Innovations for integration of LNG-CBG-Hydrogen Hubs: A Multi-Fuel Energy Business Model

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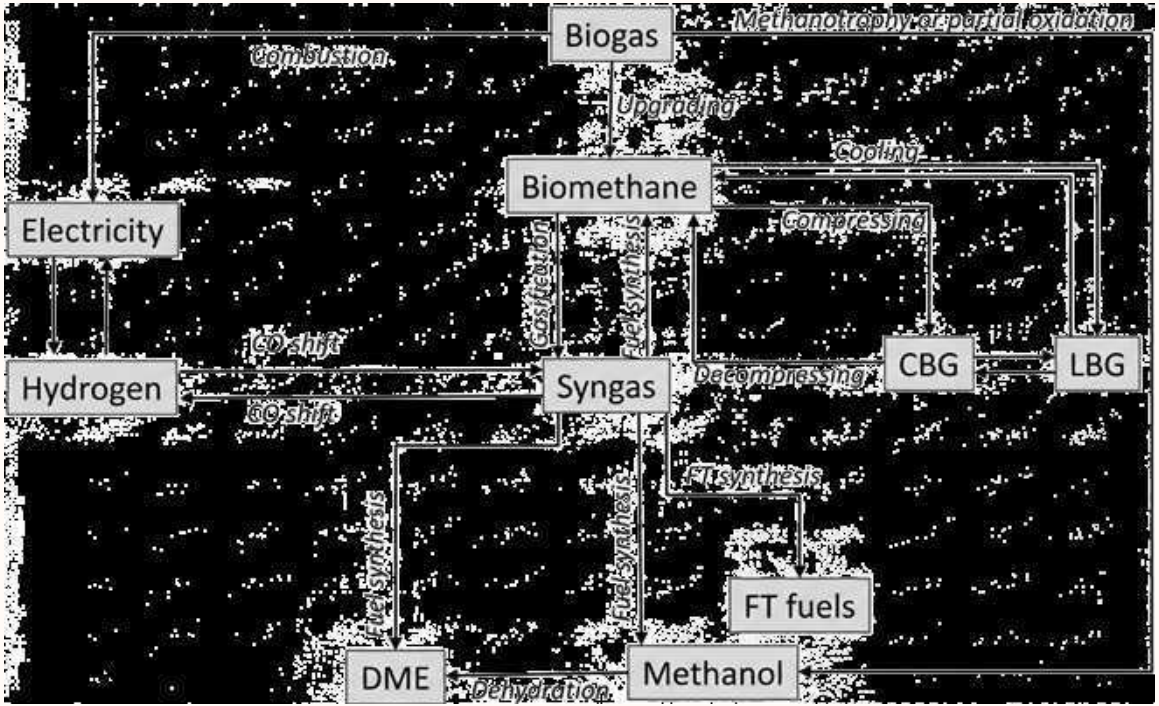
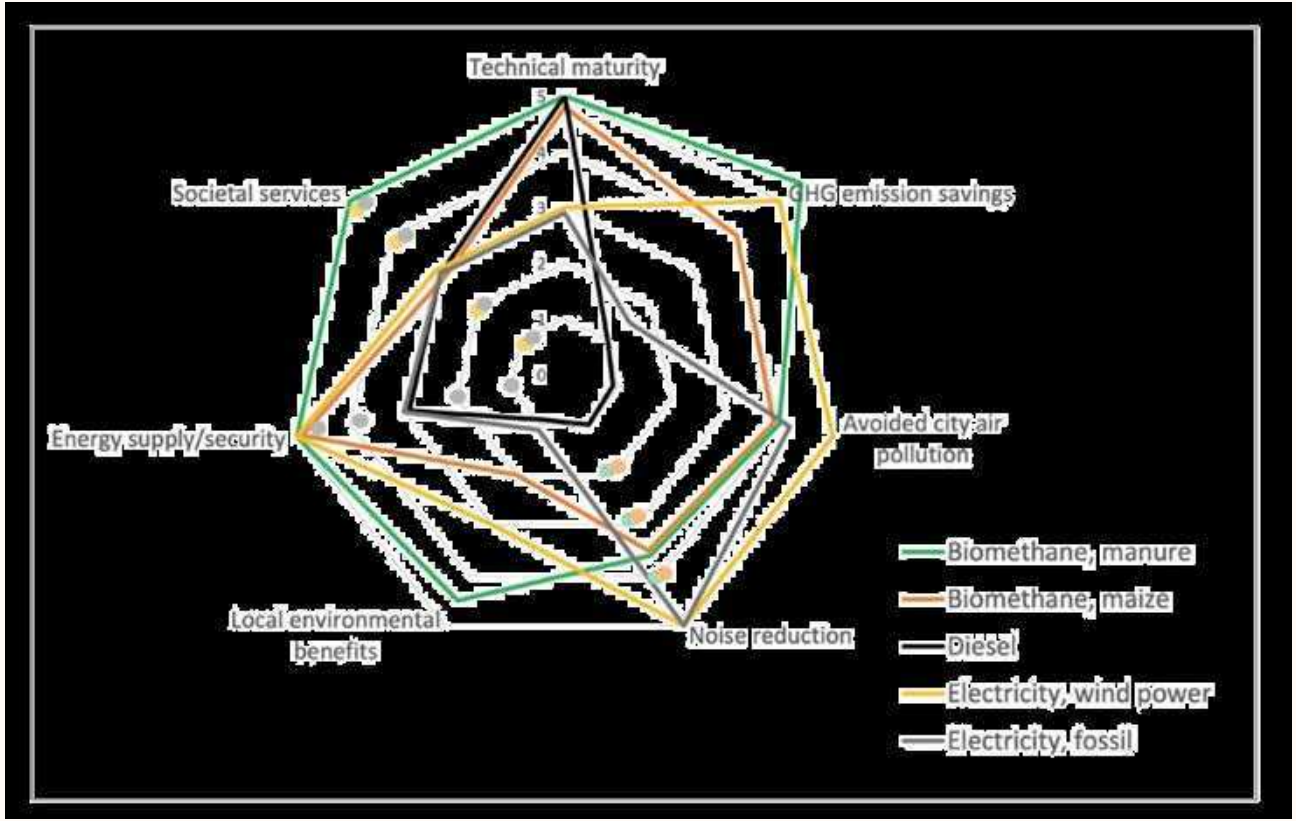
Biogas Valorization & Value Chain



The Biogas can be converted to following fuels:

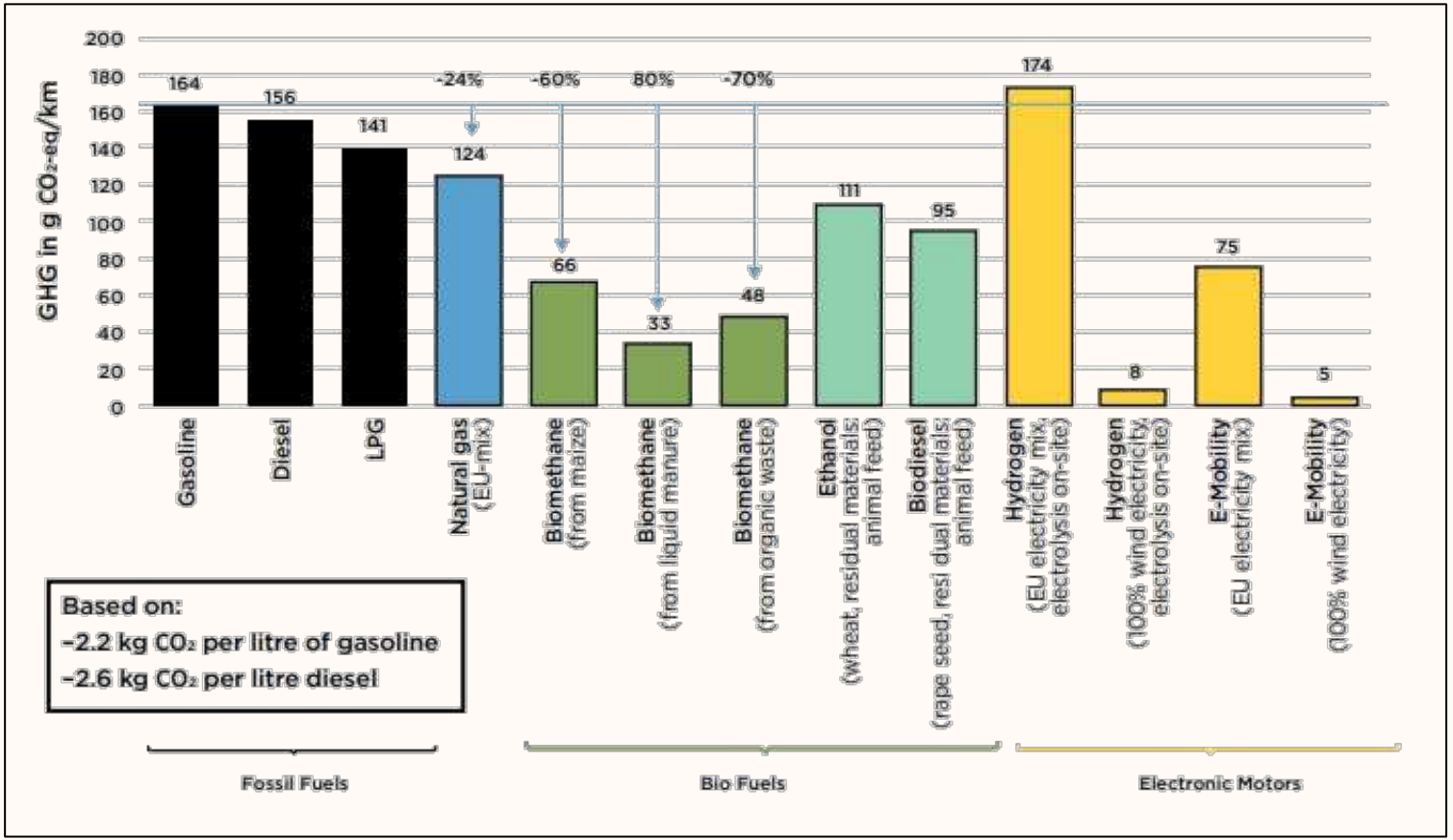
1) Compressed Bio Gas (CBG)
2) Liquefied Bio Gas (LBG)
3) Bio- Hydrogen (B-H_2)
4) Synthetic Methane (E-CH_4)
5) DME
6) Methanol
7) Syngas
8) Other FT process Fuels.

Sustainability Assessment of Alternative Vehicle Fuels



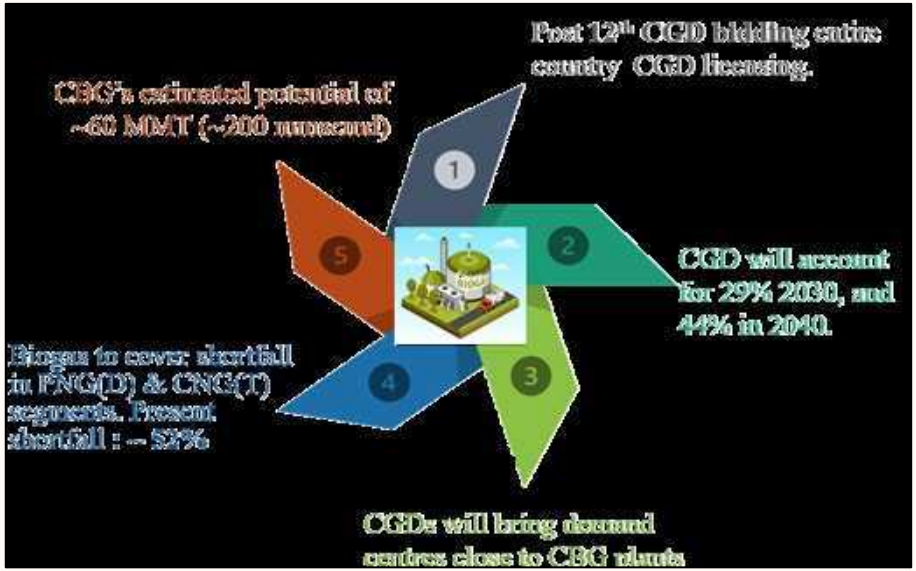
Source: EBA

Comparative GHG Emissions of Alternative Vehicle Fuels



Source: EBA

Indian CBG Market Potential & CGD Integration Pathways



Key Statistics of Indian CBG Scenario

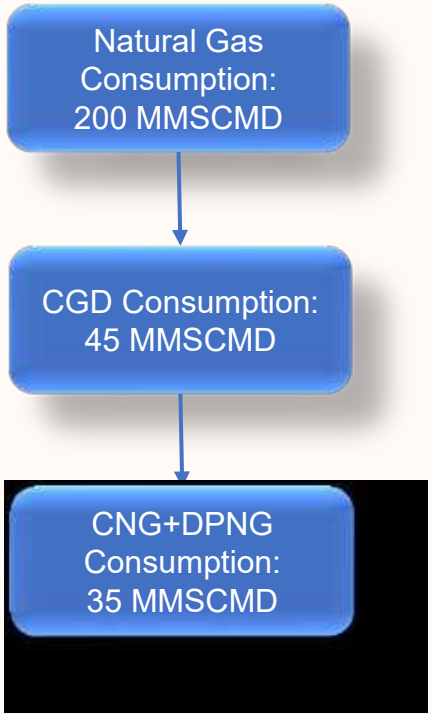
India imports ~51% of its natural gas requirement.

Domestic CBG production a strategic alternative to reduce import dependence and improve energy security.

CBG Sales Growth

Metric	FY26	FY27 (YTD)
SATAT (TPD)	~136	~260
Synchro (TPD)	~242	~480
Total CBG Sales (TPD)	~378	~740
Equivalent Gas (MMSCMD)	~0.5	~1
Penetration of DPNG+CNG Market	~0.0148	~0.029

DPNG + CNG account for ~78% of CGD demand



IGL: AI-Driven CBG Plant Optimization

Implementing a Cognitive Intelligence platform as Proof of Concept to maximize methane yield, ensure operational stability, and enhance efficiency across Bio-CNG plants.

Strategic Objectives

- **Methane & Gas Quality:** Maximize methane yield and overall purified gas standards.
- **Stability & Reliability:** Minimize process variance and prevent operational disruptions.
- **Feedstock & Waste:** Optimize feedstock utilization and cut organic process waste.
- **Energy Efficiency:** Reduce power and auxiliary heat consumption across facilities.
- **System Uptime:** Increase overall plant availability and reduce unscheduled downtime.
- **Smart Decision:** Enable automated, real-time data-driven operational insights.

Success Metrics

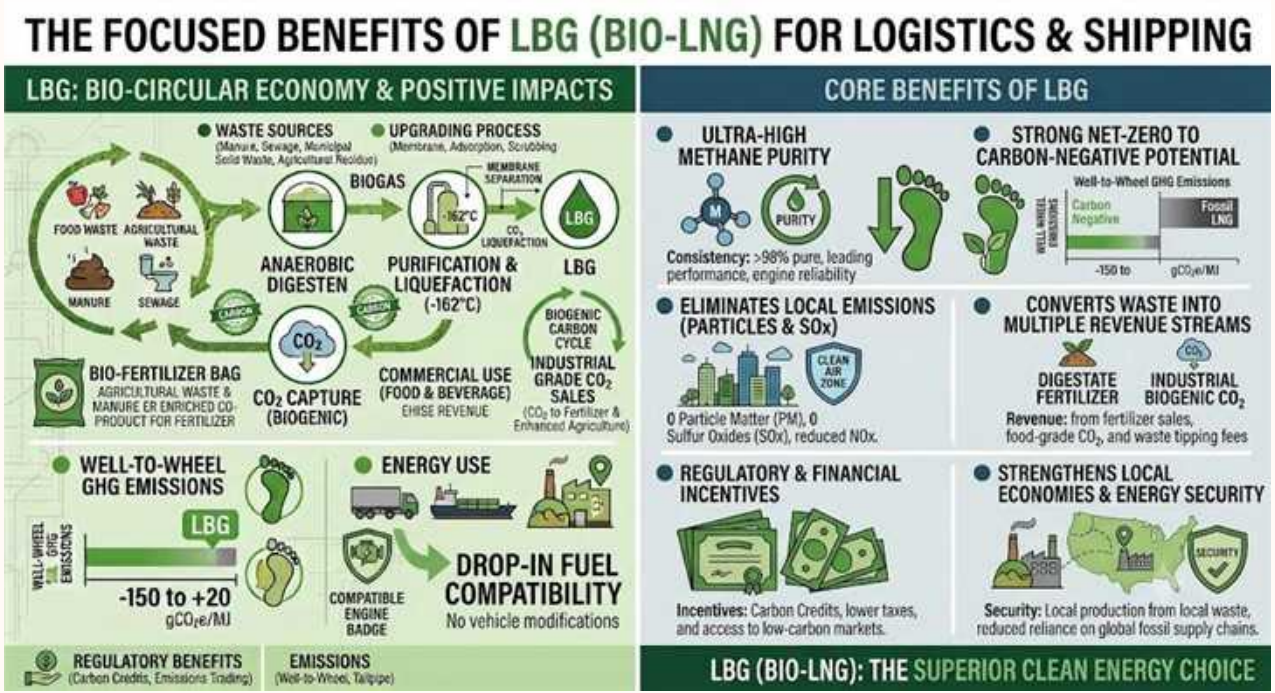
Methane Yield Increase
% increase in methane output per unit of feedstock input.

Plant Process Stability
Reduction in process variance and anaerobic instability events.

Downtime Reduction
Decrease in unplanned shutdowns and emergency maintenance hours.

Early Anomaly Detection
Improvement in time-to-alert for process risks vs baseline.

Liquefied Bio-methane (Bio LNG or LBG)



- Globally a number of CBG plants are being set up/upgraded to make LBG.
- O&G major like Shell are investing in this solution.
- GAIL has also doing PoC at a CBG plant in Punjab
- Can solve the issue LNG transportation/losses/ lack of pipeline infra →through in-situ production.
- Agriculture heavy states can use the same of farm machinery & Agri produce logistics.

Current State and Growth Projections of Indian HCV Sector

Metric	Current Data
Total heavy-duty commercial vehicles (HCV)	~3.5 million trucks — India's largest HDV fleet globally after China
LNG trucks operational (end 2025)	~1,309 — up 75% from 747 in 2024, but <0.04% of total fleet
CNG vehicles (all types)	8.5 million+ NGVs; 8,400+ CNG stations nationwide
Diesel's share of long-haul HCV fleet	~99.9% — diesel is almost entirely dominant in long-haul heavy freight
India's truck fleet growth projection	From ~3.5 million (2025) to ~17 million trucks by 2050 (NITI Aayog)
Annual diesel consumed by HCV sector	~75-80 million tons — the single largest end-use of diesel in India

Scenario	LNG Trucks 2030	LNG Trucks 2035	Fleet Share 2035	Annual Diesel Displaced	Annual Forex Saving
Conservative (Current trajectory, no new policy	8,000-12,000	25,000-40,000	<1%	2-3 MT/year	~$1.4B - $2.1B
Moderate (GST, state STC conversions, captive fleet mandates)	80,000-1,20,000	2,50,000-3,50,000	5-6%	18-25 MT/year	~$12.6B - $17.5B
Accelerated (Ethanol-mandate-style demand policy + 1,000 stations + Fleet commitment)	2,00,000-2,50,000	5,00,000-7,00,000	10-12%	40-55 MT/year	~$28B - $38.5B

10% LBG

Hydrogen categories and production pathways

Type of hydrogen		Feedstock	Energy source	Process	Products	Carbon Footprint (kg CO_2 / Kg H_2)	Remarks
Brown/Black		Coal or lignite	Coal	SMR in combination with gasification	H_2 + CO + CO_2 (released)	18 to 20	Established industrial process for converting organic or fossil materials into CO, H_2, and CO_2.
White		Naturally occurring			H_2		Geological hydrogen found underground or created via fracking.
Grey		Natural Gas	Natural Gas	SMR	H_2 + CO_2 (released)	9 to 11	SMR of fossil natural gas without any greenhouse gas capture.
Blue		Natural Gas	Natural Gas	SMR	H_2 + CO_2 (captured and stored)	1.5 to 5	Similar to grey, but the CO_2 is captured and stored with CCS technology.
Turquoise		Natural Gas	Natural Gas	Pyrolysis	H_2 + C (solid)	2.5 to 4.5	Methane pyrolysis is used to produce H_2 and solid carbon.
Red		Water	Nuclear Power	Catalytic splitting	H_2 + O_2	0.2 to 2	Thermochemical catalytic splitting powered by nuclear heat.
Purple/Pink		Water	Nuclear Power	Electrolysis	H_2 + O_2	0.2 to 2	Electrolysis powered by nuclear electricity.
Green	RFNBO (non-biological hydrogen)	Water	Renewable electricity	Water splitting (thermolysis, photolysis, electrolysis)	H_2 + O_2	0.5 to 1.5	Water splitting powered by renewable sources like solar or wind.
	Bio-hydrogen (biological hydrogen)	**Bio-hydrogen (biological origin)**	**Biogenic sources (biomass, biogas, bio-methane)**	**Biomass-derived energy**	**H_2 + biogenic CO_2 + co-products**	**-26.5 to 10.8**	**Can be Carbon Negative when combined with CCS or obtained from organic feedstock**

SMR: steam methane reforming; CSS: carbon capture and storage; RFNBO: renewable fuels of non-biological origin. Adapted from Sustainable NI (2022).

Energy system integration with Bio-Hydrogen

System Flexibility

Grid expansion, energy storage, and demand response

Cross-Sector Coupling

Unifying power, gas, heat, and transport sectors

Cost-Effective Pathways

Upgrading raw biogas & CO_2 into additional bio-methane.

Technology Readiness Level (TRL) of each Bio-hydrogen production technology

TRL Explanation	Bio-hydrogen technologies	TRL
0-3: Idea	Photo-fermentation	3
4–5: Prototype	Bio-electrochemical	3
	Dark fermentation	3–4
6–7: Validation	Bio-photolysis	4
	Pyrolysis	3–8
8–9: Production	Gasification	7–8
	BMSR	9

Comparative Cost Analysis of Bio-hydrogen Production

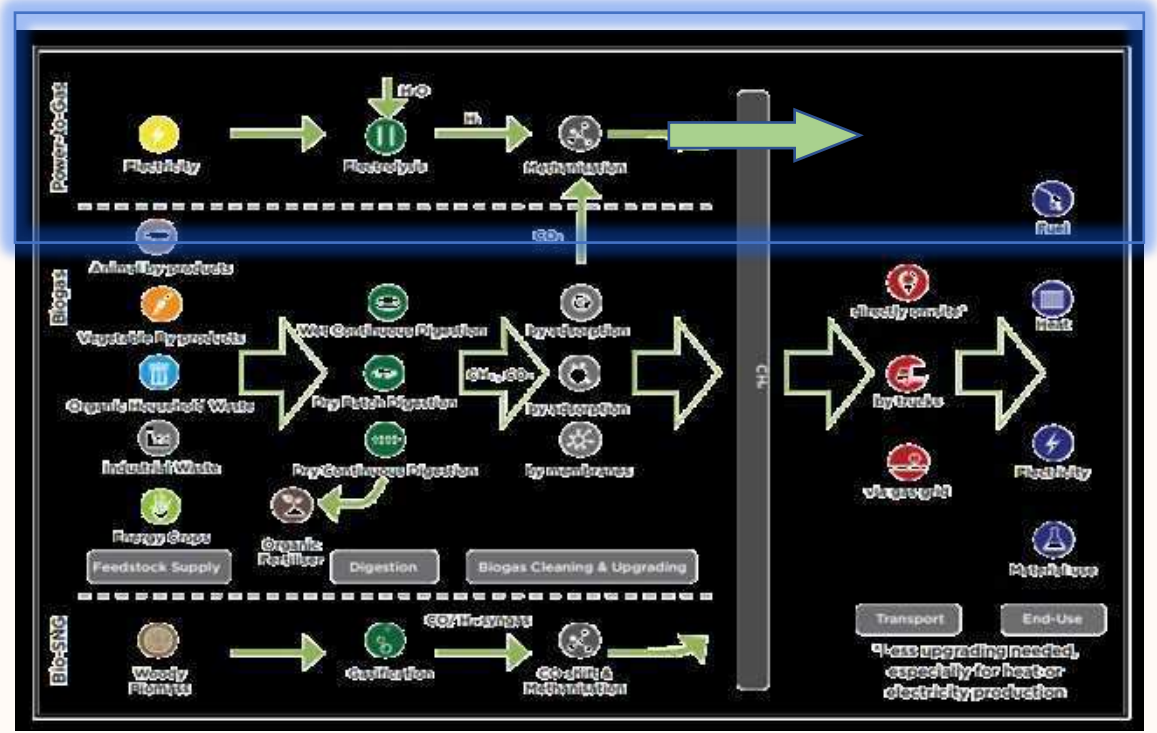
Production Cost of Bio-hydrogen Compared to Other Types of Hydrogen in (USD)

Hydrogen type	Cost range (USD/kg H_2)	Cost range (USD/kWh H_2)
Grey hydrogen	0.54 – 2.13	0.01 – 0.06
Blue hydrogen	1.54 – 2.60	0.05 – 0.08
Green hydrogen (RFNBO)	2.97 – 14.13	0.09 – 0.43
Biohydrogen (with or without CCS)	1.36 – 11.42	0.04 – 0.34

Bio-hydrogen Production Cost According to Production Technology (USD)

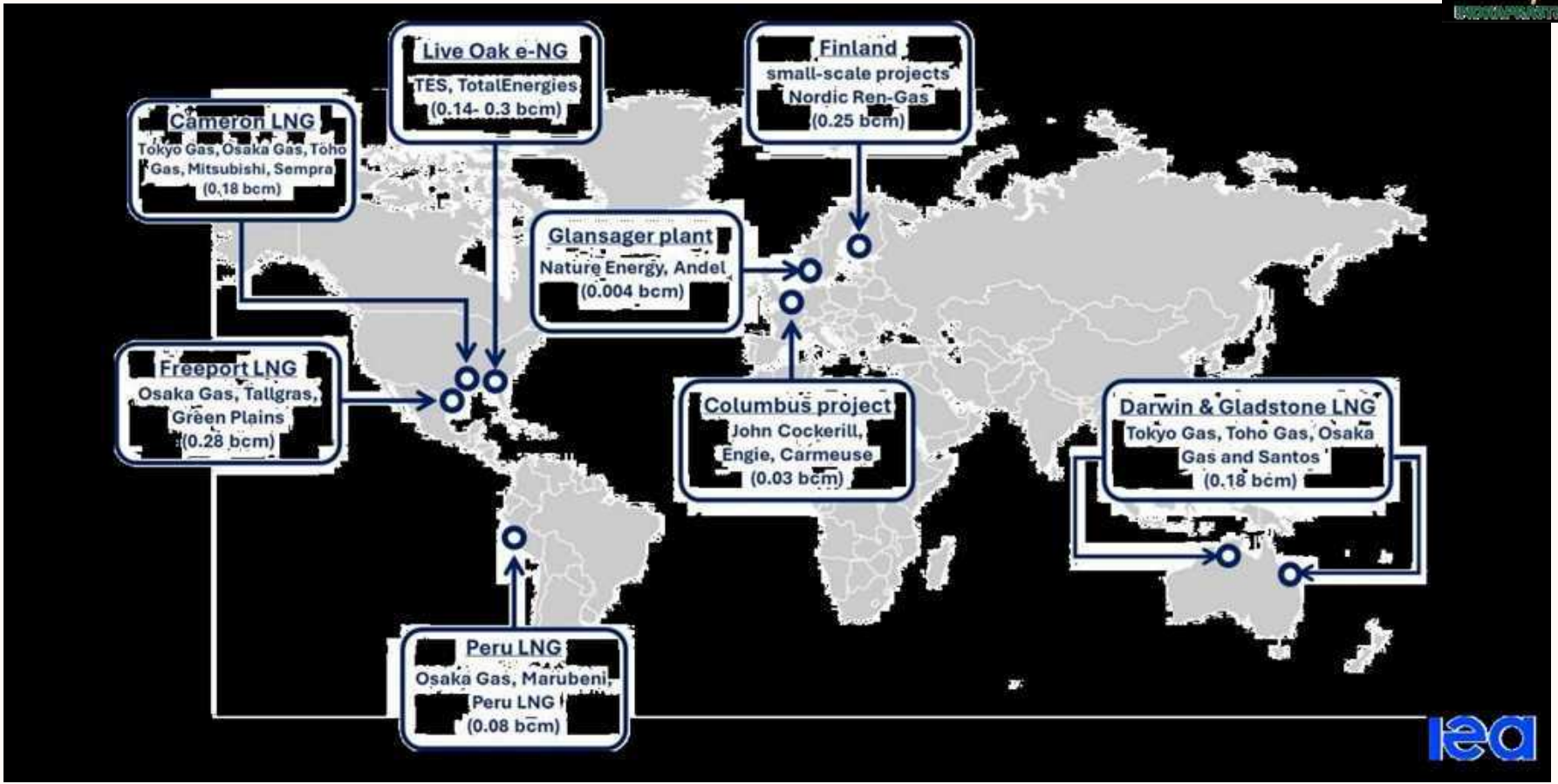
Production technology	Cost range (USD/kg H_2)	Cost range (USD/kWh H_2)
Gasification (with/without CCS)	1.54 – 11.20	0.04 – 0.33
Pyrolysis	1.41 – 11.42	0.05 – 0.34
BMSR (with or without CCS)	1.36 – 8.68	0.04 – 0.26
Dark fermentation	6.14 – 9.30	0.20 – 0.31
Biophotolysis	1.54 – 7.87	0.05 – 0.24

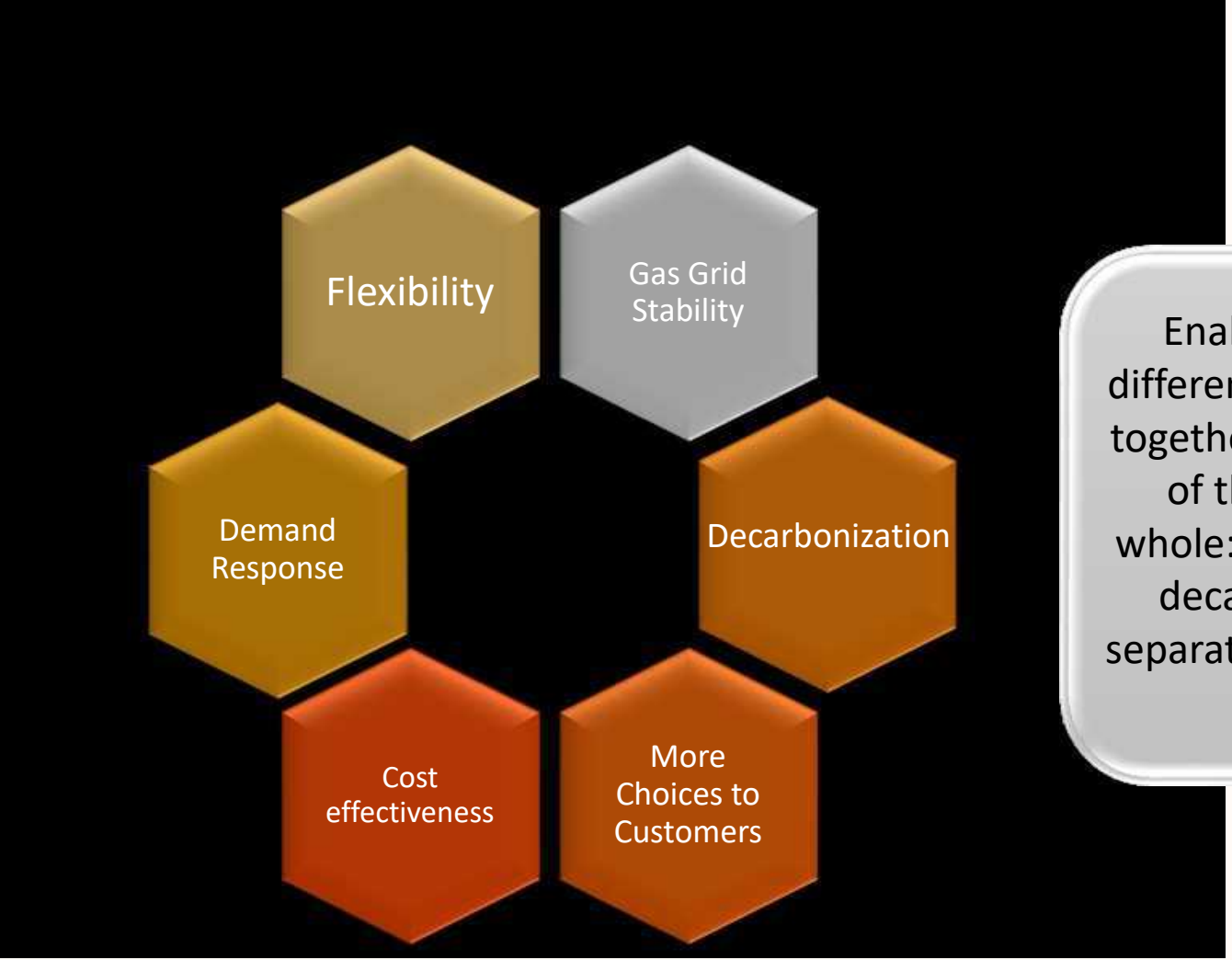
E-Methane pathway



- E-Methane refers to synthetic gas produced from RE-H_2 & recycled CO_2 from CBG production/industrial processes.
- Helps to converts non-storable electricity to storable renewable gas.
- Helps to capture otherwise flared Carbon Dioxide from CBG plants.
- Recirculation in digester is known to increase yield of biogas.
- Can be simultaneously used along with CBG, HCNG,LBG→ increasing energy dispensing capabilities.

Global e-Methane projects





Enabling and encouraging different energy sectors to work together optimizes the function of the energy system as a whole: It is more effective than decarbonizing and making separate efficiency gains in each sector individually

RE-Based CBG → LBG → Bio-H_2: The Bio-Molecule Transition Pathway

Phase 1: CBG (Today)

- Renewable energy based CBG for gas grid injection and rural mobility.
- Supports micro gas grids and decentralized fueling infrastructure.
- Synthetic methane (e-methane) from captured CO_2 further expands fuel availability.

Phase 2: LBG (Scale-Up)

- Liquefied Bio-Gas enables heavy-duty trucking and interstate bus operations.
- Delivers **800+ km range** for long-haul transport.
- Ideal for major logistics corridors such as the Delhi-Mumbai Expressway.

Phase 3: Bio-Hydrogen (Future)

- Bio-methane converted to Bio-H_2 through reforming or methane pyrolysis.
- Enables zero-emission mobility applications.
- Requires **3-5x less electricity** than water electrolysis for hydrogen production.

De-Risking Infrastructure & Forecourt Co-Dispensing

Phased Investment Strategy

- Generate immediate revenue from CBG and LBG before scaling hydrogen infrastructure.
- Minimizes stranded asset risk through a common bio-molecule ecosystem.

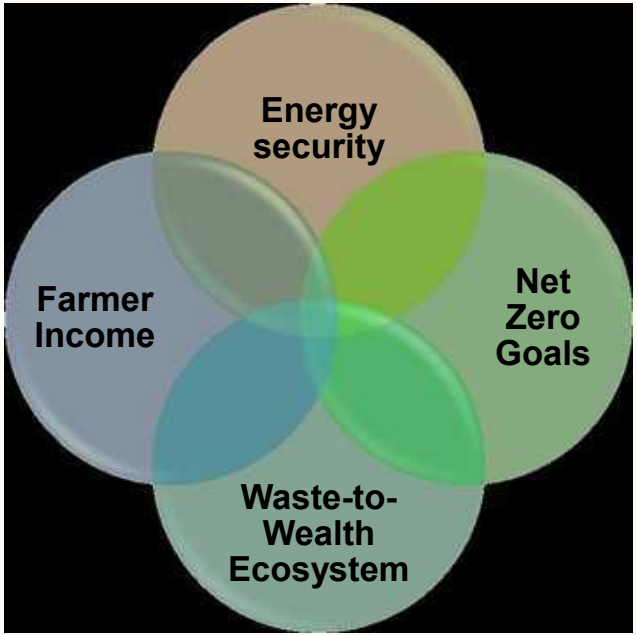
Integrated Multi-Fuel Forecourts

- Co-located CBG (200 bar), LBG, and Bio-H_2 (350/700 bar) dispensing.
- Shared utilities, safety systems, and POS infrastructure.
- Reduces station footprint by **30-40%**.

Operational Synergies

- Dynamic HCNG blending (18-20% Bio-H_2) lowers emissions from existing CNG vehicles without engine modifications.
- LBG regasification cold energy pre-cools hydrogen, reducing compressor energy consumption by **15-25%**.

Strategic Impact for India



- Reduced LNG/Fossil Fuel Imports
- Lower Emissions & Cleaner Air
- Agrarian Wealth Creation
- Waste Management
- Bio-Fertilizer Production
- Virtual Pipeline via LBG Tankers
- Lower-Cost Hydrogen Production
- Existing Vehicle Technology Utilization

Integrated CBG, Bio-LNG & Bio-CO_2 Liquefaction Plant

Plant Profile

Location:	18273 Güstrow/Germany
Capacity:	about 9,000 t Bio-LNG and 18,000 t Bio-CO_2 p.a., 3,1 MW_{el} from 5 CHPs
In-service date:	2009, conversion/upgrading in 2023
Input materials:	150,000 t p.a., mainly agricultural waste materials
Special features:	Germany's largest integrated Bio-LNG plant (Bio-LNG incl. Bio-CO_2 liquefaction plant)

Innovations for integration of LNG-CBG-Hydrogen Hubs:

A Multi-Fuel Energy Business Model

Developing integrated energy hubs combining LNG, Bio-CNG, hydrogen, EV charging, and renewable energy systems for future-ready fuel infrastructure.

KEY BENEFITS

- Decarbonization & Lower Emissions
- Energy Security & Diversity
- Scalable & Future Ready
- New Revenue Streams
- Supports Circular Economy

RENEWABLE ENERGY INTEGRATION

SOLAR POWER | WIND POWER | ENERGY STORAGE & MICROGRID

INTEGRATED BY SMART ENERGY MANAGEMENT SYSTEM (EMS)

REAL-TIME MONITORING & CONTROL | DEMAND RESPONSE & OPTIMIZATION | MULTI-FUEL DISPATCH | DATA-DRIVEN DECISIONS & REVENUE OPTIMIZATION

APPLICATIONS

HEAVY DUTY TRANSPORT | INDUSTRIAL USAGE | URBAN MOBILITY & EV FLEETS | COMMERCIAL & DOMESTIC USE

ONE HUB. MULTIPLE FUELS. ENDLESS POSSIBILITIES. | POWERING A CLEAN, RESILIENT & SUSTAINABLE FUTURE.

THANK YOU

Retail fuel outlet infrastructure in india

TECHNOLOGY	ACHIEVED	TARGET	CONSTRAINT
CNG Stations	8936	18,336	Pipeline availability, APM gas allocation
LNG Stations	20	~190	Only 1481 LNG vehicles registered — a classic chicken-and-egg
CBG Plants	~217	5,000	Feedstock aggregation; offtake and evacuation to the network
Public EV Chargers	29,277	1.32 M	~5% utilization against 10–12% needed to break even
Hydrogen refueling	1	16 (sanctioned)	70 pilot vehicles nationally; demand has not yet started

Source: PNGRB MIS, PIB, GOBARdhan portal, analytics.parivahan.gov.in

Preparing the Hub for Zero-Emission Mobility

For coordinated deployment of heavy-duty charging, hydrogen refuelling, and liquefied methane infrastructure, the hub architecture must be designed in a way to meet these requirements while managing capital deployment against confirmed demand.

EV Charging First

Deploy where grid access and fleet demand are strongest. Smart charging and fleet scheduling avoid unnecessary grid upgrade costs.

Hydrogen Selectively

Introduce for high-utilization, long-range, or payload-sensitive fleets. Modular deployment backed by confirmed offtake contracts.

On-Site Solar & Storage

Reduce charging costs, manage peak demand, support electrolysis, and improve energy resilience across all hub services.

Smart Grid Integration

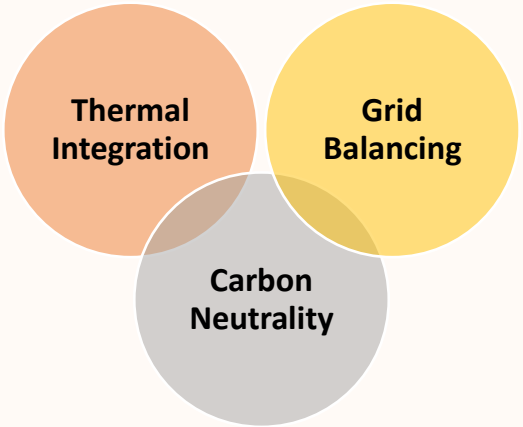
Demand response, grid flexibility services, and utility partnerships to maximize value from storage and generation assets.

Key Operational Synergies

•**Thermal Integration:** Waste heat from the SMR unit or CHP engine preheats the anaerobic digesters, eliminating external heating costs.

•**Carbon Neutrality:** Bio-LNG and Bio-Hydrogen derived from waste achieve carbon-negative intensity scores, lowering overall operational carbon footprint.

•**Grid Balancing:** Onsite battery energy storage and biogas generator back up the EV fast chargers during peak electricity tariff hours.



Five-Layer Integrated Architecture

The hub is not simply a co-location of fuel dispensers. Integration creates value beyond proximity by allowing fuels, power, data, and fleet operations to reinforce one another — each layer increasing the utilization and margin of every other layer.

Fuel Layer

- **Components:** LNG, CBG, and hydrogen dispensers; cryogenic and compressed storage; multi-fuel retail and fleet supply infrastructure.
- **Value created:** Direct fuel revenue, fleet contract anchor, and the physical foundation for all other layers.

Power Layer

- **Components:** Grid connection, solar PV, battery storage, transformers, and EV charging infrastructure.
- **Value created:** Charging capacity, peak demand management, grid resilience, and electrolysis power supply.

Conversion Layer

- **Components:** Biogas upgrading units, compression systems, and electrolysis modules.
- **Value created:** On-site renewable molecule production, feedstock aggregation margins, and fuel-quality control.

Digital Layer

- **Components:** Energy management system, fleet booking platform, carbon accounting tools, and operational intelligence dashboards.
- **Value created:** Higher asset utilization, fleet retention, regulatory compliance, and data-driven margin optimization.

Logistics Layer

- **Components:** Parking, maintenance facilities, routing services, and fleet support operations.
- **Value created:** Recurring non-fuel revenue, dwell time extension, and deeper fleet operator relationships.

Integrated Multi-Fuel Retail Outlet

The outlet combines molecules and electrons in one location, allowing fleets and customers to transition progressively rather than switching technologies overnight. Each fuel layer is independently viable and collectively synergistic — sharing land, utilities, safety systems, customer relationships, and digital infrastructure.

LNG

Long-haul and transitional heavy-duty transport. Immediate infrastructure anchor, proven fleet adoption, and the foundation for bio-LNG blending.

CBG / Bio-CNG

Renewable methane blending and gaseous-fuel fleets. Chemically compatible with existing gas infrastructure — progressive decarbonization without fleet replacement.

Hydrogen

Fuel-cell trucks and selected industrial mobility. Modular, contract-backed deployment that scales with confirmed demand rather than ahead of it.

EV Charging

Vans, buses, cars, and depot-compatible trucks. Captures electrification growth across all vehicle segments with smart charging and fleet scheduling.

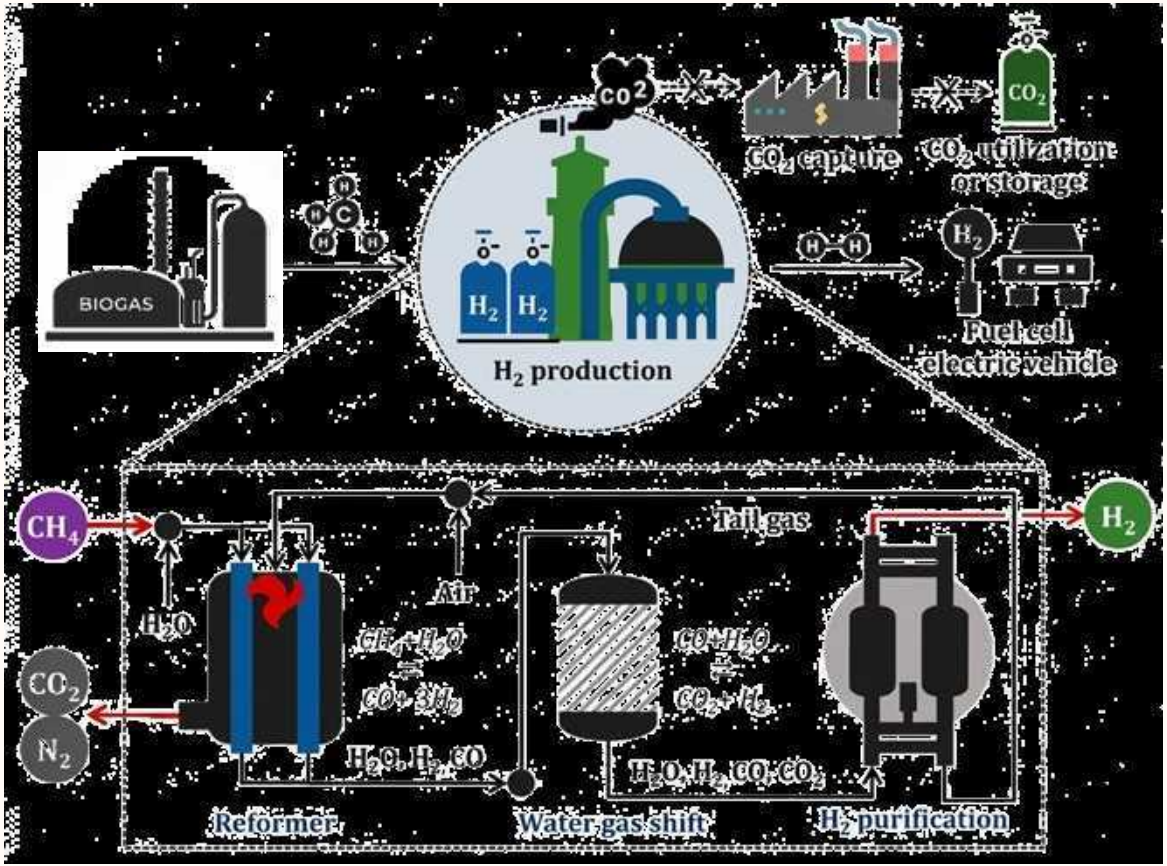
Renewable Power & Storage

Solar PV and batteries for cost management, peak demand reduction, electrolysis support, and operational resilience across all hub services.

Mass Energy Density Comparison: BioCNG vs BioLNG

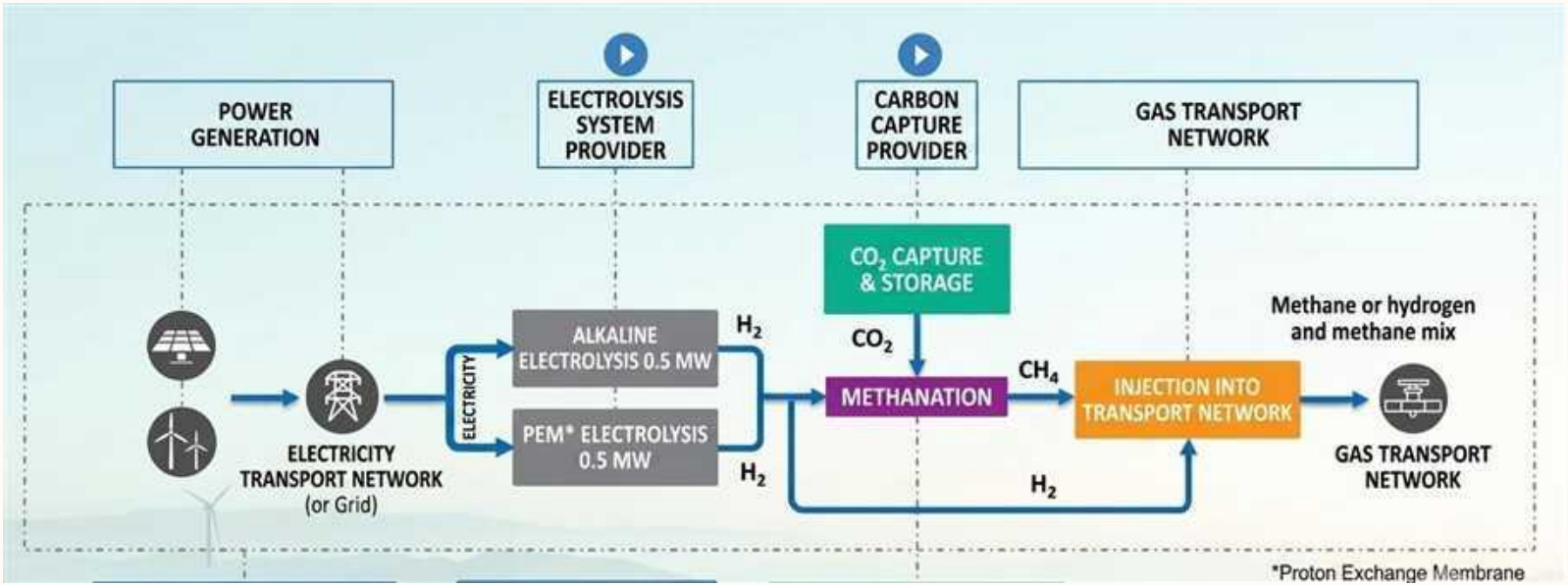
Parameter / Metric	Gaseous Biomethane (Compressed)	Liquid Biomethane (Liquefied)	Unit / Notes
Operating Conditions	15 °C, 250 bar_abs	-162 °C, 1.01325 bar_abs	Temperature, Pressure
Biomethane Volume	1.0 m^3	1.0 m^3	Base Volume
Methane Concentration	97.0% vol	99.995% vol	50 ppm CO_2
Methane Volume	0.97 m^3	0.99995 m^3	1 × concentration
Methane Density	186.88 kg/m^3	424.14 kg/m^3	Mass per unit volume
Methane Mass	**181.27 kg**	**424.12 kg**	Methane Volume × Density
Mass Ratio	—	**2.34x**	Liquid Mass/Compressed Mass

CO_2 Capture from Bio-SMR based Hydrogen unit



E-Methane for reducing carbon emissions

- Recovers the CO_2 released by industries or biogas purification



Mandates that land on the same forecourt

CBG Blending Obligation

1% → 5%

Mandatory from FY2025-26 (1%), rising 3% / 4% / 5% by FY 2028-29. Expected to pull ₹37,500 Cr and 750 projects.

National Green Hydrogen Mission

5 MMTPA

by 2030 with 125 GW of RE. 3,000 MW/yr electrolyser manufacturing and 862,000 tonnes/year production already awarded.

PM e-Drive Charging

₹2,000 Cr

for ~72,000 public charging stations, explicitly including deployment at fuel outlets; up to 80% subsidy on upstream infrastructure.

Carbon Credit Trading Scheme

FY 26 · FY 27

First compliance years notified against an FY 2023-24 baseline, creating a domestic price signal for abated tonnes.