viability differs	Select locations near gas grids, urban waste sources, or transport corridors

Prominent Players in the Indian Market

Company / Entity	Project Details
Verbio India	Punjab straw-based biorefinery producing ~33 TPD CBG; largest operational project.
EverEnviro Resource Mgmt.	Developing 20+ CBG plants; JV with ONGC for national rollout.
GPS Renewables	Partnering with BPCL & Oil India to build multi-plant CBG portfolios.
Indian Oil / BPCL / HPCL (OMCs)	Anchor offtakers under SATAT with long-term purchase agreements.
Adani Gas / Torrent Gas	Integrating CBG into city gas distribution (CGD) networks.
PRESPL	Biomass aggregation and pelletisation; collaborating with developers for CBG feedstock supply.
Carbonlites	Unique circular economy solution that converts wet waste into CBG and organic fertilisers.
Torrent Gas	City Gas Distribution (CGD) business with nationwide presence.

Innovation Perspectives

Innovation	Business Opportunity	For Senior Management
Biomethane as a global traded molecule	Global **biomethane trading desk**,	Book-and-claim markets, corporate green gas contracts
Waste-to-value at massive scale	Roll-up of **stranded methane assets**	AI-driven landfill optimization, carbon-negative fuels
Ultra-low CI fuels	Premium **negative-CI fuel markets**	Carbon removal-linked fuel products
Residue-first feedstock innovation	Large-scale **straw-to-BioCNG/BioLNG**	Replicable **crop-residue platforms** across Asia, Africa, Eastern Europe
CBG at population scale	Ability to deploy hundreds of plants with captive demand	**CBG-as-a-network**, rural energy + fertilizer loops, gas-to-chemicals integration
City-scale circular gas	**Urban circular-economy platforms**, long-term city decarbonization contracts	Links municipal waste, heat, power & gas grids
CBG as a fleet decarbonization service	Fuel-plus-carbon-credits bundles	Zero-capex fleet conversion models
Biogas plant as a product	Platformization of plants	Licensing + O&M-as-a-service globally
Early-stage biomethane pipeline capture	Locking up prime sites before market maturity	**First-mover advantage** in Iberian green gas certificates & contracts

Concentric & Satellite Opportunities

- Feedstock aggregation & logistics networks: FPO- and startup-led systems for collecting, preprocessing and supplying dung, press-mud and crop residues.
- CBG plant EPC & technology providers: Concentric firms offering turnkey biogas-to-CBG systems with local digester and upgrader manufacturing.
- Bio-fertiliser processing & marketing units: Enterprises converting digestate into branded organic fertilisers for regional agri-markets.
- Rural clean-fuel entrepreneurship clusters: Village-scale franchise models for community CBG stations and local transport refuelling.

- Agro-industrial integration models: Satellite ecosystems linking sugar mills, dairies and food processors into circular bioenergy hubs.
- CBG-PNG Blending Infrastructure: Injection kits for city gas networks (10-20% blend).
- CBG Compressors & Bottling Stations: High-pressure cascades for CNG-equivalent filling (200-250 bar).

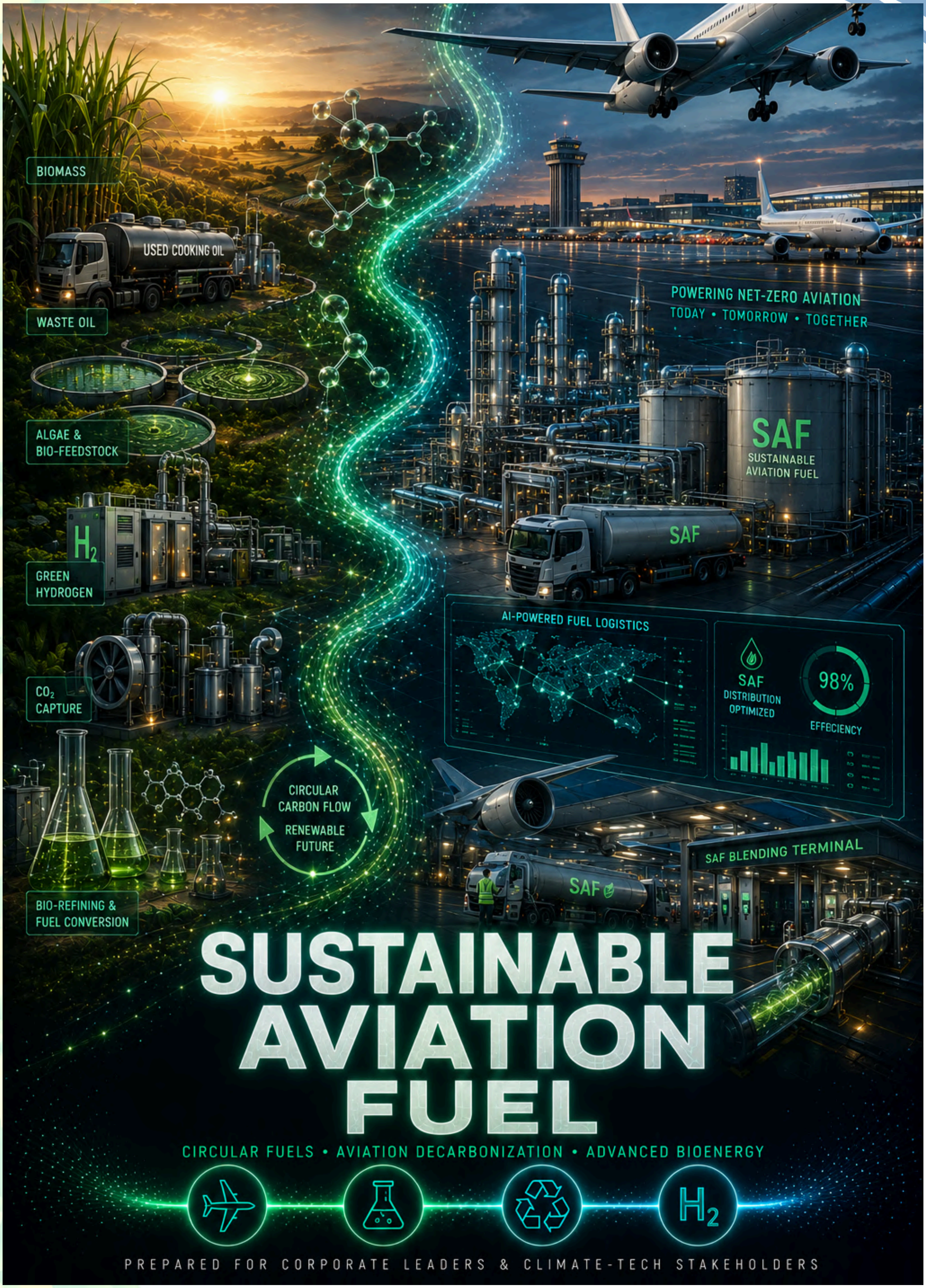
Key Takeaway for Senior Management

Takeaway	Details
Feedstock ecosystems determine long-term defensibility	• CBG economics are driven by reliable organic waste aggregation, not just plant technology • ***Examples***: cattle manure networks, agri-residue contracts, municipal waste tie-ups, press mud sourcing • **Competitive advantage:** proprietary waste aggregation platforms create supply moats competitors cannot replicate
CBG is a circular economy infrastructure business, not a fuel plant	• Profits come from integrated monetization of gas + fertilizer + carbon benefits • *Sub-components:* digestate processing, bio-fertilizer branding, carbon credit stacking • **Competitive advantage:** diversified revenue stabilizes returns beyond gas pricing cycles
Offtake partnerships shape bankability more than production capacity	• Revenue certainty depends on long-term OMC contracts, fleet agreements, and industrial buyers • ***Examples***: transport fuel supply contracts, city gas distribution tie-ins
Operational uptime is the hidden IRR driver	• Digester stability, gas purification efficiency, and maintenance discipline define output • ***Examples***: biological process optimization, predictive maintenance, gas analytics • **Innovation focus:** AI-driven digester control and performance monitoring, and digital plant intelligence can significantly increase yield and reliability
Cluster deployment beats isolated projects	• Feedstock density and logistics economics favor regional platforms especially around feedstock availability clusters • ***Examples***: dairy clusters, sugar belts, agro-processing zones • **Competitive advantage:** lower logistics cost and scalable platform growth

Next Steps for Corporate Leaders

Compressed Biogas is advancing as a low-carbon substitute for CNG/LPG in transport, industrial heat, and city gas networks, supported by feedstock availability, waste-to-energy policy, SATAT programs, and interest from OMCs and CGD operators. CBG's value proposition is strengthened by circular bioeconomy applications, digestate utilization for soil health, and carbon market opportunities — though project viability hinges on feedstock aggregation, gas purity, pipeline integration, and long-term offtake.

This could be an attractive climate tech opportunity for industries and firms in specific sectors and industries keen on catering to this fast growing market.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USED COOKING OIL
WASTE OIL
ALGAE & BIO-FEEDSTOCK
GREEN HYDROGEN
CO_2 CAPTURE
BIO-REFINING & FUEL CONVERSION
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H_2
PREPARED FOR CORPORATE LEADERS & CLIMATE-TECH STAKEHOLDERS

Bio Energy

Sustainable Aviation Fuel

This section provides key inputs on the Indian Sustainable Aviation Fuel Opportunities for corporate leaders.

Highlights

- Massive structural demand growth driven by airline net-zero commitments, ICAO mandates, and emerging blending requirements
- Premium pricing environment as SAF commands green fuel premiums relative to conventional jet fuel
- Feedstock diversity opportunity (waste oils, agri residues, municipal waste, alcohol-to-jet pathways) enabling circular economy integration
- Strong policy and ESG tailwinds attracting climate finance, government incentives, and long-term offtake agreements

Key recommendations for corporate leaders include:

- Invest in proven conversion technologies while maintaining flexibility for next-gen pathways
- Secure long-term airline and fuel offtake partnerships to guarantee revenue visibility
- Build feedstock aggregation ecosystems to stabilize input costs and plant utilization
- Design SAF projects as integrated circular platforms monetizing carbon credits and co-products.

Opportunity Snapshot: Sustainable Aviation Fuel (SAF)

Low-carbon aviation fuel from biomass, waste oils, or synthetic (e-fuels)

Market Signals

- Demand due to airline decarbonisation
- India exploring blending targets (1-5%) by 2030
- Annual Market size by 2030:₹1000 - 2000 Cr

What Makes or Breaks It?

- Access to sustainable feedstock (oils, agricultural residues)
- Ability to achieve cost competitiveness vs jet fuel (scale+tech efficiency)
- Long-term offtake agreements with airlines ensuring revenue visibility

Why It Matters NOW?

- Secured future demand, as industry committing to net zero by 2050
- Early mover advantage; lock in long-time supply contracts, premium pricing

Well Aligned Opportunity for

- Refineries, oil marketing companies- brownfield leverage
- Biofuel producers especially ethanol, biodiesel or advanced fuels
- Integrated energy companies

Key Challenges

- High production cost; 2-4x more than conventional fuel
- Lack of domestic policy clarity and guaranteed offtake in India

Business Models

- Partnerships with airlines
- Integration with existing refineries
- Long-term supply agreements

Explore this opportunity further with EAI

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Introduction and Business Case

Aviation is one of the hardest sectors to decarbonise — batteries are too heavy and offsets are not enough. Sustainable Aviation Fuel (SAF), liquid fuels quite similar to the ones currently used, and produced from feedstocks like agri-residues, used cooking oil, municipal waste and synthetic fuels (Power-to-Liquids), are perhaps the only feasible option for the aviation sector to significant decrease lifecycle CO_2 emissions.

For India, with air travel projected to triple by 2040, SAF is both a climate necessity and an economic opportunity: reducing import dependence, building new rural value chains and positioning India as a SAF export hub for global airlines.

While SAF still faces challenges on technology maturity and economics, strong industry and policy tailwinds, along with the significant attendant bio-economy benefits, are likely to make SAF an attractive investment domain for select Indian industries and companies.

Market Potential for Sustainable Aviation in India

Year	Market Size (₹ Cr)	Capacity Outlook	Drivers
2025	Less than 100	Pilot/demo plants	Airline blending pilots; global pressure.
2030	1,000-2,000	100-200 million litres	ICAO CORSIA compliance; oil refiners scaling SAF.
2040	35,000-40,000	5-6 billion litres	Large-scale adoption; India as SAF export hub.

Market Segments and Applications

Segment	Applications	Business Model	Key Drivers
Global airlines, fuel distributors	Drop-in SAF for commercial aviation	Large-scale production + long-term offtake	Airline decarbonization mandates & global SAF quotas
North American airlines	Jet fuel replacement	Dedicated SAF refinery + contracts	U.S. tax credits & early airline demand
Airlines, airports, fuel traders	Co-processed and neat SAF	Refinery integration + fuel trading	EU ReFuelEU Aviation mandate
Airlines, corporate aviation	SAF supply, blending,	Global supply & trading platform	Corporate Scope-3 reduction commitments

	certificates		
Airlines, fuel blenders	HEFA & ATJ SAF	Integrated fuels + technology partnerships	Policy incentives + refinery transition
Airlines, ethanol producers	ATJ-based SAF	Technology licensing + project equity	Feedstock flexibility beyond waste oils
Airlines, corporates	Net-zero / carbon-negative SAF	Project development + long-term offtake	Premium pricing for low-CI fuels
Airlines, municipalities	MSW-to-SAF	Waste-to-fuel plant ownership	Landfill diversion + circular economy economics
Airlines, fuel marketers	HEFA & ATJ SAF	Integrated biofuels platform	Vertical integration & U.S. SAF incentives
Airlines, financiers	Multi-pathway SAF	Platform & aggregation model	Capital-light scale via ecosystem control

Typical Project Capacities & Investments Required in India

Project Type	Typical Capacity	Indicative CapEx (₹ Cr)	Notes
HEFA/HVO → SAF (lipids: UCO, tallow, non-edible oils)	100-400 KTPA	1,800-6,500	Mature route; hydroprocessing + isomerisation; renewable diesel + SAF cut.
Alcohol-to-Jet (ATJ; 2G ethanol/iso-butanol)	50-200 KTPA	1,500-4,500	Integrates with 2G ethanol; dehydration-oligomerisation-hydrogenation.
Fischer-Tropsch (FT; biomass/MSW/biogas + green H_2)	50-150 KTPA	2,500-8,000	Gasification + FT; complex syngas clean-up; co-produces naphtha/diesel.
Co-processing in existing refineries (HEFA blend-in)	20-80 KTPA	250-900	Uses available hydrotreater capacity; limited SAF %; fast-to-market.
e-SAF (Power-to-Liquids; CO_2 + green H_2)	10-50 KTPA	3,000-10,000	Early-stage; high RE/H_2 intensity; premium export potential.

Underlying Technologies & Processes

Element	Options	Key Traits
Feedstocks	Used cooking oil (UCO), agri-residues, municipal solid waste, lignocellulosic biomass, synthetic (e-fuels)	Defines sustainability, availability and cost.
Conversion pathways	HEFA (Hydroprocessed Esters & Fatty Acids), ATJ (Alcohol-to-Jet), FT (Fischer-Tropsch), PtL (Power-to-Liquids)	HEFA most mature; ATJ and FT scaling; PtL long-term.
Blending	Certified up to 50% with fossil jet fuel	Drop-in solution; requires no aircraft/engine modification.
Infrastructure	Integration with existing refineries, dedicated SAF biorefineries	Reduces CapEx, speeds adoption.
Policy drivers	ICAO CORSIA, EU mandates, Indian biofuel policy	Ensures long-term demand pull.

Key Challenges

Challenge Area	Key Issues	Business Impact	India Specific	Strategic Implications
High Production Cost & Economic Viability	SAF significantly more expensive than conventional jet fuel; technology costs still high	Limits airline adoption without mandates or incentives; margin pressure	India lacks strong SAF blending mandates compared to EU/US	Need policy incentives, carbon pricing, and scale-driven cost reductions
Feedstock Availability & Supply Chain Complexity	Competition for feedstock (used cooking oil, agri-residue, waste oils, biomass)	Feedstock price volatility impacts project economics	Competing demand from bio-diesel, 2G ethanol, and CBG sectors	Diversified feedstock strategy and localized sourcing essential
Demand Certainty & Offtaker Agreements	Airlines sensitive to fuel price increases; voluntary adoption limited	Revenue uncertainty without long-term purchase agreements	Indian airlines operate on thin margins; cost sensitivity high	Long-term SAF purchase agreements with airlines and export buyers critical
Technology Maturity & Infrastructure	Multiple production pathways	Operational risk and high technical	Limited domestic commercial-scale SAF plants	Partnerships with global technology providers and

Gaps	(HEFA, ATJ, FT) still evolving; certification requirements	complexity	currently	phased deployment
Policy, Geopolitics & Market Timing	Dependence on global carbon regulations and aviation decarbonization targets	Export competitiveness influenced by global sustainability standards	Opportunity to become SAF export hub but policy clarity evolving	Alignment with ICAO/CORSIA frameworks and strategic airport hubs

Prominent Players in the Indian Market

Company / Entity	Focus Areas
Indian Oil Corporation (IOCL)	SAF trials with Indian airlines; feedstocks include waste oils and bio-based lipids.
Hindustan Petroleum (HPCL) / Bharat Petroleum (BPCL)	Building SAF capacity in upcoming bio-refineries.
CSIR-IIP (Indian Institute of Petroleum)	Developed indigenous SAF production technology.
Praj Industries	Tech provider for alcohol-to-jet (ATJ) pathways.
Airlines (Indigo, SpiceJet, Air India)	Early adopters of SAF blends for pilot flights.
Startups (GPS Renewables, BuyoFuel)	Building pathways for waste-based biofuels; exploring SAF-linked opportunities.

Innovation Perspectives

Innovation	Business Opportunity	For Senior Management
SAF as a long-term contracted infrastructure asset	SAF infra platforms, project finance at scale	Bankable cash flows similar to midstream assets
Feedstock-flexible fuel pathways	Multi-pathway SAF hubs	Reduces supply risk and policy dependence
Ultra-low & negative-CI SAF	Carbon-negative aviation fuels	Premium pricing + carbon credit upside
Alcohol-to-Jet (ATJ) scaling	Repurposing ethanol assets for SAF	Breaks HEFA feedstock bottleneck

Waste-to-SAF circular economy	City-linked SAF plants	Solves waste + fuel problems simultaneously
Power-to-Liquid (e-SAF)	Airport-adjacent e-fuel hubs	Long-term net-zero aviation solution
Platform & aggregation models	SAF marketplaces & certificate trading	Capital-light, high-control model
SAF certificates & book-and-claim	Digital SAF credit exchanges	Enables global corporate demand
Refinery co-processing transformation	Brownfield refinery repurposing	Low-capex, fast scaling
Airline-embedded SAF partnerships	Airline-anchored SAF ecosystems	Demand-locked growth

Concentric & Satellite Opportunities

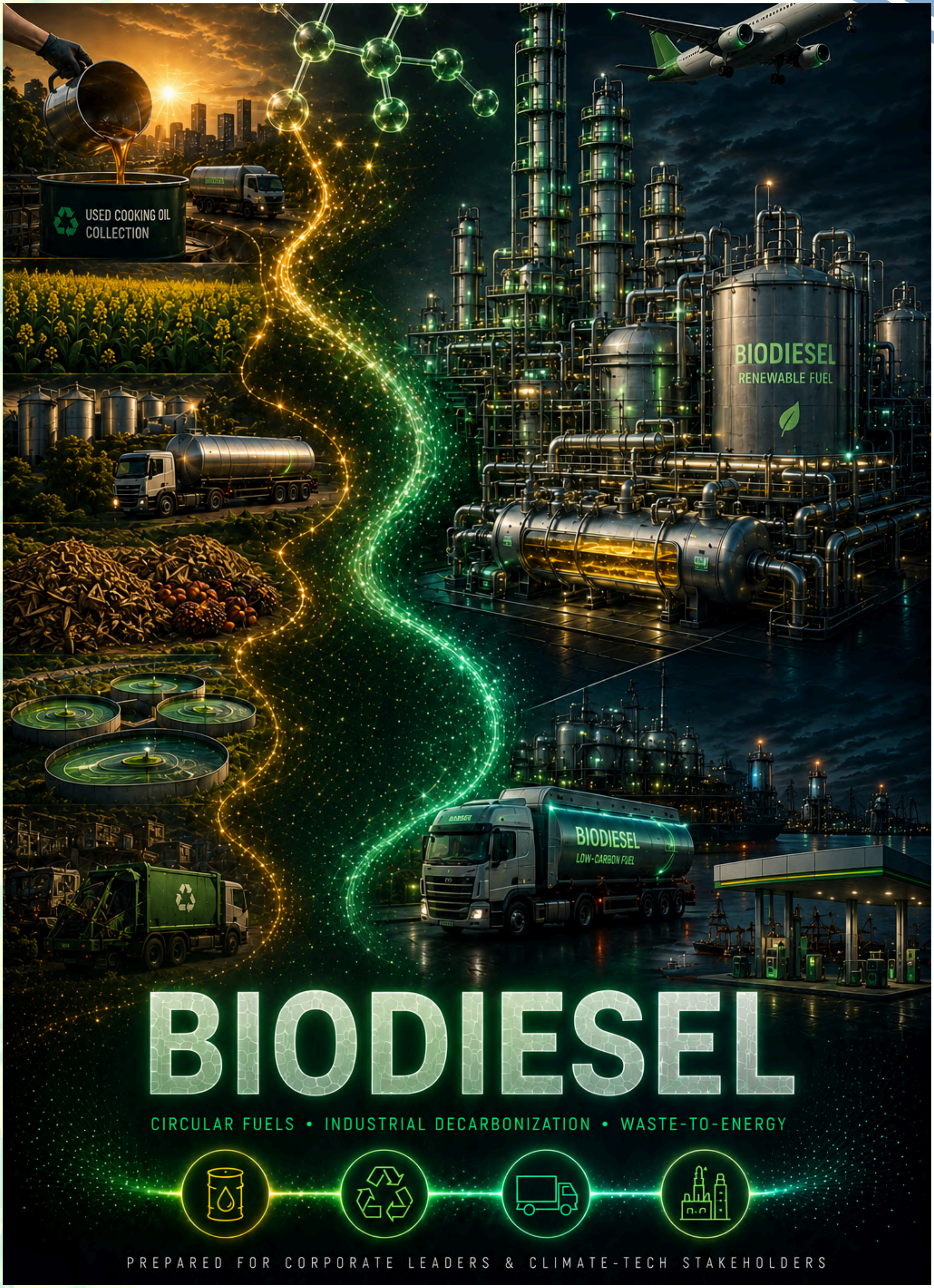
- Feedstock aggregation and traceability networks: Concentric supply chains digitising the collection of used cooking oil, non-edible oils and agri residues with blockchain-backed traceability and assured quality.
- Refinery co-processing retrofits: Brownfield integration of SAF production within existing hydrotreater units at IOC, BPCL and HPCL refineries for low-capex, near-term deployment.
- Hydrogen and CO_2 integration hubs: Shared green hydrogen and captured CO_2 infrastructure serving ATJ, FT and e-SAF facilities under cluster-based industrial parks.
- Airport blending and storage upgrades: Infrastructure developers modernising aviation fuel hydrant systems, segregated tanks and quality labs for safe SAF handling and scalability.
- MRV and carbon credit platforms: Digital systems capturing feedstock-to-flight lifecycle data to issue CORSIA/EU-compliant carbon intensity credits and SAF certificates.
- Catalyst and process optimisation R&D: Satellite ventures innovating catalysts and process intensification for ATJ/FT pathways tailored to Indian feedstock chemistry.
- Export-oriented e-fuel projects: Coastal e-SAF facilities leveraging abundant solar and wind power for high-value export markets under long-term offtake contracts.
- Rural lipid & biomass farming cooperatives: FPO-led energy crop plantations (Pongamia, Jatropha, Sal seed) linking sustainable feedstock production with rural job creation.

Key Takeaway for Senior Management

Takeaway	Details
SAF is a long-term demand certainty market, not a speculative fuel play	• Airline net-zero commitments, ICAO/CORSIA frameworks, and blending mandates create structural demand • ***Examples****:* airline offtake agreements, airport SAF hubs, long-term supply contracts • **Competitive advantage:** early movers lock in premium customers and long-term pricing power
Feedstock ecosystems determine scalability and margin stability	• SAF plants compete on feedstock reliability, not just conversion efficiency • ***Sub-components****:* waste oils, agri residues, municipal waste streams, alcohol-to-jet feedstocks • **Competitive advantage:** proprietary feedstock ecosystems reduce volatility and protect margins
Technology flexibility is a hedge against pathway risk	• HEFA, ATJ, and FT pathways evolve rapidly; rigid plants risk obsolescence • ***Examples****:* modular upgrading units, multi-feedstock reactors • **Innovation focus:** flexible process architecture and rapid retrofit capability
Integrated carbon monetization amplifies project economics	• SAF value includes fuel + carbon credits + ESG premiums • ***Examples****:* carbon markets, airline sustainability premiums, lifecycle emissions certification • **Competitive advantage:** diversified revenue beyond fuel sales
Cluster deployment creates infrastructure platforms	• SAF hubs near airports and logistics centers reduce transport costs and enable scale • ***Examples****:* airport fuel clusters, port-based SAF terminals • **Competitive advantage:** shared infrastructure and platform logistics

Next Steps for Corporate Leaders

Sustainable Aviation Fuels are accelerating as airlines, airports, and corporates pursue aviation decarbonization pathways aligned with CORSIA, ICAO, and net-zero commitments. Drop-in blending capabilities, multiple technology pathways (HEFA, ATJ, FT, and emerging e-fuels), and growing policy support are expanding the market — while supply constraints, feedstock competition, and cost premiums remain primary barriers. As corporates face increasing Scope 3 travel emissions scrutiny, SAF is becoming a core lever for compliant, credible emissions reduction without fleet or infrastructure change.
This could be an attractive climate tech opportunity for industries and firms in specific sectors and industries keen on catering to this market.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PREPARED FOR CORPORATE LEADERS & CLIMATE-TECH STAKEHOLDERS

Bio Energy

Biodiesel

This section provides key inputs on the Indian Biodiesel Opportunities for corporate leaders.

Highlights

- Policy-supported growth opportunity driven by blending targets, waste oil mandates, and energy security goals
- Waste-to-fuel ecosystem converting used cooking oil, animal fats, and agri-waste into transport fuel
- Growing industrial and fleet demand for low-carbon diesel substitutes under ESG pressure
- Relatively mature conversion technology enabling faster plant deployment compared to newer biofuel pathways

Key recommendations for corporate leaders include:

- Design a combination that is built for redundancy by choosing a technology that can utilize multiple feedstocks and building supply chains around diverse feedstocks such as edible oil waste, used cooking oil, animal fat
- Form long-term offtake partnerships with OMCs, logistics fleets, and industrial buyers

Opportunity Snapshot: Biodiesel

Diesel substitute/blend from used sustainable sources such as non-edible oils, cooking oil (UCO) etc

Market Signals

- India targeting ~5% biodiesel blending
- Strong demand from transport fleets, OMCs, and industrial users
- Annual Market size by 2030: ₹5,000 - 7,000 Cr

What Makes or Breaks It?

- Used cooking oil sourcing through HoReCa and aggregator networks
- Long-term offtake agreements with aOMCs(IOC/BPCL/HPCL) and bulk fleet/industrial users.
- Transition to 2G biodiesel using HVO technology

Why It Matters NOW?

- Cost competitive alternative fuel with rising diesel prices
- Waste- to-fuel model using used cooking oil & select agri residues

Well Aligned Opportunity for

- Fuel distributors and aggregators
- Agri/oil processing companies
- Waste management and UCO collection players

Key Challenges

- Feedstock such as used cooking oil requires city-level aggregation networks, currently fragmented
- Margin volatility due to diesel linked pricing
- Strict BIS fuel standards for OMS offtake

Business Models

- Set up plants near urban UCO clusters, partner with aggregators/restaurants for feedstock sourcing
- Offtake partnerships with OMCs and bulk fuel consumers

Introduction and Business Case

Biodiesel—typically FAME (Fatty Acid Methyl Ester) produced from used cooking oil (UCO), non-edible oilseeds, waste fats and agricultural by-products—has emerged as a strategic renewable fuel in India's transition toward cleaner energy.

Diesel accounts for nearly half of India's petroleum consumption in heavy transport, railways, Agricultural machinery, construction & mining. These segments cannot electrify rapidly, ensuring long-term demand stability for biodiesel as a complement to diesel. Biodiesel plants present economically viable operations at scale, but only when feedstock for such large scale operations is secured.

If the feedstock supply challenges are taken care of - we do admit that this is a BIG IF - biodiesel is one of the few renewable fuels in India that can deliver significant national benefits across energy, environment, industry and livelihoods, thus presenting a high-impact and attractive business opportunity.

Market Potential for Biodiesel in India

Year	Market Size (₹ Cr)	Capacity Outlook	Drivers
2025	2000	0.17 million tonnes	Reduces dependence on imports.
2030	5,000-7,000	0.40 million tonnes	Broadening the demand base.
2040	10,000-15,000	1 million tonnes	Lower lifecycle CO_2 emissions.

Market Segments and Applications

Segment	Applications	Business Model	Key Drivers
Advanced biodiesel (HVO / renewable diesel)	Road diesel blending, heavy-duty transport	Large-scale refinery production + long-term offtake	Low-carbon fuel mandates & premium pricing
Waste- & residue-based biodiesel	Transport fuel, industrial diesel	Feedstock-secured production	Sustainability criteria & lower carbon intensity
Agri-origin biodiesel	Road transport, agriculture machinery	Vertical integration (farm → fuel)	Abundant oilseed supply & rural policy support

Rendering & by-product biodiesel	Transport fuel blending	Waste conversion + supply contracts	Circular economy economics
Refinery co-processing biodiesel	Drop-in diesel replacement	Brownfield refinery integration	Low capex SAF/biofuel scale-up
Merchant biodiesel producers	Blended diesel markets	Spot market + short-term contracts	Biodiesel blending mandates
Export-oriented biodiesel	International fuel markets	Trade & arbitrage model	Regional policy differentials
Forest & non-food biomass biodiesel	Transport, industrial fuel	Technology-driven production	Food-vs-fuel risk mitigation
Low-carbon credit-optimized biodiesel	Transport fuels	Fuel + carbon credit monetization	LCFS & carbon pricing regimes
Integrated biofuels platforms	Multi-fuel (biodiesel, RD, SAF)	Portfolio diversification model	Risk hedging across policies & markets

Typical Project Capacities & Investments Required in India

Project Type	Typical Capacity	Indicative CapEx (₹ Cr)	Notes
Medium	30 KLPD	6 - 8	Medium-scale operation
Large	100 KLPD	15 - 20	Large-scale operation

Underlying Technologies & Processes

Element	Options	Key Traits
Feedstocks	Used Cooking Oil (UCO), non-edible oil crops (Tree-borne Oils - TBO), animal fats, palm stearin and industrial by-product oils	Requires strong pre-treatment, Dehulling & expelling, strong acidic esterification
Conversion pathways	Transesterification (Base-catalyzed), Two-step Esterification, Enzymatic (Lipase-based) Conversion, Hydrotreating (HVO / Renewable Diesel)	Low-FFA oils react quickly, transesterification at mild conditions, No catalyst, Thermal cracking
Blending	5% - 20% blending of HEFA (Hydroprocessed Esters and Fatty Acids),	Easy rollout, no engine changes, Larger renewable penetration, Major emission

	ATJ (Alcohol-to-Jet), PtL / e-SAF (Power-to-Liquid / e-Kerosene)	gains. Requires large-scale feedstock, Limited OEM uniform approval, Needs engine testing.
Infrastructure	Feedstock collection, production, storage & logistics, blending	Pre-filtration, Decorticators, Oil expellers, Acid esterification, Multi-feedstock compatibility, Moisture-free design
Policy drivers	Sets a target of 5% biodiesel blending, Repurpose Used Cooking Oil initiative, OMC Procurement Programs	Blending Targets, Approval of Multiple Feedstocks, Depot-Level Blending Mandate, RUCO Traceability, Feedstock Source Verification, sector-specific policy provisions

Key Challenges

Challenge Area	Key Issues	Business Impact	India Specific	Strategic Implications
Feedstock Availability & Cost Volatility	Limited availability of used cooking oil (UCO), non-edible oils, waste fats; fragmented collection systems	Raw material cost fluctuation reduces margins and production stability	Dependence on imports for some feedstocks; UCO aggregation ecosystem still developing	Strong sourcing networks, waste collection partnerships, and diversified feedstock strategy essential
Policy Support & Blending Mandate Uncertainty	Lack of strong mandatory biodiesel blending compared to ethanol blending	Demand growth slower; revenue visibility limited	National Biofuel Policy supports biodiesel but implementation varies	Need clearer mandates, incentives, and consistent pricing mechanisms
Offtaker & Pricing Challenges	Dependence on Oil Marketing Companies (OMCs) procurement programs	Pricing tied to policy decisions; limited private market adoption	Indian fuel market dominated by OMCs; contract execution variability	Diversify customers (industrial users, mining, logistics fleets)
Competition from Alternative	EV adoption, green hydrogen,	Long-term demand	India's electrification	Focus on niche applications

Decarbonization Technologies	and other biofuels competing for investment	uncertainty impacts investor confidence	push may reduce diesel demand over time	(heavy-duty transport, generators, marine)
Operational & Quality Compliance Challenges	Feedstock variability affecting fuel quality; storage and oxidation issues	Higher operational costs and compliance requirements	BIS standards and certification requirements must be maintained	Invest in quality control systems and technology upgrades

Prominent Players in the Indian Market

Company / Entity	Focus Areas
Emami Agrotech	Large-scale FAME production, feedstock sourcing (edible & non-edible oils), exports, OMC supply contracts
Indian Oil Corporation (IOCL)	Procuring & blending biodiesel (UCO based)
Bharat Petroleum Corporation (BPCL)	Procurement, blending trials, supplier tie-ups
Pan Oleo Energy	Large scale producers of biodiesel and other chemicals.
Godavari Biorefineries	Biorefining (ethanol, chemicals) and diversification into biofuels value chains
Praj Industries	Enzymatic biodiesel tech (Ecodiezel™), plant design, integrated biorefinery solutions

Innovation Perspectives

Innovation	Business Opportunity	For Senior Management
Feedstock-control platforms	Feedstock marketplaces, long-term supply monopolies	Structural cost and CI advantage
Advanced biodiesel (HVO) scale-up	Refinery conversion & HVO hubs	Higher blending limits, premium pricing
Carbon-intensity optimization	Carbon-optimized fuel portfolios	Unlocks credit-driven margins
Multi-fuel biorefineries	Integrated low-carbon fuel	Risk diversification across

	complexes	mandates
Waste-to-fuel circular models	Municipal waste partnerships	Secures cheap feedstock
Brownfield refinery repurposing	Refinery transition strategies	Lower capex, faster deployment
Export arbitrage strategies	Global biofuel trading desks	Policy-driven margin uplift
Non-food biomass pathways	Advanced feedstock R&D platforms	Avoids food-vs-fuel backlash
Digital traceability & certification	Data-led fuel certification services	Regulatory compliance moat
Credit stacking business models	Carbon-backed biodiesel platforms	Multiple revenue streams

Concentric & Satellite Opportunities

- Continuous High-Yield Transesterification OEM: Modular reactor skids for ultra-fast, continuous conversion, minimizing catalyst and improving ester yield.
- Crude Glycerin Purification and Valorization Hubs: Co-located units refining crude glycerin co-product into high-grade chemical inputs (e.g., propylene glycol).
- Integrated Multi-Feedstock Pre-treatment Systems: Acid esterification and degumming units handling high Free Fatty Acid (FFA) wastes (UCO) with optimal catalyst efficiency.
- Sustainable Feedstock Aggregation Networks: Digitized reverse-logistics for collection, grading and spec-locked delivery of Used Cooking Oil (UCO) and other non-food lipids.
- Next-Gen Oilseed/Algae Cultivation and Harvest Tech: Providers licensing high-yield, non-food competing oilseed crops or advanced photobioreactors for scalable algal oil production.
- Algae-bacteria bioreactors: R&D and manufacturing of consortium systems for nutrient-rich wastewater to lipids; dual wastewater treatment.
- Busbar & connector fabrication: Precision copper/aluminum stamping for cell-to-pack wiring; high-current designs
- Biodiesel Cold Flow Additive/Formulation R&D: Satellite labs developing proprietary additives and blend recipes to significantly improve fuel performance in cold weather.
- Specialized Biodiesel Blending & Distribution Hubs: Optimized tank farms and logistics infrastructure near markets for blending and ensuring quality control of B20/B100 fuels for fleet customers.

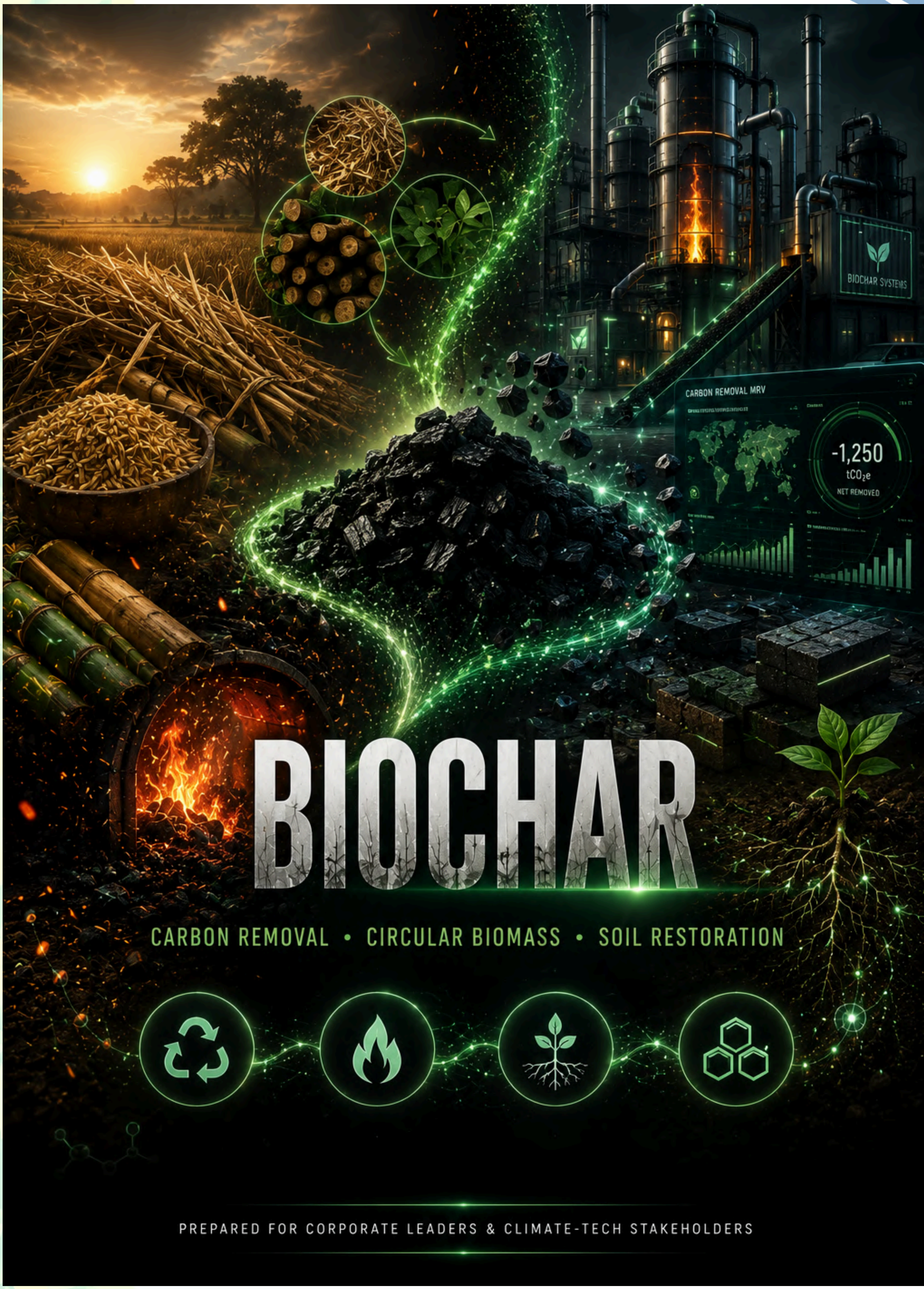
Key Takeaway for Senior Management

Takeaway	Details
Feedstock ecosystems are the true competitive battlefield	• Biodiesel profitability depends more on used cooking oil and waste-fat aggregation than plant efficiency • ***Examples****:* restaurant collection networks, municipal grease recovery, industrial waste oil contracts • **Innovation focus:** digital feedstock marketplaces, IoT collection tracking, smart logistics routing
Quality standardization determines long-term market access	• Transport fleets and OMCs require consistent fuel specifications • ***Sub-components****:* ester purity control, filtration systems, compliance testing, certification labs • **Innovation focus:** automated quality analytics and traceability platforms
Digital plant intelligence improves lifetime IRR	• Predictive maintenance and process analytics increase uptime, decrease unit costs and enhance profitability. • ***Examples****:* automated process monitoring and optimization, intelligent plant control systems

Next Steps for Corporate Leaders

Biodiesel is gaining traction as a near-term, drop-in solution for decarbonizing logistics, heavy vehicles, diesel gensets, and industrial heat with minimal infrastructure change. Feedstock diversification (used cooking oil, animal tallow, palm stearin, distillers' corn oil, and other residual lipids), transesterification technology maturity, and the emergence of carbon markets are strengthening viability — though global supply remains constrained by feedstock competition and cost differentials against fossil diesel. As Scope 1 and logistics-related Scope 3 emissions face increasing scrutiny, biodiesel offers an immediately actionable pathway for fuel substitution.

This could be an attractive climate tech opportunity for industries and firms in specific sectors and industries keen on catering to this market.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Bio Energy

Biochar

This section provides key inputs on Biochar Opportunities for corporate leaders.

Highlights

- Biochar delivers long-term carbon sequestration (hundreds of years) while improving soil health, water retention, and nutrient efficiency
- Durable CDR buyers, corporate net-zero commitments, and regenerative agriculture programs are driving demand for verified biochar credits and products
- Agricultural residues, forestry waste, and organic by-products can be locally sourced, reducing logistics cost and enabling decentralized deployment
- Carbon removal credits + biochar sales (agriculture, construction, filtration) + waste-handling fees enhance project IRRs

Key recommendations for corporate leaders include:

- Anchor projects around assured agri-residue, forestry waste, or organic by-product supply to ensure stable operations
- Design projects to meet durable carbon removal standards with digital traceability and lifecycle accounting
- Lock in buyers in agriculture, soil remediation, construction materials, and filtration to diversify revenue

Opportunity Snapshot: Biochar

Produce carbon-rich material via pyrolysis of agri waste, used for soil enhancement and other uses

Market Signal

- Rising demand for carbon removal solutions (voluntary carbon markets)
- Growing interest from global buyers for carbon credits (CDR markets)
- Annual Market size by 2030: ₹4000 - 6000 Cr

What Makes or Breaks It?

- Ability to monetize carbon credits
- Consistent feedstock supply within 50–100 km radius
- Reliable pyrolysis systems with stable yield (~25–35% biochar output)

Why It Matters NOW?

- Increasing focus on carbon removal; not just emission reduction
- Increasing adoption in agriculture (soil health, water retention) and emerging industrial uses

Well Aligned Opportunity for

- Agri aggregators and FPOs
- Carbon credit developers/platforms
- Waste management and biomass players

Key Challenges

- Low standalone product value without carbon credit monetization
- Lack of standardized carbon credit verification frameworks (MRV complexity)

Business Models

- Set up decentralized pyrolysis units near agri clusters
- Partner with carbon registries for credit certification
- Sell to agriculture and carbon markets

Explore this opportunity further with EAI
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Introduction and Business Case

Biochar is a carbon-rich product made by pyrolyzing agricultural and forestry residues. When it is used as a soil nutrient and buried into the soil, it locks carbon into a stable form for centuries, making it a powerful carbon removal tool while improving soil health, water retention and nutrient efficiency.

Biochar projects thus create triple value: climate mitigation through negative emissions, sustainable agriculture through better yields and lower fertilizer use and rural income by valorizing agri-waste.

With carbon markets opening up and India generating millions of tonnes of residues, biochar is an emerging climate tech opportunity for Indian businesses.

Market Potential for Biochar Projects in India

Year	Market Size (₹ Cr)	Drivers
2025	800-1,200	Pilot plants, carbon credit pilots, organic farming use.
2030	4,000-6,000	Scale-up through carbon markets; agri & horticulture adoption; blending into cement/construction.
2040	12,000-18,000	Large-scale deployment in farming systems, carbon removal credits, integration in industrial materials.

Market Segments and Applications

Segment	Applications	Business Model	Key Drivers
Carbon Removal Biochar	Durable carbon sequestration	Carbon credit offtake contracts	Corporate net-zero and carbon-removal demand
Agricultural Soil Amendment	Crops, pasture, horticulture	Product sales + agronomy partnerships	Soil health, yield resilience, nutrient efficiency
Waste Biomass Conversion	Forestry residues, ag waste, organics	Waste processing fees + biochar sales	Waste reduction and circular economy mandates
Distributed Biochar Systems	On-farm or regional biomass	Equipment sales + service contracts	Local feedstock utilization and logistics efficiency

Industrial-Scale Pyrolysis	High-volume biochar and co-products	Capex-heavy production + long-term offtake	Economies of scale and consistent output
Biochar-Based Carbon Credits	Verified carbon markets	Credit issuance + verification fees	High-quality, permanent carbon credit demand
Biochar in Construction Materials	Concrete, asphalt, composites	Material supply + licensing	Embodied carbon reduction in construction
Environmental Remediation	Soil, water, mine reclamation	Project-based contracts	Pollution control and regulatory compliance
Energy Co-Products & Bio-Oil	Renewable fuels, energy recovery	Co-product sales + integration	Improved project economics
Biochar Blends & Specialty Products	Horticulture, consumer soils	Branded product sales	Premium markets and ease of adoption

Typical Project Capacities & Investments Required in India

Project Type	Typical Capacity	Indicative CapEx (₹ Cr)	Notes
Modular pyrolysis (entry)	1-3 TPD feedstock	2-5	Containerised kilns; village/mandi scale; sells to farms & composters.
Cluster pyrolysis hub (mid-scale)	10-30 TPD	12-35	Multiple reactors + dryer; anchors carbon credit programs; power/heat recovery.
Industrial plant (large)	50-100 TPD	40-90	Continuous kilns, waste-heat boiler, densification line; serves construction/water treatment.
Activation & finishing line	3-10 TPD biochar input	10-25	Steam/chemical activation for higher-value adsorbent grades.
Mobile pyrolysis fleet	0.5-1 TPD per unit	0.8-1.5 / unit	Follows harvests; reduces agri-burning; feeds a central finishing hub.
MRV & lab package	NA	3-6	QA (pH, carbon content, PAH), carbon accounting & project monitoring.

Underlying Technologies & Processes

Element	Options	Key Traits
Feedstock	Crop residues (paddy straw, husk, shells), forestry residues, organic waste	Abundant, low-cost, region-specific supply.
Conversion process	Slow pyrolysis • Fast pyrolysis • Gasification-derived biochar	Determines char yield vs. syngas/oil; affects carbon stability.
Co-products	Bio-oil, syngas, heat	Can be used for process energy or sold as additional fuels.
Applications	Soil amendment, animal feed additive, construction filler, activated carbon	Multi-sector uses increase project viability.
Carbon credits	Verified under VCS/Gold Standard methodologies	Drives financial viability via carbon removal markets.

Key Challenges

Challenge Area	Key Issues	Business Impact	India Specific	Strategic Implications
Biomass Feedstock Supply Chain & Logistics	Securing consistent biomass supply (agri residues, forestry waste) at scale	Production variability and cost volatility	Seasonal availability; competing uses (fodder, fuel, biomass power); fragmented collection systems	Develop localized feedstock clusters and long-term sourcing contracts
Monetization & Market Development	Limited domestic demand awareness for biochar applications (soil amendment, carbon sequestration)	Revenue uncertainty without diversified markets	Early-stage market maturity; limited agronomy adoption	Combine revenue streams (soil products, carbon credits, waste management fees)
Carbon Credit Verification &	Biochar economics often	Delayed revenue	Evolving carbon market	Invest in robust MRV systems and

MRV Complexity	depend on carbon credit revenues	realization and compliance costs	standards and methodologies	verified methodologies early
Technology Selection & Operational Reliability	Choice of pyrolysis technology affects efficiency, emissions, and output quality	High capex risk if technology underperforms	Limited local track record of large-scale biochar facilities	Pilot projects and modular scalable systems recommended
Policy, Regional & Financing Constraints	Limited policy clarity and financing structures for biochar projects	Slower investment and scaling	Regional agricultural practices vary; evolving biomass regulations	Align with waste management, regenerative agriculture, and carbon policy frameworks

Prominent Players in the Indian Market

Company / Entity	Project Details
Takachar (startup from IIT Delhi)	Portable small-scale pyrolysis units for rural deployment; global awards for biochar innovation.
ArSta Eco	ArSta eco offers Biochar based soil improvers for all your agriculture and horticulture needs.
Anulekh	Their premium biochar is a versatile solution for landscaping, construction, and carbon credit initiatives.
MASH Makes	They use thermochemical processes to convert agricultural waste into bio oil, hydrogen, and electricity. The main byproduct of this process is biochar—a form of charcoal that captures CO2 from the atmosphere. Biochar can then be added to soil to support plant growth.
CarbonLites / GPS Renewables	Exploring biochar as part of agri-waste valorization portfolios and carbon-credit generation.
Farm2Energy	Punjab-based company piloting biochar production from paddy straw.
International Collaborations (Charm Industrial, Carbonfuture)	Partnering with Indian players for carbon removal credits and technology transfer.

Innovation Perspectives

Innovation	Business Opportunity	For Senior Management
Biochar as Durable Carbon Removal	Long-term carbon removal offtake platforms	Premium pricing and long-term contracts
Feedstock Control & Aggregation	Regional feedstock hubs	Cost-curve leadership and scalability
Multi-Revenue Biochar Plants	Integrated project economics	Higher IRR and resilience to price swings
Distributed Pyrolysis at Scale	Asset-light deployment models	Faster expansion and local partnerships
Industrial-Scale Carbon Plants	Anchor projects with large buyers	Institutional capital attraction
Biochar-Enabled Low-Carbon Materials	Supply agreements with construction players	Access to massive embodied-carbon markets
Outcome-Based Soil Carbon Solutions	Performance-linked agronomic products	Farmer adoption and recurring demand
Digital MRV Platforms for Biochar	Third-party MRV-as-a-service	Platform economics and ecosystem lock-in
Waste-to-Biochar Partnerships	Long-term waste-processing contracts	De-risked feedstock and stable cash flow
Biochar + Nature Credit Stacking	Multi-credit monetization platforms	Revenue diversification beyond carbon

Concentric & Satellite Opportunities

- Agri-waste collection & pyrolysis unit manufacturing: Local fabrication of low-cost, modular pyrolysis reactors for smallholder and FPO clusters.
- Soil amendment & carbon farming services: Concentric ventures linking farmers with biochar application training and verified soil-carbon credits.
- Carbon credit aggregation platforms: Fintech-enabled registries pooling small-scale producers for high-integrity, MRV-compliant offset projects.
- Biochar-enhanced fertilizer blending: Integration of biochar into compost and NPK formulations to improve soil health and moisture retention.
- Construction and material innovation: Satellite use of biochar in bricks, concrete and asphalt for lightweight, low-carbon building materials.

- Activated carbon & specialty products: High-value biochar conversion into activated carbon, pigments and electrode materials.
- Screw auger reactors: Continuous herbaceous waste processing at 450°C; 25% bio-oil co-product for rural energy.

Key Takeaway for Senior Management

Takeaway	Details
Biochar is durable carbon removal infrastructure, not just an agri input	• Biochar locks carbon for centuries while delivering agronomic and environmental co-benefits • ***Examples****:* soil carbon sequestration, improved water retention, nutrient efficiency; carbon-negative construction additives • **Suggested focus:** positioning biochar as long-lived CDR with co-benefits, and enhancing eligibility for premium, durable CDR markets vs short-lived offsets
Feedstock security and quality determine scalability and costs	• Stable, low-cost biomass supply underpins project economics • ***Sub-components****:* agri residues (rice husk, corn stover), forestry waste, organic by-products; moisture and ash content management • **Suggested focus:** feedstock aggregation, preprocessing, and multi-feedstock flexibility • **Competitive advantage:** predictable operations and lower unit costs competitors struggle to replicate
Monitoring, Reporting & Verification (MRV) credibility is key to obtain premium carbon revenues	• Buyers demand verified permanence and traceability • ***Sub-components****:* lifecycle analysis, batch tracking, digital chain-of-custody, third-party standards • **Competitive advantage:** access to premium buyers and faster offtake vs unverifiable projects
Revenue stacking materially improves IRRs and resilience	• Single-revenue projects underperform • ***Examples****:* CDR credits + biochar sales (agriculture, construction) + waste handling fees + heat/power co-products • **Competitive advantage:** higher, more stable cash flows across market cycles

Next Steps for Corporate Leaders

Biochar projects are emerging as a strategic pathway for carbon removal, soil enhancement, and biomass residue valorization. Demand is being driven by voluntary and compliance carbon markets, regenerative agriculture programs, and corporate Scope 3 strategies. Biochar enables long-term carbon storage, improves soil fertility, and creates circular value from agricultural, forestry, and industrial biomass residues. As certification standards mature and farmer ecosystems evolve, biochar is transitioning from niche sustainability projects to scalable climate and circularity investments.

This could be an attractive climate tech opportunity for industries and firms in specific sectors and industries keen on catering to this fast growing market.