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CTCN

UN environment programme

INDONESIA
Hydrogen Economy

GREEN HYDROGEN PRODUCTION AND FUEL CELL RD&D

INDONESIA'S RESEARCH, INNOVATION AND FUTURE COLLABORATION OPPORTUNITIES

CTCN LEARNING VISIT 2026

Collaboration with KIST, KRICT and KIER

Seoul & Daejeon, Republic of Korea

14 – 16 July 2026

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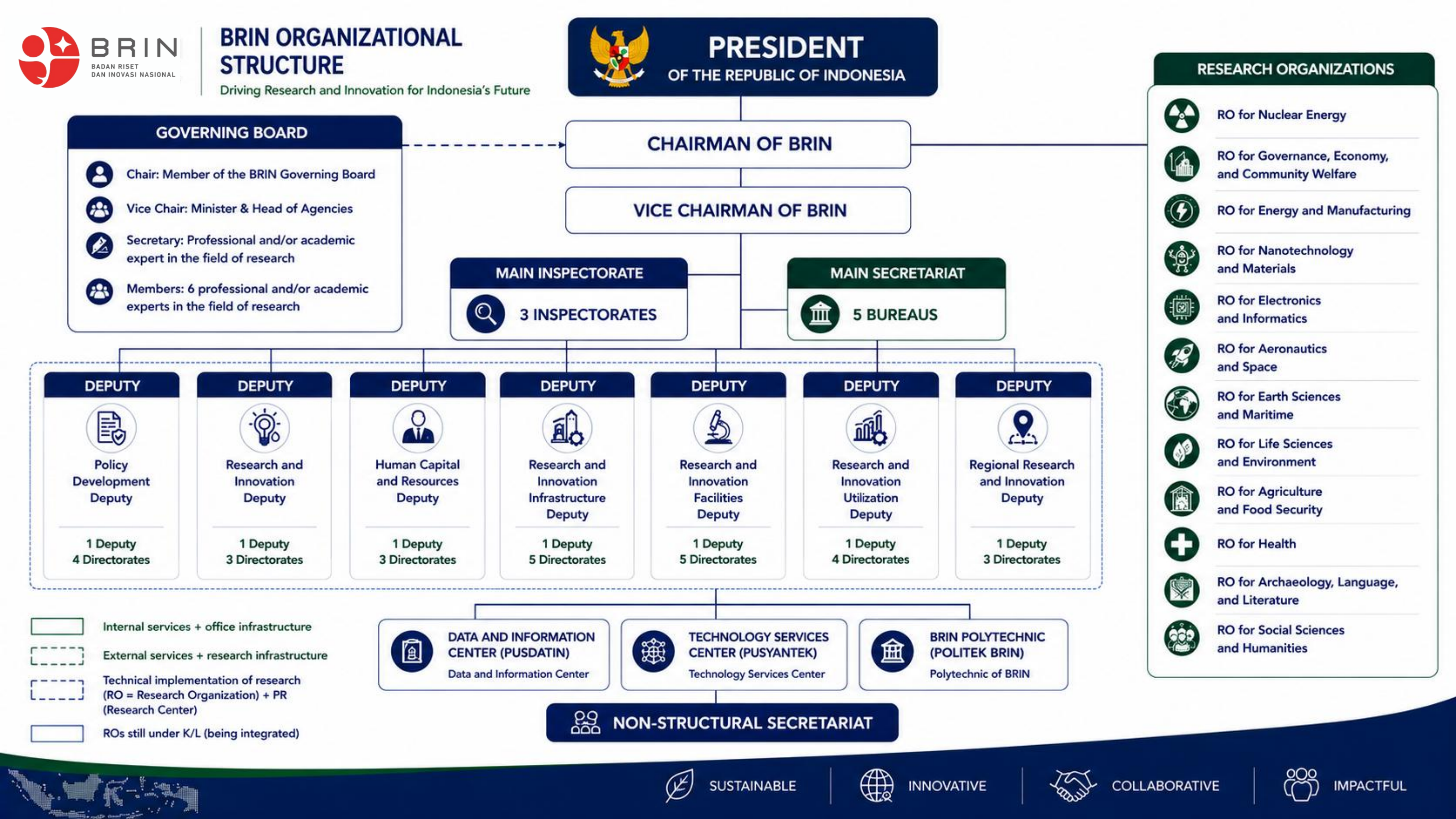
Research Center for Energy Conversion Technology
National Research and Innovation Agency (BRIN)
Indonesia

RESEARCH
INNOVATION
DEMONSTRATION
COLLABORATION
HYDROGEN ECONOMY

KEY THEMES

- Green Hydrogen Production
- Fuel Cell Technologies
- Hydrogen Storage
- Pilot Demonstration
- Future Joint RD&D
- ASEAN Collaboration

Advancing Hydrogen Innovation Through International Collaboration and Sustainable Energy Solutions


BRIN
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BRIN ORGANIZATIONAL STRUCTURE
Driving Research and Innovation for Indonesia's Future
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OF THE REPUBLIC OF INDONESIA
GOVERNING BOARD
Chair: Member of the BRIN Governing Board
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5 BUREAUS
DEPUTY
Policy Development Deputy
1 Deputy
4 Directorates
DEPUTY
Research and Innovation Deputy
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RESEARCH ORGANIZATIONS
RO for Nuclear Energy
RO for Governance, Economy, and Community Welfare
RO for Energy and Manufacturing
RO for Nanotechnology and Materials
RO for Electronics and Informatics
RO for Aeronautics and Space
RO for Earth Sciences and Maritime
RO for Life Sciences and Environment
RO for Agriculture and Food Security
RO for Health
RO for Archaeology, Language, and Literature
RO for Social Sciences and Humanities
Internal services + office infrastructure
External services + research infrastructure
Technical implementation of research (RO = Research Organization) + PR (Research Center)
ROs still under K/L (being integrated)
DATA AND INFORMATION CENTER (PUSDATIN)
Data and Information Center
TECHNOLOGY SERVICES CENTER (PUSYANTEK)
Technology Services Center
BRIN POLYTECHNIC (POLITEK BRIN)
Polytechnic of BRIN
NON-STRUCTURAL SECRETARIAT
SUSTAINABLE
INNOVATIVE
COLLABORATIVE
IMPACTFUL

1 BRIN HYDROGEN & FUEL CELL RD&D PORTFOLIO

Integrated Research Across the Hydrogen Value Chain

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BRIN develops end-to-end hydrogen and fuel cell technologies to accelerate Indonesia's clean energy transition through innovation, pilot-scale demonstration, and strategic collaboration.

OUR RD&D FOCUS AREAS

1. HYDROGEN PRODUCTION

- SOEC-based low-emission hydrogen production
- Water electrolysis catalysts and electrode development
- Hydrogen hydrolysis reactor optimization
- Techno-economic and feasibility assessment

2. HYDROGEN STORAGE

- Metal hydride materials (AB_5, Mg-based, etc.)
- Sorbent-based storage (activated carbon, MOF, zeolite, etc.)
- Sodium-based solid hydrogen storage
- System integration and safety evaluation

3. FUEL CELLS

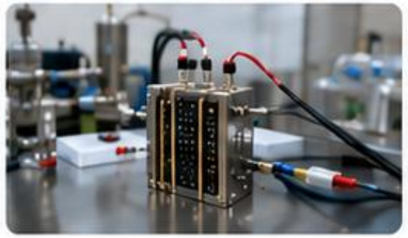
- PEMFC for mobility and backup power
- SOFC for stationary power and industrial use
- High-temperature fuel cells and components
- Durability, performance testing, and system optimization

4. SYSTEM INTEGRATION

- Hybrid microgrid with fuel cells
- Small islands and remote communtties
- Renewable energy integration
- Energy management and optimization

SELECTED MAJOR RD&D PROJECTS

PROJECT TITLE	PARTNER / SPONSOR
SOEC-Based Low-Emission Hydrogen Production	Pertamina NRE
Fuel Cell Hybrid Microgrid Implementation	PLN Enjiniring
Advanced Hydrogen Storage System	BRIN – LPDP
Hydrogen Hydrolysis Reactor Development	PLN (Puslitbang)
Electrolysis Catalyst Development	Ministry of Research & Technology



STRONG TRACK RECORD

- **220+** Publications
- **1,700+** Citations
- **24** Patents
- Contributor to National Hydrogen Standards (SNI)
- Strong Collaboration with Industry, Government, Universities, and International Research Institutions

Driving Innovation for Indonesia's Hydrogen Future

SUSTAINABLE | INNOVATIVE | COLLABORATIVE | IMPACTFUL

2 RD&D ACHIEVEMENTS AND FUNDING SOURCES

Proven Track Record in Innovation, Collaboration, and Impact

BRIN delivers high-impact research outputs, leads national initiatives, and secures competitive funding to advance Indonesia's hydrogen and fuel cell ecosystem.

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RESEARCH IMPACT & OUTPUT

- **220+** Publications (Scopus Indexed)
- **1,700+** Citations (Scopus)
- **24** Patents (Granted)
- Contributor to National Hydrogen Standards (SNI) TC 206 & TC 207 (Hydrogen Technology)
- Active Collaboration with 20+ national and international institutions

Key Strengths

- Multidisciplinary R&D Leadership
- From Materials to System Integration
- Pilot-Scale Demonstration Capability
- Techno-Economic & Feasibility Expertise
- Policy, Standardization & Ecosystem Development

NATIONAL & REGIONAL ROLES AND LEADERSHIP

- **IFHE — Deputy**: Indonesian Fuel Cell and Hydrogen Energy (IFHE). Advancing national hydrogen & fuel cell development
- **ASEAN SCMST Focal Point**: Representing Indonesia in ASEAN Committee on Science, Technology & Innovation
- **SNI Technical Committee Member**: Active in TC 206 & TC 207 for Hydrogen Technology Standardization
- **Advisor & Reviewer**: National R&D Programs, Technology Assessment, and Policy Formulation
- **International Engagement**: Workshops, Invited Talks and Knowledge Sharing in ASEAN & Global Platforms

MAJOR FUNDING SOURCES & GRANT SCHEMES

FUNDING SOURCE	SCOPE / FOCUS AREA	TYPE
BRIN Badan Riset dan Inovasi Nasional	Strategic National Research on Hydrogen & Fuel Cells	Government (National)
lpdp lembaga pengelola dana pendidikan Grant	Hydrogen Storage Materials (Metal Hydride & Sorbent)	Government (Competitive Grant)
PLN Enjiniring	Fuel Cell Systems, Hybrid Microgrid, Hydrogen Technologies	State-Owned Enterprise (SOE)
PLN PUSLITBANG	Hydrogen Storage System Development	State-Owned Enterprise (SOE)
PERTAMINA NRE	SOEC-Based Low-Emission Hydrogen Production	State-Owned Enterprise (SOE)
Ministry of Research & Technology	Electrolysis Catalyst Development	Government (National Grant)

STRATEGIC PARTNERS

- AIST — Japan
- Noritake — Japan
- Hubei University — China
- Chinese Academy of Sciences — China
- ENTEC NSTDA — Thailand
- asean — ASEAN Initiatives
- 弘前大学 HIROSAKI UNIVERSITY — Japan
- 東京大学 The University of Tokyo — Japan
- Swinburne University of Technology, Sarawak Campus — Malaysia
- UTM Universiti Teknologi Malaysia — Malaysia
- Universiti Kebangsaan Malaysia, National University of Malaysia — Malaysia
- Institut Teknologi Bandung 1920 — Indonesia
- TGGS The Sirindhorn International Thai-German Graduate School of Engineering — Thailand

Driving Innovation for **Indonesia's Hydrogen Future**

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3 INDONESIA HYDROGEN INITIATIVES

Building a National Ecosystem for a Clean and Competitive Hydrogen Economy

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Indonesia is advancing hydrogen as a key pillar of energy transition through roadmap, pilot projects, industrial engagement, and research & innovation.

NATIONAL DRIVERS & POLICIES

National Hydrogen & Ammonia Roadmap
Government roadmap to accelerate the development of hydrogen and ammonia ecosystem in Indonesia.

Net Zero Emission 2060
Indonesia's commitment to achieve net zero emission by 2060 or earlier.

Energy Transition Agenda
Diversifying energy mix, enhancing energy security, and reducing carbon intensity.

Regulatory & Standardization
Development of SNI for Hydrogen Technology and alignment with international standards.

Public–Private Collaboration
Strengthening collaboration across government, SOEs, industry, academia, and communities.

KEY STAKEHOLDERS & ECOSYSTEM

HYDROGEN ECOSYSTEM INDONESIA H_2

GOVERNMENT
- MEMR, MOF, BAPPENAS
- National Policies & Incentives

INDUSTRY
- Steel, Fertilizer, Refinery
- Industrial Decarbonization

BRIN
- R&D & Innovation
- Technology Development
- Standardization
- Pilot Demonstration

ACADEMIA & RESEARCH INSTITUTIONS
- Universities
- Research Collaboration

STATE-OWNED ENTERPRISES (SOEs)
- PLN
- Pertamina
- MIND ID, Pupuk Indonesia
- PTPN, Krakatau Steel

COMMUNITIES & REGIONS
- Small Islands & Remote Areas
- Local Development & Jobs

PRIORITY APPLICATION AREAS

- Industrial Feedstock & Raw Materials
- Power Generation & Backup Power
- Transportation (Heavy Duty)
- Aviation & Maritime (Future Fuel)
- Residential & Commercial Energy
- Energy Storage & Grid Balancing

BRIN CONTRIBUTION

- Developing critical hydrogen technologies (production, storage, fuel cells).
- Leading feasibility studies and techno-economic assessments.
- Implementing pilot projects with strategic partners.
- Supporting policy formulation and standardization.
- Building national capabilities and human resources.

NATIONAL TARGETS

Hydrogen Production	~ 0.5 – 1.0 Million Ton/Year by 2030
Green Hydrogen Share in Energy Mix	2 – 5% by 2030
CO_2 Reduction Potential	~ 10 – 25 Million Ton/Year by 2030
New Green Jobs	> 50,000 Jobs by 2030
Investment Opportunity	USD 20 – 60 Billion by 2030
Energy Security & Sustainable Growth	

Hydrogen for Indonesia,
Clean Energy for the Future

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4 ASEAN & INTERNATIONAL COLLABORATION

Working Together for a Regional Hydrogen Future

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BRIN actively collaborates with regional and global partners to advance hydrogen and fuel cell technologies through joint research, capacity building, and knowledge sharing.

EXISTING COLLABORATION NETWORK

ASEAN
- ASEAN SCMST Focal Point
- ASEAN COSTI
- ASEAN Hydrogen Discussions
- Regional capacity building and policy dialogue

JAPAN
- AIST (Japan)
- Hirosaki University
- Noritake Co., Ltd.
- Advanced materials, fuel cells, and hydrogen technologies

THAILAND
- ENTEC – NSTDA
- MHESI
- Training & capacity building
- Technology and innovation collaboration

CHINA
- Chinese Academy of Sciences
- Hubei University
- Xi'an Jiaotong University
- Joint research on hydrogen materials and systems

REPUBLIC OF KOREA
- ASEAN–ROK Cooperation funds and programs
- Hydrogen technology cooperation opportunities
- Future joint RD&D initiatives

GLOBAL PARTNERS
- Universities & Research Institutes
- International Conferences & Workshops
- Technology Transfer and Knowledge Sharing

FOCUS AREAS OF COLLABORATION

JOINT RD&D
Co-develop advanced hydrogen production, storage materials, fuel cells, and systems.

PILOT DEMONSTRATION
Implement pilot projects for real-world applications and technology validation.

CAPACITY BUILDING
Training, workshops, and exchange programs to strengthen human resources.

POLICY & STANDARDIZATION
Collaborate on hydrogen standards, regulations, and best practices.

REGIONAL VALUE CHAIN DEVELOPMENT
Build a resilient hydrogen ecosystem across ASEAN and beyond.

OUR VISION
A strong and inclusive hydrogen ecosystem in ASEAN through collaborative innovation, shared knowledge, and sustainable partnerships.

COLLABORATION IMPACT

Accelerate Innovation
Access to complementary expertise and cutting-edge technologies.

Strengthen ASEAN Hydrogen Ecosystem
Promote regional integration, knowledge sharing, and joint initiatives.

Enhance Competitiveness
Position ASEAN as a global hub for hydrogen technologies.

Support Net Zero Goals
Contribute to decarbonization and sustainable energy transition.

Create Socio-Economic Value
Generate green jobs, investment, and long-term economic growth.

Together, we can unlock the full potential of hydrogen for a clean, secure, and prosperous future.

ENGAGEMENT PLATFORMS

- International Conferences & Symposia
- Research & Academic Partnerships
- Policy Dialogues & Roundtables
- Joint Labs & Demonstration Facilities
- Innovation Challenges & Grants

"Collaboration today, sustainable hydrogen future for ASEAN tomorrow."

BRIN: Connecting Indonesia to the World, Building the Hydrogen Future Together

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5 FUTURE JOINT RD&D OPPORTUNITY

Indonesia Biomethane-to-Hydrogen Platform

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Microwave-Assisted Methane Pyrolysis (MMP)

A Strategic Pathway toward ASEAN Hydrogen Economy

We invite partners to collaborate on developing and demonstrating MMP technology to produce clean hydrogen and high-value solid carbon from Indonesia's biomethane, accelerating a scalable, low-carbon, and circular hydrogen ecosystem.

PROPOSED TECHNOLOGY

Biomethane (CH_4) → Microwave-Assisted Methane Pyrolysis (MMP) → Hydrogen (H_2)

→ Solid Carbon (High-Value Product)

KEY ADVANTAGES

- No direct CO_2 emissions
- High energy efficiency
- Scalable & modular
- Dual benefits: clean H_2 and valuable carbon
- Suitable for decentralized and industrial applications

COLLABORATION FOCUS

- Advanced Reactor Design & Scale-up
- Catalyst & Additive Development
- Process Integration & System Optimization
- Characterization & Performance Evaluation
- Techno-Economic Analysis & Business Model
- Policy, Standardization & Market Development

EXPECTED OUTCOMES

- Scalable low-carbon hydrogen production technology
- High-value solid carbon for industrial applications
- Reduced carbon footprint for hard-to-abate sectors
- New green industry and job creation
- Stronger regional collaboration and technology leadership

POTENTIAL PARTNERS

- **Research Institutions** (Universities & R&D Centers)
- **Technology Providers** (Reactor, Microwave, Catalyst, Materials)
- **Industrial Partners** (Energy, Steel, Cement, Chemicals, Refineries)
- **Government & Policy Makers** (Energy, Environment, Standardization Bodies)
- **Investors & Development Partners**

INVITATION TO COLLABORATE

Let's co-create the future of hydrogen in ASEAN.

Together, we can transform Indonesia's biomethane into clean hydrogen and valuable carbon—driving innovation, sustainability, and shared prosperity.

BRIN: Your Partner for Hydrogen Innovation
From Indonesia, for Indonesia, for a Sustainable World

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6 BACKGROUND & STRATEGIC OPPORTUNITY

Building a Sustainable Hydrogen Ecosystem for Indonesia's Remote Areas

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RELEVANT SDGs

7 AFFORDABLE AND CLEAN ENERGY | 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE | 13 CLIMATE ACTION | 17 PARTNERSHIPS FOR THE GOALS

1. CHALLENGE: REMOTE AREA ENERGY GAP

- More than **3,400 villages** in Indonesia still face limited or unreliable electricity supply.
- Dependence on diesel leads to **high cost, logistic difficulty,** and **carbon emissions.**
- Indonesia's energy sector contributes **~40%** of total national emissions.
- Reliable, affordable, and clean energy is essential to ensure inclusive development for remote communities.

2. OPPORTUNITY: ABUNDANT BIOMASS POTENTIAL

Indonesia has enormous biomass resources from agricultural residues, animal waste, and organic waste.

ESTIMATED BIOMASS POTENTIAL
(Million ton/year)

Total potential **> 200 million ton/year** sufficient to support green hydrogen production at national scale.

3. STRATEGIC OPPORTUNITY: HYDROGEN SOLUTION

Green hydrogen offers a clean, flexible, and locally producible energy carrier.

- Enables **energy independence** for remote and off-grid areas.
- Converts local biomass into **high-purity** hydrogen for clean energy.
- **Reduces greenhouse gas emissions** and supports Indonesia's net-zero commitment.
- Creates new **green economy** value chains and local job opportunities.

4. HYDROGEN ECONOMY OPPORTUNITY

LOCAL BIOMASS RESOURCES
Agricultural residues, animal waste, organic waste

→ **WASTE-TO-HYDROGEN CONVERSION**
Gasification / Reforming + Green Hydrogen Production

→ **GREEN HYDROGEN PRODUCTION**
Clean, reliable, and storable energy carrier

→ **MULTI-SECTOR APPLICATION**
Power Generation, Industry, Transportation, Maritime, Remote Communities

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7 WHY METHANE PYROLYSIS (MP)?

Key Insights and Opportunities

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LOW CARBON SOLUTION | DUAL PRODUCT VALUE | RESOURCE EFFICIENCY | MODULAR & SCALABLE | STRATEGIC FOR INDONESIA

CARBON PRODUCT REVENUE

MP's major advantage is the opportunity to generate carbon product revenue to offset the cost of hydrogen.

COST COMPETITIVE

Cost competitive with SMR with CCS at a carbon product price over $250 per ton of carbon products.

LOW EMISSIONS

MP offers the best emissions profile and resource requirements. Lower lifecycle emissions vs SMR w/ CCS, consumes less electricity than electrolysis, and less water than SMR and electrolysis.

RAMPABLE & SCALABLE WITH RENEWABLES

Using microwaves, H_2 can be generated immediately with no heat up/ramp up times, allowing it to scale with intermittent renewable energy.

MODULARITY

Compact MP reactors capable of producing ~1 ton H_2/day. Designed for modular deployment; scale production by adding more reactors as demand grows.

LEVERAGING EXISTING INFRASTRUCTURE

Can utilize existing natural gas infrastructure and generate diverse revenue streams (H_2 + carbon).

ENERGY EFFICIENT

MP is less energy intensive than current methods, even renewable hydrogen.

METHANE AWAY

Redirects methane from the atmosphere and incentivizes its capture from oil & gas sites, livestock farms, and landfills polluting gas into a useful hydrogen fuel.

LOCATED ANYWHERE

Requires only a natural gas (biomethane) hookup of sufficient capacity. Suitable for distributed production near the source.

LESS WATER CONSUMPTION

MP requires only water for cooling. Microwave reactors are designed with lower demands integrating closed-loop cooling systems.

METHANE PYROLYSIS REACTION

$$\underset{\text{Methane}}{CH_4} \longrightarrow \underset{\text{Solid Carbon}}{C_{(s)}} + \underset{\text{Hydrogen}}{2\,H_2}$$

No CO_2 is produced during the process.

TECHNOLOGY OPTIONS FOR MP

Thermal Pyrolysis | Molten Metal Pyrolysis | Microwave-Assisted Pyrolysis | Plasma Pyrolysis | Entrained Flow / Drop Tube Reactor

Microwave-assisted MP is gaining strong interest due to fast start-up, energy efficiency, modularity, and compatibility with renewable energy.

KEY TAKEAWAYS

- MP provides a low-carbon, cost-competitive pathway for clean H_2.
- Produces high-value solid carbon as co-product, creating additional revenue.
- High flexibility, modularity, and low water requirement enable distributed deployment.
- Well aligned with BRIN roadmap toward hydrogen economy and Net Zero 2060.

Methane pyrolysis transforms biomethane into clean hydrogen and valuable solid carbon without CO_2 emission, offering a scalable, efficient, and economically attractive pathway toward a hydrogen economy.

IDEAL FEEDSTOCK

Biomethane (>97% CH_4)
from landfill-based biogas upgrading

8 TECHNOLOGY OVERVIEW & TRL STATUS

Where We Are Today

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INNOVATIVE TECHNOLOGY | SCALABLE SOLUTION | LOW CARBON IMPACT | ENERGY SECURITY | SUPPORTS NET ZERO 2060

METHANE PYROLYSIS REACTION

$$\underset{\text{Methane}}{CH_4} \longrightarrow \underset{\text{Solid Carbon}}{C_{(s)}} + \underset{\text{Hydrogen}}{2\,H_2}$$

No CO_2 is produced during the process.

TECHNOLOGY OPTIONS FOR METHANE PYROLYSIS

Thermal Pyrolysis
Conventional heating using external heat sources.

Molten Metal Pyrolysis
Uses molten metals to transfer heat efficiently for high conversion.

Microwave-Assisted Pyrolysis
Microwave energy for rapid, selective, and efficient methane decomposition.

Plasma Pyrolysis
High-temperature plasma for fast decomposition and high carbon quality.

Entrained Flow / Drop Tube Reactor
Feedstock moves through hot zone for very fast reactions.

Microwave-assisted MP is gaining strong interest due to fast start-up, energy efficiency, modularity, and compatibility with renewable energy.

TRL (TECHNOLOGY READINESS LEVEL)

SMR (Steam Methane Reforming)	9
SMR + CCS	8 – 9
PEM Electrolysis	8 – 9
SOEC (Solid Oxide Electrolysis)	6 – 8
Thermal Methane Pyrolysis	5 – 7
Molten Metal Pyrolysis	5 – 6
Microwave Methane Pyrolysis	4 – 6
Plasma Methane Pyrolysis	4 – 6

Methane pyrolysis technologies are advancing rapidly. MP is approaching demonstration and early commercial stages.

TRL EXPLANATION

9	Commercially proven (Operating plants)
7 – 8	Demonstration scale (Pre-commercial)
4 – 6	Pilot / Pre-commercial (Technology validation)
< 4	Lab scale / Early research (Concept validation)

COMPARISON WITH OTHER HYDROGEN PATHWAYS

Pathway	CO_2 Emission (Direct)	Energy Intensity	Water Requirement	Maturity	Scalability	Cost Potential
SMR	High	High	High	★★★★☆	★★★★☆	★★★☆☆
SMR + CCS	Medium	High	High	★★★★☆	★★★★☆	★★★☆☆
Electrolysis (PEM)	Zero	High	High	★★★★☆	★★★★☆	★★★☆☆
Methane Pyrolysis (MP)	Zero	Low – Medium	Low	★★★☆☆	★★★★☆	★★★★☆

MP offers the potential for zero direct CO_2 emissions, lower energy and water requirements, and valuable solid carbon co-product—positioning it as a future cornerstone technology for clean hydrogen production.

ZERO DIRECT CO_2
No CO_2 formed during the pyrolysis process.

LOWER RESOURCES
Less electricity and water compared to other routes.

DUAL VALUE
Produces clean H_2 and high-value solid carbon.

9 METHANE PYROLYSIS (MP) IN THE BRIN ROADMAP

From Landfill Leachate to Clean Hydrogen Economy

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Turning waste into clean energy, clean hydrogen, and high value carbon for a sustainable future.

- CLEAN ENERGY NET ZERO
- HYDROGEN ECONOMY
- BRIN INNOVATION ECOSYSTEM
- GLOBAL PARTNERSHIP OPPORTUNITY

LANDFILL LEACHATE	UASB ANAEROBIC DIGESTION	BIOGAS PRODUCTION	BIOGAS UPGRADING	METHANE PYROLYSIS (MP)	HYDROGEN (H_2)	FUEL CELL APPLICATION
Leachate Generation	High-rate Anaerobic Treatment	Biogas (55–65% CH_4)	Biomethane (>97% CH_4)	H_2 + Solid Carbon (No CO_2 Emission from Process)	Clean Hydrogen (>99.9%)	Clean Power & Heat (Electricity, Heat, Mobility)

CONVENTIONAL ROUTE (SMR)

Biomethane → Steam Methane Reforming (SMR) → H_2 + CO_2

CO_2 Handling / CCS Required

METHANE PYROLYSIS ROUTE (MP)

Biomethane → Methane Pyrolysis → H_2 + Solid Carbon

No CO_2 Emission from Process

KEY ADVANTAGES OF MP FOR BRIN ROADMAP

- Produces H_2 and valuable solid carbon
- No direct CO_2 emission
- Low water requirement
- Suitable for modular and distributed system
- Supports carbon negative pathway from landfill
- Multiple revenue stream: H_2 + carbon products
- Energy security and independence
- Cost competitive with carbon product revenue

Methane pyrolysis (MP) converts biomethane into clean hydrogen and high-value solid carbon without CO_2 emissions, creating a dual-product, low-carbon pathway aligned with BRIN's vision for a sustainable hydrogen economy.

10 CARBON BLACK AS SYNTHETIC FEEDSTOCK

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High-Value By-product from Biogas Landfill via Methane Pyrolysis

Converting landfill biogas into clean hydrogen, high-value carbon black, and industrial heat with negative CO_2 emissions.

MAIN REACTION (METHANE PYROLYSIS)

$$CH_4 \rightarrow C_{(s)} + 2H_2$$

$\Delta H° = +75$ kJ/mol (endothermic)

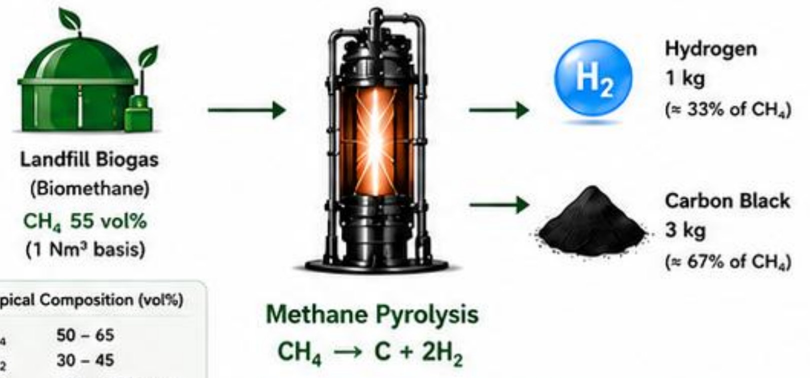
NEGATIVE CARBON CONCEPT

Bio-CO_2 in landfill biogas ≈ Net Zero / Negative with carbon credit from solid carbon (C)

MARKET POTENTIAL

- Out of 4 kg Methane, Methane Pyrolysis generates 1 kg H_2 and 3 kg Carbon black.
- H_2 used for heat and power with zero emission.
- Carbon Black used as feedstock in several industries.
- Negative CO_2 emissions result from: Biomethane pyrolysis, and Carbon Black used to replace or supplement plastics, building materials, etc.
- Price: approx. 250–450 €/t

FROM LANDFILL BIOGAS TO CARBON BLACK



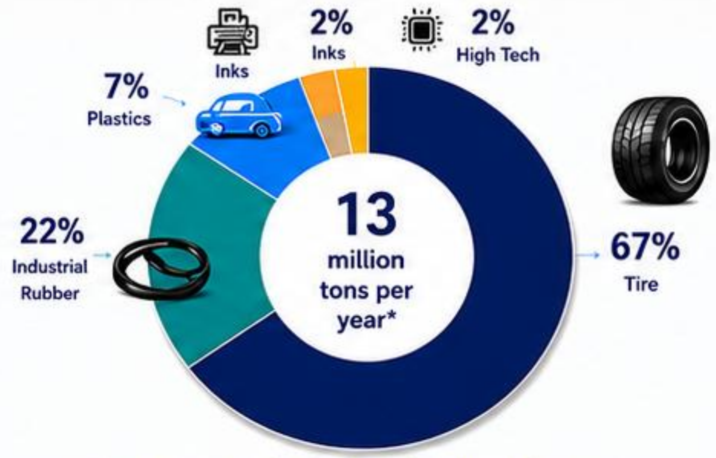
Typical Composition (vol%)

CH_4	50 – 65
CO_2	30 – 45
H_2S	100 – 2,000 ppm
N_2	0 – 5
Others	0 – 5

Typical Operating Conditions

- Pyrolysis Temperature: 600 – 20,000 °C
- Residence Time: 1 – 10 ms
- CH_4 Conversion: > 95%
- H_2 Selectivity: > 95%
- Operating Pressure: ~ 1 bar(g)
- Reactor Medium: Ar (optional)

MAIN APPLICATIONS OF CARBON BLACK BY INDUSTRY SALES



Global carbon black market size
USD 24.5 Billion (2023)
CAGR 5.0% (2024–2030)**

Main applications of carbon black by industry sales – World Production: 13 million tons per year*

LARGE MARKET POTENTIAL: CARBON BLACK APPLICATIONS BASED ON CONTRIBUTION & MARKET VALUE

1. TIRE (RUBBER)
Largest application (~67%). Provides strength, durability, and performance in tires.
Estimated Market Value ≈ USD 16.4 Billion (2023)
Volume: ≈ 8.7 million ton/year

2. INDUSTRIAL RUBBER
Used in belts, hoses, seals, conveyor, vibration control, and other technical rubber products.
Estimated Market Value ≈ USD 5.4 Billion (2023)
Volume: ≈ 2.9 million ton/year

3. PLASTICS
Provides black color, UV stabilization, conductivity, and material strength.
Estimated Market Value ≈ USD 1.7 Billion (2023)
Volume: ≈ 0.9 million ton/year

4. INKS
Used as pigment in printing inks, coatings, and industrial inks.
Estimated Market Value ≈ USD 0.5 Billion (2023)
Volume: ≈ 0.3 million ton/year

5. HIGH TECH
Special applications: conductive carbon, batteries, capacitors, semiconductors, EMI shielding, etc.
Estimated Market Value ≈ USD 0.5 Billion (2023)
Volume: ≈ 0.3 million ton/year

FUTURE APPLICATIONS (GROWING)
- Concrete & Asphalt (strength & durability)
- Coffee Capsules (food grade CB)
- Soil Enhancement (carbon sequestration)
- Biochar Blends (added carbon value)
- Masterbatch & Advanced Composites

SUSTAINABLE & NEGATIVE CARBON FOOTPRINT

Landfill biogas (biomethane) + methane pyrolysis produces clean hydrogen and high-value carbon black with negative CO_2 emissions.

Reduce CO_2 Emissions (Net Zero / Negative) → High-Value By-product Carbon Black → Replace Fossil-Based Materials & Plastics (Circular & Sustainable) → Support Industrial Decarbonization & Energy Security

* Source: Grand View Research, 2023
** Source: Fortune Business Insights, 2024
Note: Market value estimation (2023)

11

WHY MICROWAVE-ASSISTED METHANE PYROLYSIS (MMP)?

A STRATEGIC PATHWAY TO CLEAN HYDROGEN AND HIGH-VALUE CARBON FROM BIOMETHANE

Turning landfill waste into hydrogen, advanced carbon materials, and national energy security

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WHY MMP?

NEAR-ZERO CO_2 EMISSIONS
No combustion.
No process CO_2 by-product.

LOW WATER CONSUMPTION
Significantly lower than steam methane reforming and electrolysis.

HIGH HYDROGEN YIELD
70–90% hydrogen yield with high purity potential.

VALUABLE SOLID CARBON
Produces high-value solid carbon for advanced materials, batteries, and industrial uses.

MODULAR & SCALABLE
Compact system, flexible scale from decentralized to industrial deployment.

ENERGY EFFICIENCY
Direct microwave heating for fast and uniform energy transfer with lower energy loss.

BIOMETHANE TO HYDROGEN VIA MIOROWAVE-ASSISTED METHANE PYROLYSIS

FEEDSTOCK
Biomethane
($\geq$97% CH_4)

MICROWAVE ENERGY
2.45 GHz

DIRECT MICROWAVE HEATING
Fast, uniform, and volumetric heating for high efficiency

MICROWAVE REACTOR
Catalyst + Absorbent Bed
700 – 1,100 °C | Atmospheric Pressure

HYDROGEN
(70–90% yield)
- High purity potential
- Clean energy for power, industry, and mobility
- Fuel cell ready

+

SOLID CARBON
(10–30% yield)
- High-value carbon
- Battery additives
- Conductive carbon
- Graphitic & advanced materials

STRATEGIC VALUE FOR INDONESIA

WASTE TO WEALTH
Converts landfill biogas into dual-value products: hydrogen and solid carbon.

ENERGY SECURITY
Diversifies clean energy supply and reduces fossil fuel dependency.

ECONOMIC OPPORTUNITY
Creates new green industry and high-value carbon market.

ENVIRONMENTAL IMPACT
Supports net-zero target with minimal emissions and sustainable process.

TECHNOLOGY LEADERSHIP
Positions Indonesia as a regional leader in innovative hydrogen and carbon technologies.

MMP DELIVERS DUAL VALUE, MAXIMUM IMPACT

70–90% High Hydrogen Yield	≈ 0 CO_2 Emissions (Process)	10–30% Valuable Solid Carbon	12–18 kWh/kg H_2 Specific Energy Consumption	Modular & Scalable From Mini-Pilot to Industrial

CLEAN HYDROGEN. VALUABLE CARBON. SUSTAINABLE FUTURE.

12

DETAILED MECHANISM

HOW MICROWAVE-ASSISTED METHANE PYROLYSIS WORKS

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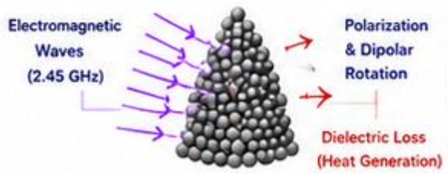
The Synergy of Microwave + Catalyst + Absorbent for High H_2 Yield and Clean Solid Carbon

1. ROLE OF MICROWAVE

Microwaves (2.45 GHz) interact with microwave-susceptible materials (susceptor + catalyst) to generate rapid, uniform, and volumetric heating.

- Penetrates the reactor and heats the bed internally
- Fast start-up and high energy efficiency
- Precise temperature control
- No flame, no direct combustion
- Lower CO_2 footprint

MICROWAVE HEATING PRINCIPLE

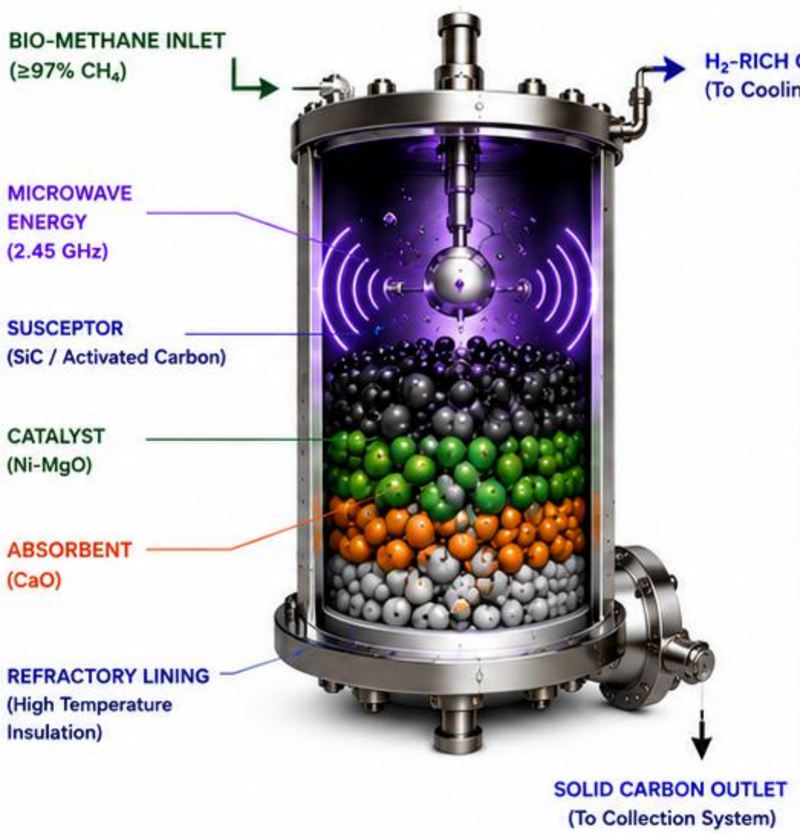


SUSCEPTOR (HEAT GENERATOR)

Silicon Carbide (SiC) / Activated Carbon

- High microwave absorption
- Converts EM energy to heat
- Enables high temperature (700–1,100 °C) inside the bed

2. OVERALL REACTION MECHANISM INSIDE THE MICROWAVE REACTOR



H_2-RICH GAS OUTLET (To Cooling & Purification)

STEP-BY-STEP MECHANISM

1. **ADSORPTION** — CH_4 adsorbs on catalyst active sites. CH_4 ↓
2. **C–H BOND ACTIVATION** — Microwave energy lowers activation energy and breaks C–H bond. $CH_4^* \rightarrow CH_3^* + H^*$
3. **SURFACE REACTIONS** — CH_x species react on catalyst surface. $CH_3^* \rightarrow CH_2^* + H^*$
4. **HYDROGEN FORMATION** — Adjacent H^* recombines to form H_2. $H^* + H^* \rightarrow H_2 \uparrow$
5. **CARBON FORMATION** — Carbon nucleates and grows on catalyst surface. $CH_x^* \rightarrow C(s)$
6. **ABSORPTION (BY ABSORBENT)** — CaO captures CO_2 and acidic impurities (CO_2, H_2S, moisture). $CO_2 + CaO \rightarrow CaCO_3$
7. **PRODUCT RELEASE** — H_2 desorbs and exits as gas. Solid carbon continuously removed from bed.

3. ROLE OF CATALYST (Ni-MgO)

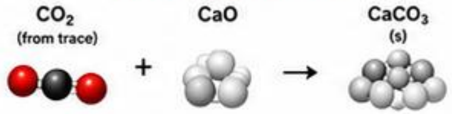
- Provides active sites for CH_4 adsorption and C–H bond activation
- High activity and stability at 700–1,100 °C
- Promotes high H_2 yield and carbon selectivity
- Resists sintering with MgO support

Ni-MgO CATALYST FUNCTION

4. ROLE OF ABSORBENT (CaO)

- Captures CO_2 and acidic impurities in-situ
- Improves gas purity and protects catalyst
- Enhances overall process stability

ABSORBENT REACTION



KEY INTERACTIONS & SYNERGY

MICROWAVE + SUSCEPTOR → Converts electromagnetic energy into heat rapidly and uniformly.

MICROWAVE + CATALYST → Microwave lowers activation energy → accelerates C–H bond cleavage → increases reaction rate & H_2 yield.

CATALYST + ABSORBENT — Catalyst produces H_2 and C. Absorbent captures CO_2/impurities → higher purity H_2 and longer catalyst life.

RESULT: DUAL-VALUE PRODUCTS

- High Purity Hydrogen (70–90% yield) — H_2
- High Value Solid Carbon (10–30% yield)
- Near Zero CO_2 Emission (process level) — CO_2 ~ 0

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PILOT REACTOR CONFIGURATION

MICROWAVE-ASSISTED METHANE PYROLYSIS (MMP)

Optimized Configuration for High H_2 Yield, High Carbon Quality, and Stable Operation

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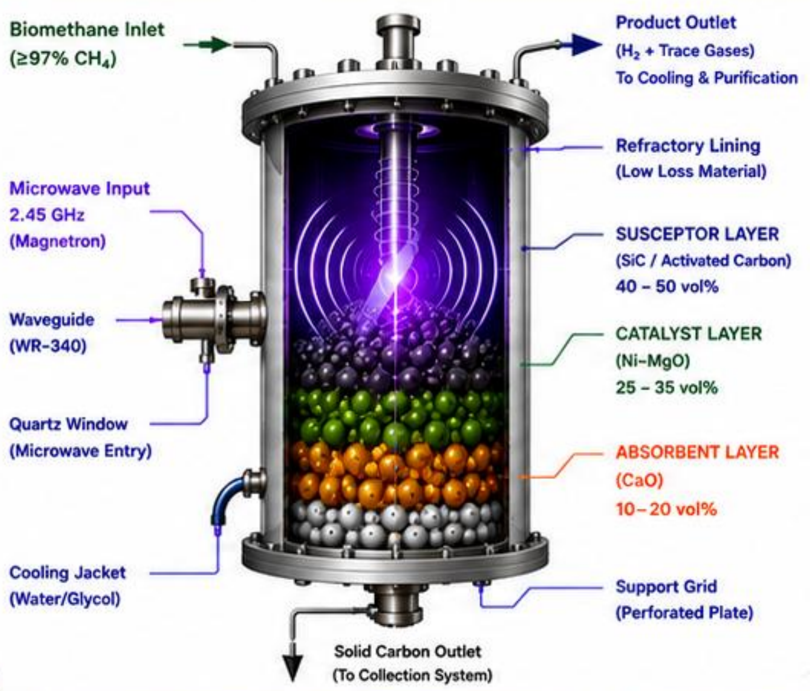
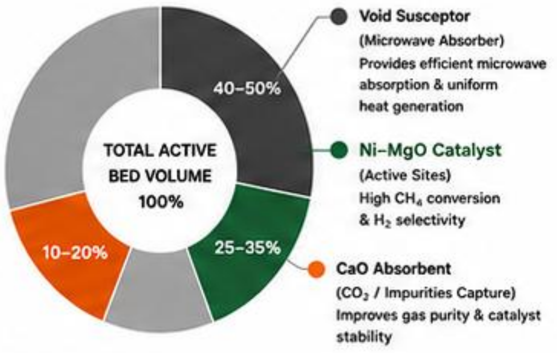
1. REACTOR OVERVIEW

Reactor Type	Microwave Fixed / Fluidized Packed Bed Reactor
Frequency	2.45 GHz (Industrial Magnetron)
Microwave Power	20 kW (Modular: 2 × 10 kW)
Reactor Diameter (ID)	0.35 m
Active Bed Height	1.50 m
Total Reactor Height	2.10 m
Active Volume	≈ 50 L
Operating Pressure	Atmospheric (0 barg)
Operating Temp.	850 – 900 °C
Heating Mode	Microwave Volumetric (Through Susceptor)
Cooling	External Water Jacket (Refractory Protected)
Materials (Hot Zone)	SS310S / Inconel 800H
Refractory Lining	High Alumina + Ceramic Fiber

2. REACTOR SCHEMATIC & FLOW CONFIGURATION



3. BED COMPOSITION & VOLUMETRIC RATIO



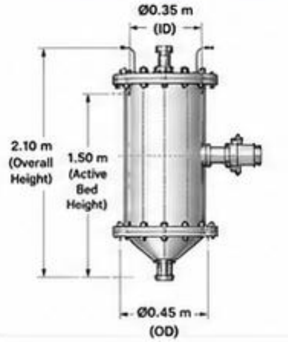
EXAMPLE FOR 50 L ACTIVE BED VOLUME

Component	Volume (L)	Volume Fraction (%)	Function
SiC Susceptor	22 – 25 L	45	Microwave absorption & heat generation
Ni-MgO Catalyst	13 – 17 L	30	CH_4 activation & H_2 formation
CaO Absorbent	5 – 10 L	15	CO_2 & acidic impurities capture
Void Space	5 – 8 L	10	Flow channel / pressure drop control
TOTAL	50 L	100	–

4. OPERATING CONDITIONS

Feed Gas	Biomethane ($\geq$97% CH_4)
CH_4 Flow Rate	10 Nm³/h
Superficial Gas Velocity	0.15 – 0.25 m/s
Residence Time (Est.)	1 – 3 seconds
Microwave Power	20 kW
Power Density	0.4 kW/L (Active Volume)
Operating Temp.	850 – 900 °C
Pressure	Atmospheric
Moisture in Feed	< 50 ppmv
Sulfur in Feed	< 1 ppmv
Start-up Time	30 – 45 minutes
Mode of Operation	Continuous
Availability Target	> 95%

5. DIMENSIONS (REFERENCE DESIGN)



REFERENCE DIMENSIONS

Reactor Diameter (ID)	0.35 m
Active Bed Height	1.50 m
Microwave Zone Height	1.30 m
Freeboard Height	0.30 m
Bottom Cone Height	0.30 m
Total Height	2.10 m
Active Volume	≈ 50 L
Total Volume	≈ 80 – 90 L

6. MATERIALS OF CONSTRUCTION

Part	Material
Reactor Shell	SS310S / Inconel 800H
Refractory Lining	High Alumina Castable + Ceramic Fiber
Microwave Window	High Purity Quartz
Waveguide	Copper (Internal) + SS (External)
Susceptor / Bed Material	SiC / Activated Carbon
Catalyst	Ni-MgO (Granule 2–5 mm)
Absorbent	CaO (Granule 2–5 mm)
Support Grid	SS310S (Perforated Plate)
Gaskets / Seals	Graphite / High Temp Ceramic

7. SAFETY & INSTRUMENTATION

Thermocouples (Multi-point)	Bed temperature monitoring
Pressure Transmitter (PT)	Reactor pressure monitoring
Differential Pressure (DP)	Bed ΔP monitoring
Gas Analyzer (Online GC)	CH_4 conversion & H_2 purity
Oxygen Analyzer	Residual O_2 monitoring
Interlock System	High T, High ΔP, Microwave Leakage Protection
Microwave Leakage Monitor	Operator safety

8. KEY PERFORMANCE TARGETS

- CH_4 Conversion: 85 – 95%
- H_2 Yield: 70 – 90% (Mol Basis)
- H_2 Production: ≈ 1.5 – 2.0 kg/h (20 Nm³/h)
- Solid Carbon Production: 0.5 – 1.5 kg/h
- Energy Consumption: 12 – 18 kWh/kg H_2
- CO_2 Emission: ~ 0 (Process Level)
- Availability: > 95%
- Operation: Continuous

OPTIMIZED CONFIGURATION FOR PILOT / MINI PILOT SCALE

High H_2 Yield • High Carbon Value • Stable Operation • Scalable Design • Cost Effective

Efficient Microwave Heating | High Activity Catalyst | Effective Impurity Capture | Low Pressure Drop Design | Robust & Safe Operation | Ready to Scale-up to Pilot Plant

14 PILOT REACTOR CONFIGURATION

MICROWAVE-ASSISTED METHANE PYROLYSIS (MMP)

Design Concept for Mini Pilot Scale (10 Nm^3/h CH_4 Feed)

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REACTOR TYPE

- Microwave Fixed
- Packed Bed Reactor (Atmospheric Pressure)

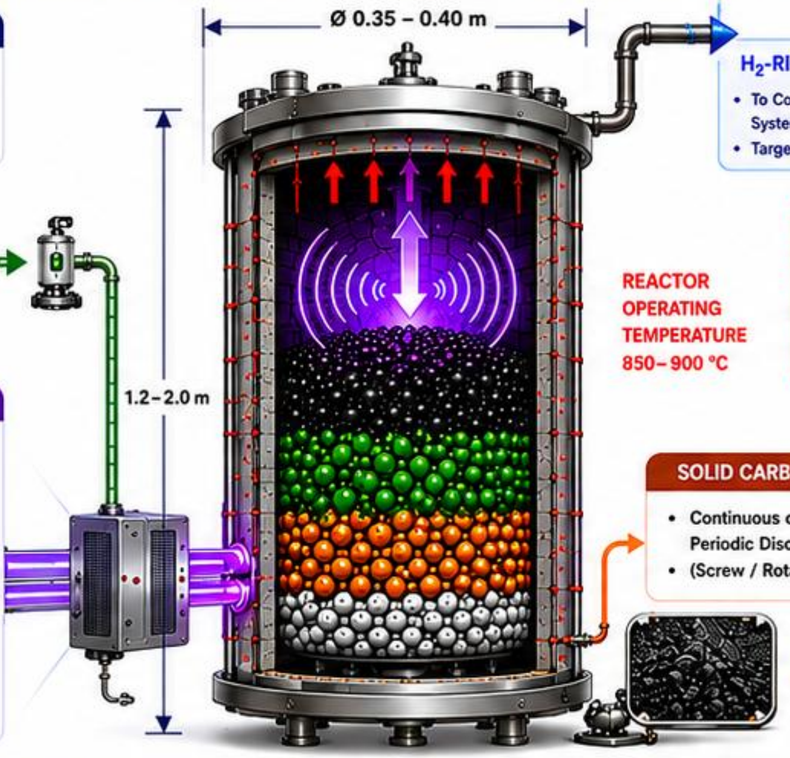
FEED INLET SYSTEM

- Biomethane (≥97% CH_4)
- Preheated (250–350 °C)
- Flow Control & Mass Flow Meter

MICROWAVE SYSTEM

2.45 GHz Magnetron (Industrial Type)

- Power : 20 kW
- Frequency : 2.45 GHz
- Waveguide : Rectangular
- Cooling : Water Cooled



H_2-RICH GAS OUTLET

- To Cooling & Purification System
- Target : 20 Nm^3/h H_2

REFRACTORY INSULATION

- High Temperature Insulation (Ceramic Fiber)
- Min. 100 mm

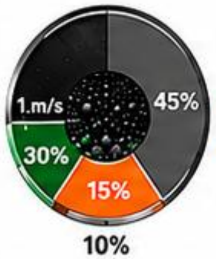
REACTOR OPERATING TEMPERATURE 850–900 °C

SOLID CARBON OUTLET

- Continuous or Periodic Discharge
- (Screw / Rotary Valve)

Solid Carbon (10–30% yield)

PACKED BED LAYOUT (Volume Basis)



- SiC Susceptor (45 vol%)
- Ni-MgO Catalyst (30 vol%)
- CaO Absorbent (15 vol%)
- Void / Free Space (10 vol%)

BED LAYER CONFIGURATION (Axial Direction)

Layer	Material	Thickness (m)	Function
Top Zone	SiC	0.20 – 0.30	Microwave absorption & heat generation
Active Zone 1	Ni-MgO	0.40 – 0.60	CH_4 activation & H_2 formation
Active Zone 2	CaO	0.20 – 0.30	CO_2 & impurity capture & gas purification
Bottom Zone	SiC	0.20 – 0.30	Heat distribution & carbon discharge

PROCESS FLOW DIAGRAM (Pilot Scale Concept)

OPERATING CONDITIONS (Target)

Feedstock	Biomethane (≥97% CH_4)	CH_4 Conversion	85 – 95%
Feed Flow	10 Nm^3/h	H_2 Yield	70 – 90%
Operating Temp.	850 – 900 °C	Residence Time	1 – 5 sec
Pressure	Atmospheric (0 barG)	Reactor Diameter	0.35 – 0.40 m
Microwave Power	20 kW	Reactor Height	1.2 – 2.0 m
Frequency	2.45 GHz		

EQUIPMENT MAIN DIMENSIONS (Example)

Equipment	Dimension (Approx.)
Reactor Diameter	0.35 – 0.40 m
Reactor Height (Active Bed)	1.2 – 2.0 m
Total Reactor Height	2.5 – 3.0 m
Microwave Power	20 kW (2.45 GHz)
System Footprint	~ 4 m (L) x 3 m (W) x 3 m (H)

MATERIAL OF CONSTRUCTION

Reactor Shell	SS310S / Inconel 600
Refractory Lining	Alumina Fiber + SiC
Waveguide	SS / Copper
Piping (High Temp.)	SS310S
Valves	High Temp. Alloy

ESTIMATED PILOT PLANT LAYOUT (10 Nm^3/h CH_4 Feed)

KEY FEATURES

- Compact & Modular
- High Efficiency Microwave Heating
- High H_2 Yield (70–90%)
- Near Zero CO_2 (Only Trace Level)
- High Value Solid Carbon
- Easy Scale-Up

Pilot Scale 10 Nm^3/h CH_4

H_2 Production 20 Nm^3/h (≈1.8 kg H_2/h)

Solid Carbon 0.5 – 1.5 kg/h

Conversion 85 – 95%

Energy Consumption 12 – 18 kWh/kg H_2

Start-up < 30 Minutes

15 MASS & ENERGY BALANCE

Performance Projection for Mini Pilot Scale (10 Nm^3/h CH_4 Feed)

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1. MASS BALANCE & PROCESS FLOW DIAGRAM (Basis: 10 Nm^3/h CH_4 Feed)

FEED

Biomethane
(≥97% CH_4)

10 Nm^3/h
(At 0 °C, 1 atm)

Composition (Vol%)

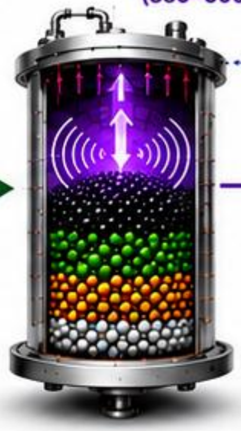
CH_4	≥97%
CO_2	≤2%
N_2	≤1%
H_2S	<10 ppmv
H_2O	<50 ppmv

PRETREATMENT

Desulfurization & Filtration

- Removes H_2S, moisture, particles
- Protects catalyst

MICROWAVE REACTOR
(850–900 °C)



Reaction:
$CH_4 \rightarrow C\ (s) + 2H_2$

Conversion
85 – 95%

Residence Time
1 – 3 s

H_2-RICH GAS OUTLET
(To Cooling & Purification)

~20 Nm^3/h
(70–90% H_2)

H_2	70 – 90%
CH_4	5 – 15%
Others*	5 – 10%

*CO, CO_2, N_2, H_2O (trace)

SOLID CARBON
(Collected)

0.5 – 1.5 kg/h
(10 – 30% yield)

2. HYDROGEN & CARBON OUTPUT SUMMARY

HYDROGEN PRODUCTION

~20 Nm^3/h
(70–90% purity)

≈ 1.8 kg H_2/h

≈ 36 kg H_2/day
(20 h operation)

CARBON PRODUCTION

0.5 – 1.5 kg/h
(10 – 30% yield)

≈ 10 – 30 kg/day
(20 h operation)

3. ENERGY SUMMARY

Microwave Power (Delivered)	Net Energy Consumption	Thermal Efficiency (Overall)	System Efficiency (H_2 LHV Basis)	Heat Recovery Potential
20 kW	12 – 18 kWh/kg H_2	60 – 75%	30 – 40%	20 – 30%

4. ENERGY CONSUMPTION COMPARISON

Technology	Feedstock	H_2 Yield (%)	Energy Consumption (kWh/kg H_2)	CO_2 Emission (kg CO_2/kg H_2)	Water Use
MMP (Microwave Pyrolysis)	Biomethane (CH_4)	70 – 90	12 – 18	≈ 0 (Trace level)	Very Low (No water required in process)
Steam Methane Reforming (SMR)	Natural Gas (CH_4)	70 – 85	20 – 30	9 – 12 (With CCS)	High (9 – 12 L/kg H_2)
Electrolysis (Alkaline/PEM)	Electricity	60 – 70	50 – 55	≈ 0 (If renewable)	High (8 – 10 L/kg H_2)
Plasma Pyrolysis	Methane	60 – 80	20 – 40	≈ 0 (Trace level)	Very Low

MMP offers the lowest energy consumption after reforming with CCS, with near-zero CO_2 emission and minimal water use.

5. CARBON CHARACTERISTICS & VALUE POTENTIAL

TYPICAL CARBON PROPERTIES
(from MMP Process)

- Purity (Fixed Carbon): 90 – 98%
- Ash Content: <5 wt%
- BET Surface Area: 50 – 300 m^2/g
- Particle Size: 0.1 – 100 µm
- Electrical Conductivity: Moderate to High (Depends on structure)
- Morphology: Amorphous / Graphitic

VALUE POTENTIAL

- Battery Anode Material
- Conductive Additive
- Graphitic Carbon
- Activated Carbon
- Carbon Black
- Industrial Carbon Material

Market Price Range (Indicative): USD 600 – 3,000 / ton (Depending on grade & application)

6. KEY PERFORMANCE INDICATORS (TARGET)

Hydrogen Yield (Mol Basis)	70 – 90%
Methane Conversion	85 – 95%
Solid Carbon Yield	10 – 30% (wt. basis)
Specific Energy Consumption	12 – 18 kWh/kg H_2
CO_2 Emission	≈ 0 (Trace Level)
Water Consumption	Very Low (No water in process)
Availability Target	> 95%
Operation Mode	Continuous

MMP DELIVERS HIGH-PURITY HYDROGEN AND HIGH-VALUE CARBON WITH LOW ENERGY CONSUMPTION, NEAR-ZERO CO_2 EMISSION, AND MINIMAL WATER USAGE — ENABLING A SUSTAINABLE HYDROGEN ECONOMY.

Near Zero CO_2 Emission | Minimal Water Use | Low Energy Consumption | Modular & Scalable | High Value Products

16

INDONESIA BIOMETHANE-TO-HYDROGEN PLATFORM ROADMAP

Microwave-Assisted Methane Pyrolysis (MMP) Development Pathway (2026 – 2038)

From Research to Commercialization for Indonesia's Clean Hydrogen Future

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01 PHASE 1 RESEARCH & TECHNOLOGY VALIDATION 2026 – 2028

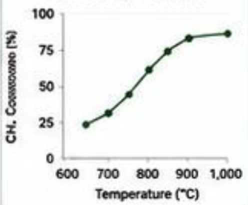
KEY ACTIVITIES

- Catalyst screening (Ni-MgO, alternatives)
- Susceptor optimization (SiC)
- Reactor simulation & design
- Lab-scale validation (< 1 Nm³/h CH_4)

KEY OUTPUT

- Optimized catalyst & susceptor
- Proof of concept
- Performance & stability data
- Lab-scale demonstration

Lab Test Performance



TARGET TRL 3 – 4

02 PHASE 2 MINI PILOT DEMONSTRATION 2028 – 2031

KEY ACTIVITIES

- 10 Nm³/h biomethane feed
- Continuous operation (>1,000 h)
- Hydrogen & carbon validation
- Integration with UASB + biomethane upgrading
- Safety, reliability & operability assessment

KEY OUTPUT

- Stable H_2 & carbon production
- Performance optimization
- Techno-economic evaluation
- Mini pilot demonstration

Pilot Target (Mini Pilot)

H_2 10 Nm³/h CH_4 ↓ ~20 Nm³/h H_2

0.5 – 1.5 kg/h Solid Carbon

TARGET TRL 4 – 5

03 PHASE 3 PILOT SCALE & MARKET VALIDATION 2031 – 2034

KEY ACTIVITIES

- 100 – 500 Nm³/h biomethane feed
- Offtake agreement validation (H_2 & Carbon)
- Carbon market validation
- System integration: microwave, catalyst, heat management
- FEED & investment preparation

KEY OUTPUT

- Pilot plant operation
- Bankable performance data
- LCA & environmental validation
- Investment decision readiness

Pilot Target

H_2 100 – 500 Nm³/h CH_4 ↓ 200 – 1,000 Nm³/h H_2

5 – 15 kg/h Solid Carbon

TARGET TRL 6 – 7

04 PHASE 4 COMMERCIAL DEPLOYMENT 2034 – 2038+

KEY ACTIVITIES

- >1,000 Nm³/h biomethane feed
- Hydrogen hub development
- Carbon products commercialization
- Export opportunity
- Strategic partnership & industrial scale-up

KEY OUTPUT

- Commercial plant operation
- Hydrogen & carbon market leadership
- Technology licensing & export
- National & global impact

Commercial Target (2038+)

H_2 > 1,000 Nm³/h CH_4 ↓ > 180 kg/day H_2

> 1 ton/day Solid Carbon

TARGET TRL 8 – 9

TARGET CAPACITY (2038+)

Biomethane Feed Capacity	> 1,000 Nm³/h
Hydrogen Production	> 180 kg/day (> 65,000 kg/year)
Carbon Production	> 1 ton/day (> 300 ton/year)
Plant Availability	> 95%
Hydrogen Purity	> 99%
Carbon Purity	> 90% (wt. basis)

FUTURE REVENUE STREAMS

MMP PLATFORM Value Creation

HYDROGEN SALES
Clean H_2 for industry, power, mobility & export

CARBON PRODUCTS
High-value carbon for batteries, composites, rubber, adsorbent

CARBON CREDITS
Certified emission reductions (VER) & carbon trading

TECHNOLOGY LICENSING
Export of MMP technology & know-how

POTENTIAL STRATEGIC PARTNERS

BRIN – Research & Innovation	PLN – Energy Offtaker & Integration	KOGAS – Hydrogen Offtaker & Investment
POSCO – Carbon Market & Offtaker	SK E&S – Hydrogen Business & Investment	Hanwha Energy – Energy Solution & EPC

LOCAL GOVERNMENT & LANDFILL OPERATORS
Feedstock Supply, Land & Community Partnership

STRATEGIC IMPACT

- Strengthen Indonesia's Energy Independence through clean H_2 production
- Reduce CO_2 Emissions > 1 Million ton/year (Potential by 2038+)
- High-Value Green Industry Creation & New Jobs
- Position Indonesia as Regional Leader in Clean Hydrogen & Advanced Carbon

FROM LANDFILL BIOMETHANE
Turning Waste into Energy

TURNING WASTE INTO HYDROGEN, ADVANCED CARBON MATERIALS, AND NATIONAL ENERGY SECURITY

- ✓ Clean Hydrogen for a Sustainable Future
- ✓ High-Value Carbon for Advanced Industries
- ✓ Near-Zero Emission & Circular Economy
- ✓ Energy Security for Indonesia

17 EXPECTED OUTPUTS & NATIONAL CONTRIBUTION

Delivering Innovation, Impact, and Leadership for Indonesia's Green Hydrogen Future

From pilot system to national impact – generating knowledge, technology, and solutions for a sustainable future.

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01 1. PILOT SYSTEM & TECHNOLOGICAL OUTPUT

- 1 unit integrated pilot plant (PV–Biogas–MMP–H_2–Fuel Cell)
- Validated MMP (Microwave-Assisted Methane Pyrolysis) system
- Stable H_2 production from biogas with high efficiency
- Operational data for techno-economic and environmental analysis
- Modular & scalable design for remote area deployment

H_2 Production	System Capacity	Application	Feedstock
5 – 10 Nm³/day (Pilot Scale)	5 – 15 kW (Electrical)	Remote Area & Island	Biogas from Biomass Waste

02 2. SCIENTIFIC & INTELLECTUAL CONTRIBUTION

High-impact Publications
Peer-reviewed articles in Q1–Q2 journals on MMP technology, system integration, and hydrogen economy.

Patents & IP
Patents for MMP reactor design, integration system, and process optimization.

Human Capital Development
Training and capacity building for researchers, engineers, and students in green hydrogen technology.

Data & Knowledge Repository
Comprehensive dataset and knowledge base for future R&D and industrial development.

03 3. STRATEGIC & POLICY CONTRIBUTION

Support National Hydrogen Roadmap
Provide pilot data and policy inputs for Indonesia's hydrogen strategy and regulations.

Model for Remote Area Energy
Demonstrate replicable model for clean energy independence in 3T (Terdepan, Terluar, Tertinggal) regions.

Circular Carbon Economy
Utilization of solid carbon (carbon black) as valuable product for industrial applications.

Strengthen National Innovation Ecosystem
Foster collaboration among BRIN, universities, industry, and local communities.

04 4. SOCIO-ECONOMIC & ENVIRONMENTAL IMPACT

KEY ACTIVITIES
- >1,000 Nm³/h biomethane feed
- Hydrogen hub development
- Carbon products commercialization
- Export opportunity
- Strategic partnership & industrial scale-up

KEY OUTPUT
- Commercial plant operation
- Hydrogen & carbon market leadership
- Technology licensing & export
- National & global impact

Commercial Target (2038+)
H_2 > 1,000 Nm³/h CH_4
↓
> 180 kg/day H_2
↓
> 1 ton/day Solid Carbon

5. KEY PERFORMANCE INDICATORS (KPIs)

Hydrogen Production Efficiency	System Availability	Cost Competitiveness	GHG Reduction	Local Community Engagement
≥ 75% (Target)	≥ 90% (Target)	≤ 4 USD/kg-H_2 (Target in Scale-up)	≥ 60% (vs. Conventional)	≥ 3 Sites (Pilot Deployment)

6. DELIVERABLES

- Integrated Green Hydrogen Pilot Plant (Operational)
- Techno-economic & Environmental Assessment Report
- Scientific Publications & Conference Presentations
- Patents / Intellectual Property Rights
- Policy Brief & Recommendations
- Capacity Building & Training Modules
- Replication & Scale-up Roadmap

7. ALIGNMENT WITH SDGs

- 7 AFFORDABLE AND CLEAN ENERGY
- 8 DECENT WORK AND ECONOMIC GROWTH
- 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
- 13 CLIMATE ACTION
- 14 LIFE BELOW WATER
- 15 LIFE ON LAND
- 17 PARTNERSHIPS FOR THE GOALS

LONG-TERM VISION

Establish Indonesia as a regional leader in green hydrogen innovation and deployment.

Empowering islands, strengthening nations, sustaining the future.

This project will deliver innovative technology, scientific excellence, and real impact for Indonesia's green hydrogen journey.
From Indonesia, for Indonesia, and for a Sustainable World.

BRIN
BADAN RISET
DAN INOVASI NASIONAL

CTCN
UN Climate Tecnology Centre
& Network

UN environment programme

INDONESIA
Hydrogen Economy

THANK YOU

For Your Attention and Collaboration

RESEARCH | INNOVATION | DEMONSTRATION | COLLABORATION | HYDROGEN ECONOMY

Seoul & Daejeon, Republic of Korea | 14 – 16 July 2026

SUSTAINABLE | INNOVATIVE | COLLABORATIVE | IMPACTFUL

Indonesia Biomethane-to-Hydrogen Platform

Microwave-Assisted Methane Pyrolysis as a Strategic Pathway toward the Hydrogen Economy

Turning Waste into Hydrogen, Carbon Materials, and National Energy Security

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H_2 INDONESIA Hydrogen Economy

INTEGRATED VALUE CHAIN

1 LANDFILL LEACHATE COLLECTION

- Landfill leachate source
- High-strength organic waste

2 ANAEROBIC DIGESTION (UASB)

- High-rate anaerobic treatment
- COD removal 40–70%
- Biogas generation

3 BIOGAS UPGRADING TO BIOMETHANE

- Remove CO_2, H_2S, moisture, siloxane
- Membrane / PSA / Water Scrubbing
- Biomethane purity ≥97% CH_4

4 MICROWAVE-ASSISTED METHANE PYROLYSIS (MMP)

- Microwave energy (700–1,100 °C)
- Catalyst/absorber enhances reaction
- $CH_4 \rightarrow H_2$ + Solid Carbon
- High H_2 yield (70–90%), high purity

H_2 HYDROGEN (70–90% yield)

SOLID CARBON (10–30% yield)

5 HYDROGEN PURIFICATION & STORAGE

- PSA purification (≥99.9% H_2)
- Compression (350–700 bar)
- Storage (cascade / tube trailer)

6 APPLICATIONS

- Power & Heat (SOFC / PEMFC)
- Mobility (Fuel Cell Vehicle)
- Industrial Feedstock
- Clean Energy for Communities

WHY MICROWAVE-ASSISTED METHANE PYROLYSIS?

Technology Readiness Level (TRL)	4 – 6 (Pilot Scale)
Operating Temperature	700 – 1,100 °C
Hydrogen Yield	70 – 90% (vol.)
Carbon Yield	10 – 30% (solid)
Main Reaction	$CH_4 \rightarrow C\ (s) + 2H_2$
CO_2 Emission	Near Zero (no CO_2 formed)
Water Consumption	Very Low
Energy Efficiency	High (Direct heating & selective process)
Modularity	Excellent (Compact & Scalable)
Feedstock Flexibility	High (Biomethane ≥97% CH_4)

MASS & ENERGY FLOW (ILLUSTRATIVE)

Biomethane Input (≥97% CH_4) → Microwave Pyrolysis (MMP) 700 – 1,100 °C → Hydrogen (70 – 90%) H_2 / Solid Carbon (10 – 30%)

Energy Balance (Indicative)

Microwave Energy Input	Energy to Products (H_2 + Carbon)	Thermal Loss & Others	Overall Energy Efficiency
15 – 20 kWh per kg H_2	~ 60 – 70%	~ 10 – 20%	~ 70 – 80%

CARBON CO-PRODUCT OPPORTUNITIES

Solid Carbon (Co-product)

Carbon Black (High surface area)	Tire, Rubber, Inks
Battery Additive (Conductive carbon)	Li-ion Battery, Supercapacitor
Conductive Carbon (Electrical conductivity)	Electrode, EMI Shielding, Energy Storage
Graphitic Carbon (High purity)	Lubricant, Refractory, High-temp applications
Advanced Materials (Composites, CNT precursor)	Composite Filler, Aerospace, 3D Printing

STRATEGIC INVESTMENT OPPORTUNITY

Multiple Revenue Streams
Biomethane, Hydrogen, Carbon Products, Carbon Credits, Technology Licensing

High Market Potential
Growing demand for clean hydrogen and advanced carbon materials

ESG & Net Zero Alignment
Near-zero emissions, supports Indonesia's 2060 Net Zero target

Scalable Business Model
Modular, replicable, and adaptable across landfill and biogas sites

Strong Partnership Potential
R&D collaboration, technology transfer, co-investment, and global market access

BRIN STRATEGIC LEADERSHIP

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- Biomethane Production & Upgrading
- Microwave Pyrolysis Technology Development
- Advanced Carbon Materials Research
- Hydrogen Purification & Storage
- Fuel Cell & System Integration
- Techno-economic Analysis & Policy Support

BRIN HYDROGEN ECONOMY ROADMAP 2026–2038

Phase 1 2026 – 2028 Foundation & Pilot
- UASB Pilot & Optimization
- Biogas Production
- Biomethane Upgrading Pilot
- Feasibility Study & Basic Design

Phase 2 2028 – 2031 Pilot Demonstration
- MMP Pilot Plant (1–5 Nm^3/h CH_4)
- H_2 & Carbon Production Validation
- Process Optimization
- Techno-economic Assessment

Phase 3 2031 – 2034 Integration & Scale-up
- Integrated H_2 & Carbon System
- Purification, Compression & Storage
- Carbon Product Development
- Pre-commercial Demonstration

Phase 4 2034 – 2038 Commercial Deployment
- Commercial Scale Deployment
- Market Development (H_2 & Carbon)
- Strategic Partnerships & Investment
- National Rollout & Export Opportunity

KEY IMPACT TO INDONESIA

- **Waste to Wealth:** Convert landfill waste into clean energy and valuable products
- **Energy Independence:** Reduce fossil fuel import and enhance national energy security
- **Green Industry & Jobs:** Create high-tech industries and skilled employment
- **Environmental Protection:** Reduce methane emissions and pollution
- **Global Competitiveness:** Position Indonesia as regional leader in green hydrogen & carbon

TURNING WASTE INTO HYDROGEN, CARBON MATERIALS, AND NATIONAL ENERGY SECURITY

INNOVATE • COLLABORATE • TRANSFORM FOR A SUSTAINABLE INDONESIA

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MAINTENANCE & RELIABILITY COMPARISON

Microwave-Assisted Methane Pyrolysis (MMP) vs Plasma Pyrolysis

Lower Maintenance – Higher Reliability – Lower Operating Risk

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H_2 INDONESIA Hydrogen Economy

1. OVERALL COMPARISON SUMMARY

ASPECT	MICROWAVE PYROLYSIS (MMP)	PLASMA PYROLYSIS	ADVANTAGE
Reactor Design	**Simple packed-bed reactor** • No moving parts • No electrodes in contact with plasma	**Complex plasma reactor** • High-voltage components • Electrode erosion	MMP is simpler and easier to maintain
Major Wear Components	**Susceptor & catalyst** • Periodic replacement • Low wear rate	**Electrodes, nozzles, insulators** • High wear rate • Frequent replacement	MMP has fewer wear parts
Maintenance Frequency	**Low** • Catalyst/susceptor change every 3 – 6 months	**High** • Electrode/nozzle replacement every 1 – 4 weeks	MMP requires less frequent maintenance
Downtime (Emergency)	**< 5%** • Stable operation • Minimal unexpected shutdown	**10 – 20%** • Frequent trips • Component failure risk	MMP ensures higher uptime
Operational Risk	**Low** • No high-voltage system • No arc instability	**High** • High-voltage hazard • Arc instability & back flash risk	MMP is safer and more stable
Maintenance Cost	**Low** • Low-cost spare parts • Long component life	**High** • Expensive electrodes • High replacement frequency	MMP has lower OPEX
Scalability	**High** • Modular scaling • Straightforward design upscaling	**Medium – Low** • Scaling limited by plasma stability • Complex engineering	MMP is more scalable
Environmental Impact	**Low** • Lower energy consumption • Lower NOx formation	**Higher** • Higher energy demand • Higher NOx potential	MMP is more environmentally friendly

2. MAINTENANCE COMPONENT COMPARISON

MICROWAVE PYROLYSIS (MMP)

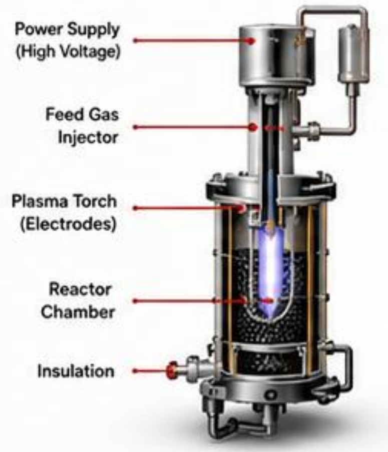
Components to Maintain
- Susceptor (SiC)
- Catalyst (Ni-MgO)

Maintenance Interval
3 – 6 months

Typical Downtime
< 3 days

Complexity
LOW

PLASMA PYROLYSIS



Components to Maintain
- Slectrodes
- Nozzles
- Insulators
- Power Supply Components

Maintenance Interval
1 – 4 weeks

Typical Downtime
3 – 7 days

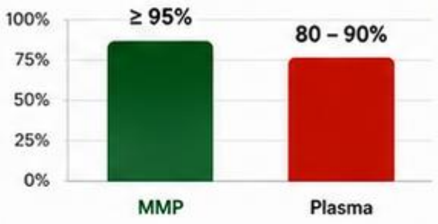
Complexity
HIGH

3. MAINTENANCE COST ESTIMATION (Indicative)

PARAMETER	MMP (Microwave Pyrolysis)	Plasma Pyrolysis	Note
Annual Maintenance Cost	\$40 – 70 / kW	\$120 – 200 / kW	MMP ~50–70% lower
Spare Parts Cost	Low	High	Electrodes are expensive
Labor Requirement	Low	High	MMP requires less skilled intervention
Expected Component Life	3 – 6 months	2 – 6 weeks	Electrodes wear fast
Total Cost of Ownership (TCO)	Lower	Higher	Significant OPEX saving with MMP

4. RELIABILITY & AVAILABILITY

Plant Availability (Target)



Higher availability means higher hydrogen production and better project economics.

KEY TAKEAWAY

MMP Technology offers a simpler design, lower maintenance frequency, lower cost, and higher reliability compared to plasma pyrolysis, making it the more practical choice for pilot and commercial deployment.

MMP MAINTENANCE HIGHLIGHTS

- Longer Component Life
- Lower Downtime
- Lower OPEX
- Higher Plant Availability

IMPACT ON PROJECT SUCCESS

- Higher Uptime & Productivity
- Lower Operating Cost
- Lower Risk & Higher Safety
- Stronger Bankability & Investor Confidence

MMP = HIGHER RELIABILITY
LOWER COST
BETTER RETURNS

TECHNOLOGY RISK & OPERABILITY ASSESSMENT

Microwave-Assisted Methane Pyrolysis (MMP) vs Plasma Pyrolysis

For Indonesia Landfill Biomethane-to-Hydrogen Project

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H_2 INDONESIA Hydrogen Economy

1 TECHNOLOGY MATURITY

PARAMETER	MMP	PLASMA
TRL	4 – 6	5 – 7
Commercial References	Limited	Limited
Scale-Up Risk	Medium	Medium – High
Technology Complexity	Medium	High
Bankability Potential	Medium – High	Medium

Both technologies are early-stage, but MMP has lower complexity and better bankability potential for distributed applications.

2 MAINTENANCE & RELIABILITY

PARAMETER	MMP	PLASMA
Maintenance Frequency	3 – 6 months	1 – 4 weeks
Main Wear Component	Catalyst / Susceptor (SiC)	Electrodes (Nozzles, Insulators)
Downtime (Annual)	< 5%	10 – 20%
Availability (Target)	≥ 95%	80 – 90%
Reliability (Continuous Operation)	High	Moderate

MMP offers much less frequent maintenance and higher plant availability.

3 OPERABILITY COMPARISON

ASPECT	MMP	PLASMA
Start-up Time	Minutes	Minutes
Automation & Control	Easy	Moderate
Operator Skill Requirement	Moderate	High
Remote Operation Capability	Excellent	Moderate
Grid Fluctuation Tolerance	High	Medium
Process Stability	High	Moderate

MMP is simpler to operate, more robust, and better suited for remote & distributed biomethane resources.

4 ECONOMIC IMPACT (INDICATIVE)

PARAMETER	MMP	PLASMA
Maintenance OPEX	Low	High
Spare Parts Availability	Standard Industrial	Specialized (Custom)
Spare Parts Cost	Low	High
Plant Availability	High	Moderate
Hydrogen Cost Potential	Lower	Higher
CAPEX Intensity	Moderate	High

MMP has lower OPEX and higher availability, resulting in lower hydrogen cost.

5 INVESTOR DECISION MATRIX

EVALUATION CRITERIA	WEIGHT (%)	MMP (SCORE 1–5)	PLASMA (SCORE 1–5)	MMP WEIGHTED SCORE	PLASMA WEIGHTED SCORE
Technical Feasibility	25	4.5	4.0	1.13	1.00
Maintenance & Reliability	20	4.8	3.0	0.96	0.60
OPEX Potential	20	4.5	3.2	0.90	0.64
Scalability & Flexibility	15	4.2	4.5	0.63	0.68
Technology Risk	20	4.0	3.5	0.80	0.70

TOTAL WEIGHTED SCORE MMP **4.42 / 5**

TOTAL WEIGHTED SCORE PLASMA **3.62 / 5**

MMP scores higher across critical investment criteria, offering the best overall value and lower project risk.

WHY MMP IS THE PREFERRED CHOICE FOR INDONESIA

- Lower maintenance frequency and cost
- Higher reliability and plant availability
- Simpler operation with lower technical risk
- Better suited for distributed landfill biomethane
- Lower hydrogen cost and better economics
- Stronger bankability and investor confidence

BEST FIT FOR INDONESIA'S CONTEXT

Distributed Biomethane Sources (Landfills)

Modular & Scalable Deployment

Lower Emission & Environmental Footprint

Attractive Economics for Investors

TYPICAL MAINTENANCE INTERVAL COMPARISON

MMP (MICROWAVE PYROLYSIS)

3 – 6 MONTHS

- Catalyst replacement / regeneration
- Susceptor (SiC) inspection
- General system check

PLASMA PYROLYSIS

1 – 4 WEEKS

- Electrode replacement
- Nozzle & insulator inspection
- Plasma stability tuning

APPLICATION SUITABILITY

MMP

Decentralized, modular, remote locations, low O&M capability areas

PLASMA

Large centralized plants, well-staffed operation, high technical support

For distributed biomethane resources such as Indonesian landfills, **Microwave-Assisted Methane Pyrolysis (MMP)** offers the **best balance of performance, reliability, maintenance simplicity, and long-term economics.**

High Reliability & Availability

Lower OPEX & Hydrogen Cost

Lower Risk & Simpler Operation

Stronger Bankability & Investor Confidence

ECONOMIC ANALYSIS & PROJECT VIABILITY (INDICATIVE)

10 Nm³/h CH_4 Mini Pilot Plant – Microwave-Assisted Methane Pyrolysis (MMP)

Converting Landfill Biomethane into Clean Hydrogen and High-Value Carbon

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H_2 INDONESIA Hydrogen Economy

1. PROJECT BASIS & KEY ASSUMPTIONS

Plant Capacity (Feed)	10 Nm³/h CH_4
Operating Days	330 days/year
Operating Hours	7,920 h/year
Methane Purity	≥ 97 %
Technology	Microwave-Assisted Methane Pyrolysis (MMP)
Hydrogen Purity (Target)	≥ 99.9 %
Carbon Purity (Target)	≥ 90 %
Plant Availability	≥ 95 %
Economic Lifetime	15 years
Discount Rate	10 %
Currency	USD

2. PRODUCTION SUMMARY (ANNUAL)

PRODUCT	AMOUNT
Hydrogen Production	≈ 65,000 kg/year (≈ 180 kg/day)
Solid Carbon Production	≈ 300 ton/year (≈ 0.9 ton/day)
CO_2 Avoided (vs. SMR)	≈ 1,150 ton CO_2/year
Energy Consumption	≈ 1.2 MWh/kg H_2
Water Consumption	Very Low (Minimal for system utilities)

3. CAPITAL EXPENDITURE (CAPEX) ESTIMATE (INDICATIVE)

NO.	DESCRIPTION	% OF TOTAL	ESTIMATED COST (USD)
1	Process Equipment (Reactor, Microwave System, Gas Handling, Cyclone, Filters)	45%	1,350,000
2	Balance of Plant (Piping, Utilities, Electrical, HVAC)	20%	600,000
3	Instrumentation & Control	10%	300,000
4	Civil & Structural	10%	300,000
5	Engineering, Procurement & Construction (EPC)	10%	300,000
6	Contingency (10%)	5%	250,000
	TOTAL CAPEX (INDICATIVE)		**3,100,000**

4. OPERATING EXPENDITURE (OPEX) ESTIMATE (ANNUAL)

DESCRIPTION	ESTIMATED COST (USD/YEAR)
Electricity	120,000
Labor (Operation & Maintenance)	80,000
Maintenance & Spare Parts	70,000
Utilities (Cooling, Compressed Air, etc.)	30,000
Consumables & Others	20,000
Insurance & Administration	15,000
TOTAL OPEX (INDICATIVE)	**335,000**

5. REVENUE ESTIMATION (ANNUAL)

PRODUCT	QUANTITY	UNIT PRICE (USD)	REVENUE (USD/YEAR)
Hydrogen	65,000 kg	6.0 / kg	390,000
Solid Carbon (High Value)	300 ton	1,000 / ton	300,000
Carbon Credit (1 ton CO_2e = 5 USD)	1,150 ton	5 / ton CO_2e	5,750
TOTAL REVENUE (INDICATIVE)			**695,750**

6. FINANCIAL SUMMARY (USD)

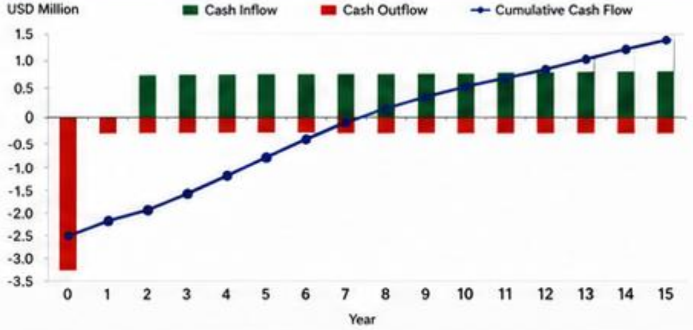
METRIC	VALUE (INDICATIVE)
Total CAPEX	3,100,000
Annual OPEX	335,000
Annual Revenue	695,750
EBITDA (Annual)	**360,750**
Payback Period (Simple)	≈ 4.3 years
IRR (After Tax)	≈ 22 – 28 %
NPV (15 years, 10% discount rate)	≈ 2.1 – 2.8 million
Levelized Cost of H_2 (LCOH)	≈ 2.0 – 2.6 USD/kg H_2

7. SENSITIVITY ANALYSIS – IRR (%)

SCENARIO		H_2 PRICE (USD/KG)			
		4.0	5.0	6.0	7.0
CARBON PRICE (USD/TON CO_2e)	0	10%	16%	22%	28%
	5	13%	19%	25%	31%
	10	16%	22%	28%	34%
	15	19%	25%	31%	37%

Project attractiveness increases significantly with higher H_2 price and carbon credit value.

8. CASH FLOW OVERVIEW (INDICATIVE)



9. KEY VALUE DRIVERS

- **Hydrogen Price** – The highest impact on project profitability.
- **Carbon Credit Value** – Improves IRR and shortens payback.
- **Plant Availability** – Higher uptime lowers H_2 production cost.
- **Scale-Up** – Larger capacity improves economies of scale.
- **Local Supply Chain** – Reduces CAPEX & OPEX, improves bankability.

10. CONCLUSION

The 10 Nm³/h MMP mini pilot plant is economically attractive with a payback period of ~4.3 years, IRR of 22–28%, and strong upside potential driven by hydrogen price and carbon credit revenue.

MMP technology provides a low-OPEX, high-reliability, and bankable solution for landfill biomethane valorization in Indonesia.

11. INVESTMENT HIGHLIGHTS

- Strong Alignment with Indonesia's Hydrogen Roadmap & Net Zero 2060
- High Value Creation: Clean H_2 + Advanced Carbon + Carbon Credits
- Low Operating Cost & High Reliability (Microwave Technology Advantage)
- Scalable, Replicable and Ready for Commercial Deployment
- Attractive Returns with Positive Environmental & Social Impact

TURNING LANDFILL BIOMETHANE INTO CLEAN HYDROGEN, ADVANCED CARBON MATERIALS, AND ECONOMIC VALUE

Clean Energy | Circular Economy | Energy Security | Green Jobs