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Cartagena de Indias Convention Center, Colombia
23-25 September 2025

Biogas Capture and Valorization for Multiple Uses in Palm Oil Mills

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Ministry of Plantation and Commodities

fedepalma | cenipalma

Presentation Outline

- Industry Performance
- Biomass/POME Circularity
  - Characteristics
  - Environmental performance
- POME Treatment
  - Conventional Technology
  - Modernised Technology
    - Biogas capture
    - Biogas utilization
- Biogas Upgrading
  - Potential Application
  - Economic Feasibility
- Decarbonisation Potential
- Conclusion

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Malaysian Palm Oil Board, HQ

Oil Palm Planted Area & Palm Oil Processing (2024)

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Region	Planted area (million ha)	Palm oil mill (no.)	Average FFB yield (t/ha)	Average OER (%)	CPO production (million t)	CPKO production (million t)
Peninsular Malaysia	2.504	238	18.42	19.46	10.89	1.34
Sabah	1.484	128	15.74	20.54	4.27	0.42
Sarawak	1.624	84	14.89	19.37	4.17	0.38
Total	**5.612**	**453**	**16.70**	**19.67**	**19.34**	**2.14**

Source: *MPOB (2025).*

Oil Palm Biomass Supply Chain 2024

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Oil palm plantation
5.61 mil. ha

Palm oil mill 453

Product - Commodity

Waste/By-product?? - Lignocellulosic biomass

Plantation biomass

Oil palm frond
(15 t/ha)
62.61 mil t

Oil palm trunk
(75 t/ha)
8.51 mil t

Fresh fruit bunch
(35 t/ha)
93.68 mil. t

Milling biomass

Palm kernel (11.9%)

Mesocarp fiber
(15%)
7.96 mil t

Empty fruit bunch
(23%)
7.53 mil t

Crude palm oil (21%)
19.34 mil t

43 **Palm Kernel crushers**

Palm kernel oil
(2.3%) 2.14 mil t

Palm kernel shell
(6%) **4.60 mil t**

Palm kernel cake
(7%)

∑ OPB
~91.21 mil t

53 **Palm oil refinery**

Refinery main & by-products

Palm oil mill effluent
(67%)
65.88 mil t

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Source: *MPOB (2025); Loh (2017). Energy Convers Manage., 141; 285–298*

Resource Diversification Strategy (4F, 1C) - Food, Feed, Fibre, Fuel & Chemicals

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Oil Palm

Resources		Applications	Value Addition
Palm oil	19.34 mil. t	Food	Salad*, Dietary fibre**
		Bio-fertilizer	Mulch*, Compost*, Organic fertilizer**
Mill byproduct Oil palm biomass	~90 mil. t, dwb	Renewable energy	Heat and power* First generation biofuel* Second generation biofuels** Advanced biofuels**
		Bio-composite & bio-products	Fiberboard**, Plywood*, Fibremat*, Biochar**, Activated carbon**
		Bio-based chemicals	Sugars/Cellulose**, Lignin**, Vitamin E**, Carotenes**, Squalene**
Refinery byproduct	~4.5 mil. t	Animal feed	Protein*, Energy**

* Developed
** Emerging

Source: *Parveez et al. (2021). J Oil Palm Res., 33(2):181-214.*

Characteristics of Oil Palm Biomass

Fertilizer Value:

Oil Palm Biomass	Nutrient content (kg/ha/yr)				
	N	P	K	Mg	Ca
Oil palm frond (annual pruning)	107.9	10.0	139.4	17.2	25.6
EFB	5.4	0.4	35.3	2.7	2.3
Mesocarp fibre	5.2	1.3	7.6	2.0	1.8
Palm kernel shell	3.0	0.1	0.8	0.2	0.2
POME (raw, dry)	12.9	2.1	26.6	4.7	5.4

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∑ Nutrient content (kg/ha/yr)
N = 150;
P = 13;
K = 200

Combustion
Slagging & fouling:
- H/C; O/C; alkali index

Fuel properties: physicochemical properties

Oil Palm Biomass	Calorific Value (MJ/kg)	Moisture Content (%)	Ash Content (%)	Volatile Matter Content (%)	Total Chloride Content (%)	Fixed carbon (%)	Carbon content (%)
EFB	18.88	66 - 69	4.60	87.0	0.331/0.128*	13.44	48.72
Mesocarp fibre	19.06	35 - 48	6.10	84.9	0.148/0.113*	19.30	46.40
Palm kernel shell	20.09	11 - 13	3.00	83.4	0.157/0.157*	22.61	57.90
Oil palm frond	15.72	62 - 77	3.37	85.1	0.404/0.250*	14.26	48.43
Oil palm trunk	17.47	67 - 81	3.35	86.7	0.248/<0.002*	14.15	51.40
POME (raw, dry)	16.99	90 - 95	15.20	77.0	1.956/0.233*	7.54	50.01

Source: *Loh (2017). Energy Conversion and Management, 141:285–298*

Major Issues at Palm Oil Mills for Environmental Regulatory Compliance






- BOD 20/50 ppm – sensitive areas
- Proposed new monitoring parameters by the DOE – odour & color
- Methane emissions - mandatory vs voluntary biogas implementation

- Clean Air Regulation 2014 (CAR 2014) - particulate emissions < 150 mg/Nm^3
- High CAPEX installation of air pollution control system (APCs)

- CAR 2014 – compliance with particulate emissions from EFB incineration
- Guideline on management plan of EFB (2021) - leachate issue

Palm Oil Mill Effluent (POME)

~0.65 t POME per t FFB processed; ~65.88 mil. t POME in 2024.
A thick brownish colloidal slurry:

- Water 95% - 96%
- Oil 0.6% - 0.7%
- Total Solid 4% – 5%
- SS 2% – 4%
- Fine cellulosic fruit residues

Final discharge of 100 ppm BOD reduces to 20 ppm in certain sensitive areas in Sabah, Sarawak and the Peninsular.

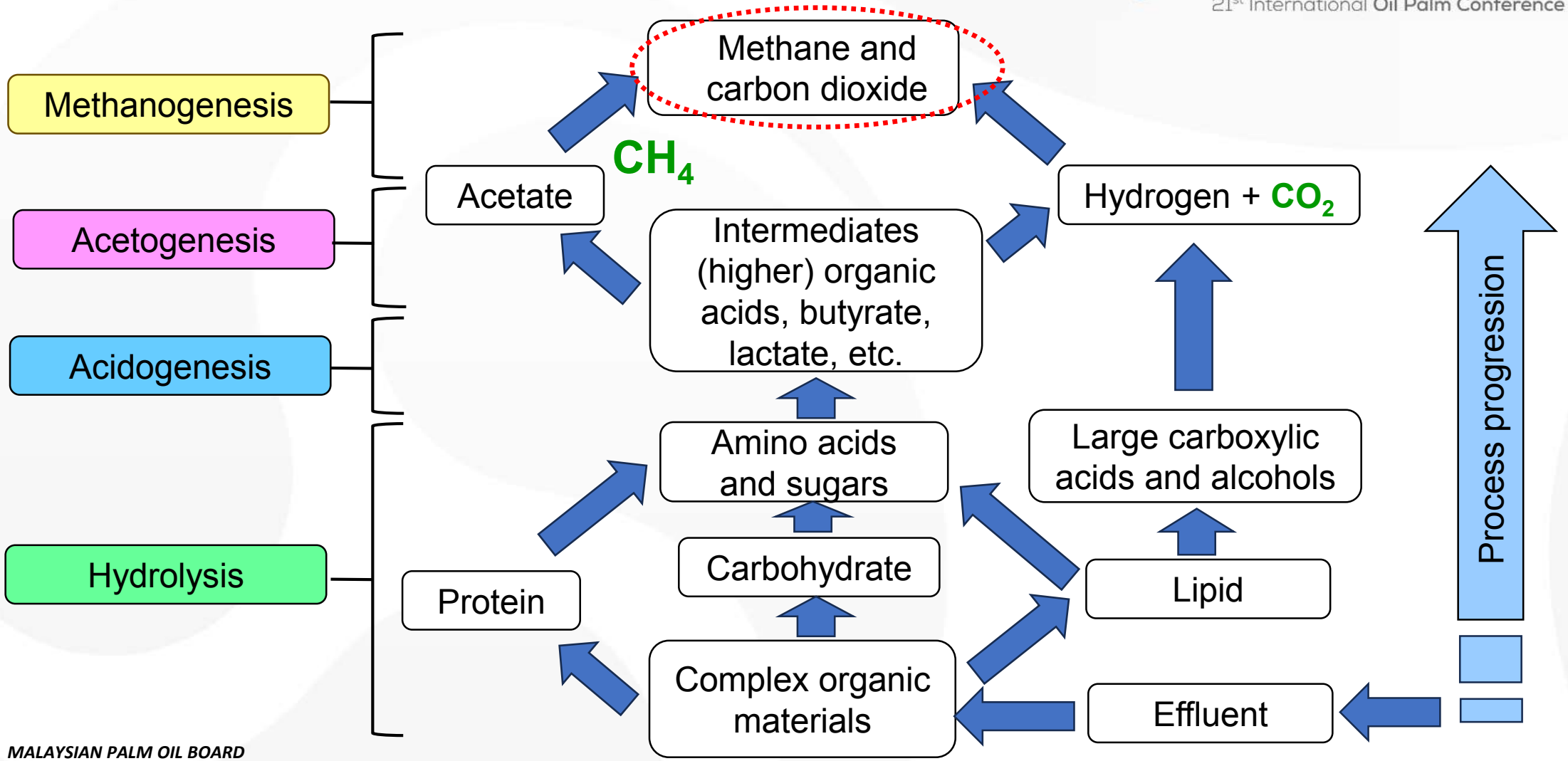
Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations, 1977

Parameter	POME Characteristics	Limit for Discharge (1984 & thereafter)	Standard A	Standard B
Temperature, °C	80-90	45	40	40
pH	3.3 – 5.7	5.0 – 9.0	6.0-9.0	5.5-9.0
BOD, mg/l	18000 - 25000	100*	20	50
COD, mg/l	45000 - 55000	-	50	100
Suspended solids, mg/l	25000 - 31000	400	50	100
Oil & grease, mg/l	5600 – 8800	50	1/ND	10
Ammoniacal N, mg/l	77 - 100	150	10	20
Total N, mg/l	670 – 780	200	-	-

Sources: *DOE, 2009; Loh et al., 2013; Liew et al., 2015 –J Environ. Manage. 149 :222-235*

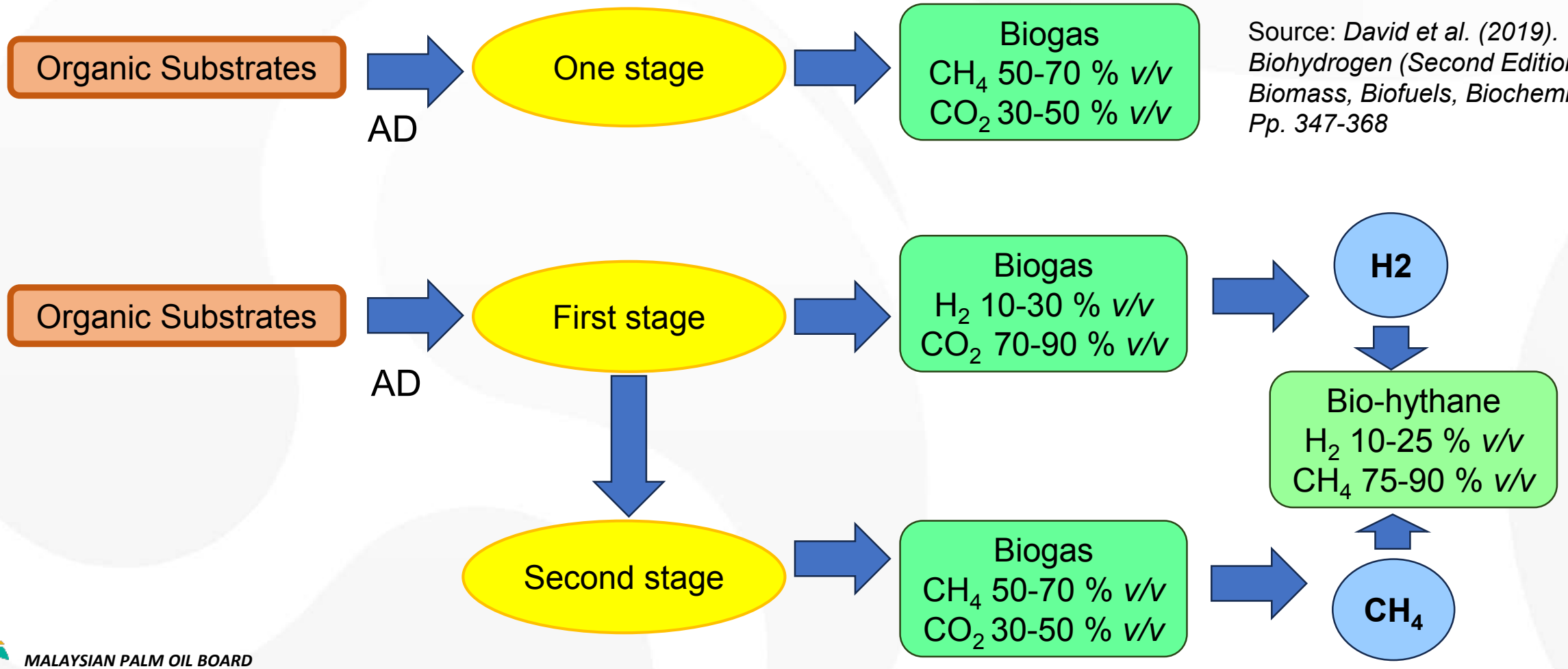
Anaerobic Digestion

Conventional: 1 stage



Biohythane

Modernised & emerging: 2 stages; Co-digestion;
- Liquefaction



Source: *David et al. (2019). Biohydrogen (Second Edition) Biomass, Biofuels, Biochemicals. Pp. 347-368*

Current POME Treatment

Common POME treatment: open ponding (78%) or open digester tank system (18%) (MPOB, 2009)

EFB = Empty Fruit Bunches

Anaerobic Digestion → Methane released to atmosphere; → Facultative Ponding System → Aerobic Ponding System → Final Discharge

CH_4 CO_2

Anaerobic Digestion → Methane released to atmosphere; → Aerobic Ponding System → Tertiary Polishing Treatment → Final Discharge

GWP CH_4 = 28x CO_2 (IPCC Synthesis Report 2014)

Anaerobic Digestion → Methane trapped (Biogas system); → Aerobic Ponding System → Final Discharge

Discharge Limit 20 ppm

Zero Discharge → Clean Water

EFB → Total/ Partial Composting POME and EFB → Methane generation avoided (due to aerobic process); → Compost

Total/Partial Evaporation of POME → Methane generation avoided (due to POME evaporation and no anaerobic digestion); → Clean Water

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Source: *Loh et al. (2020). Palm Oil Dev. 72: 1-7*

Modernised Biogas Capture Technology

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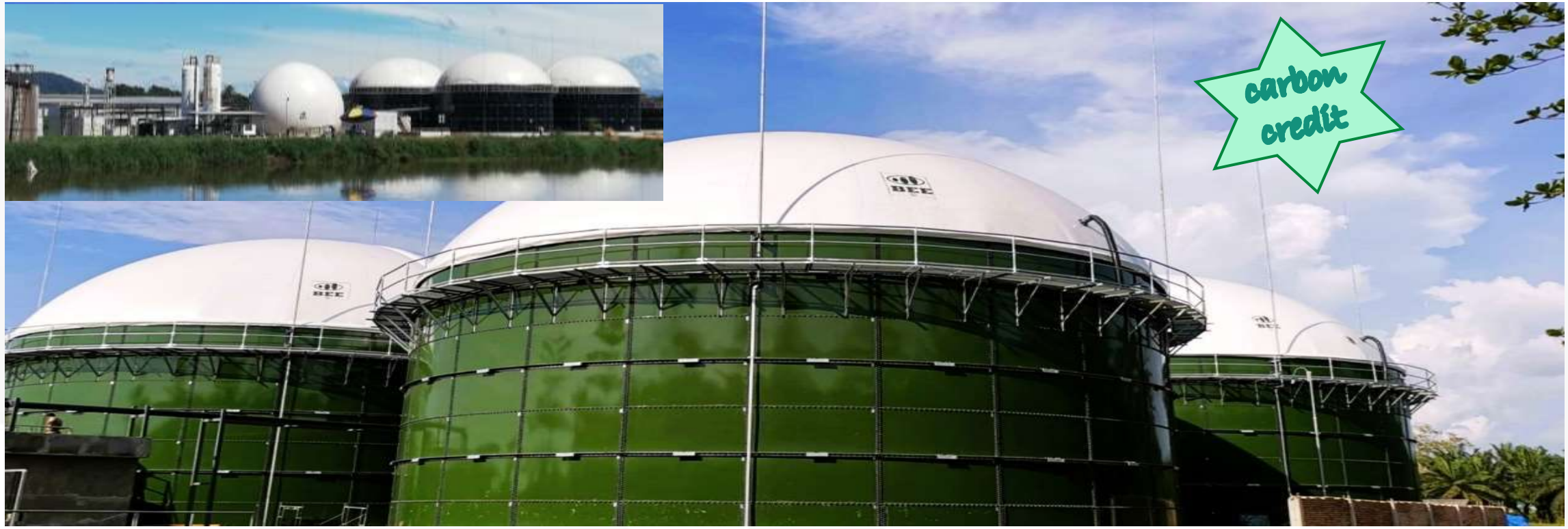
Covered lagoon AD technology

Digester tank AD technology
- Floating roof

Commercialized Technology: Digester Tank

1. Tee Teh POM (Johor, M'sia) – in operation since 2008
2. Adong POM- Woodman Group (Sarawak) – completed 2013
3. Ladang Sabah (IOI Group) – completed 2014, power generation
4. Bakong POM (RSB Group, Sarawak) – completed 2018
5. Central POM (Perak, M'sia) – completed 2019, grid-connected
6. Nam Bee POM (Negeri Sembilan, M'sia) – completed 2024
7. Sri Senggora POM (Pahang, M'sia) – completed 2024, grid-connected



Source: *Hextar Biogas BEE Sdn. Bhd.– MPOB joint collaboration; https://hextarbiogasbee.com/projects/*

Biogas Utilisation Options

Onsite : 1) Limited application/ utilisation due to surplus energy from biomass
2) Suitable for mills integrated with downstream activities, complex and staff quarters

Offsite : 1) FiT: Limited quota from SEDA
2) Bio-CNG: high investment & production cost, low natural gas price (subsidized)

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1	Onsite: steam & heat generation	Biomass-biogas boiler/burner Package boiler	Direct fuel replacement Combined heat & power	Low investment cost & technology
2	Onsite: electricity generation	Gas engine Micro gas turbine Diesel substitute	Mill use & downstream activities (Palm oil mill & refinery complex)	Moderate/ high investment cost & technology
1	Offsite: Electricity generation	Gas engine Micro gas turbine	On-grid: Feed-in tariff Rural electrification	Moderate/high investment cost & technology
2	Offsite: biogas upgrading	Membrane PSA Water/chemical	Alternative fuel for industry & transport sector via mobile pipeline (trailer) or injection to gas pipeline	High investment cost and technology

Biogas for Co-Firing – Palm Oil Mill

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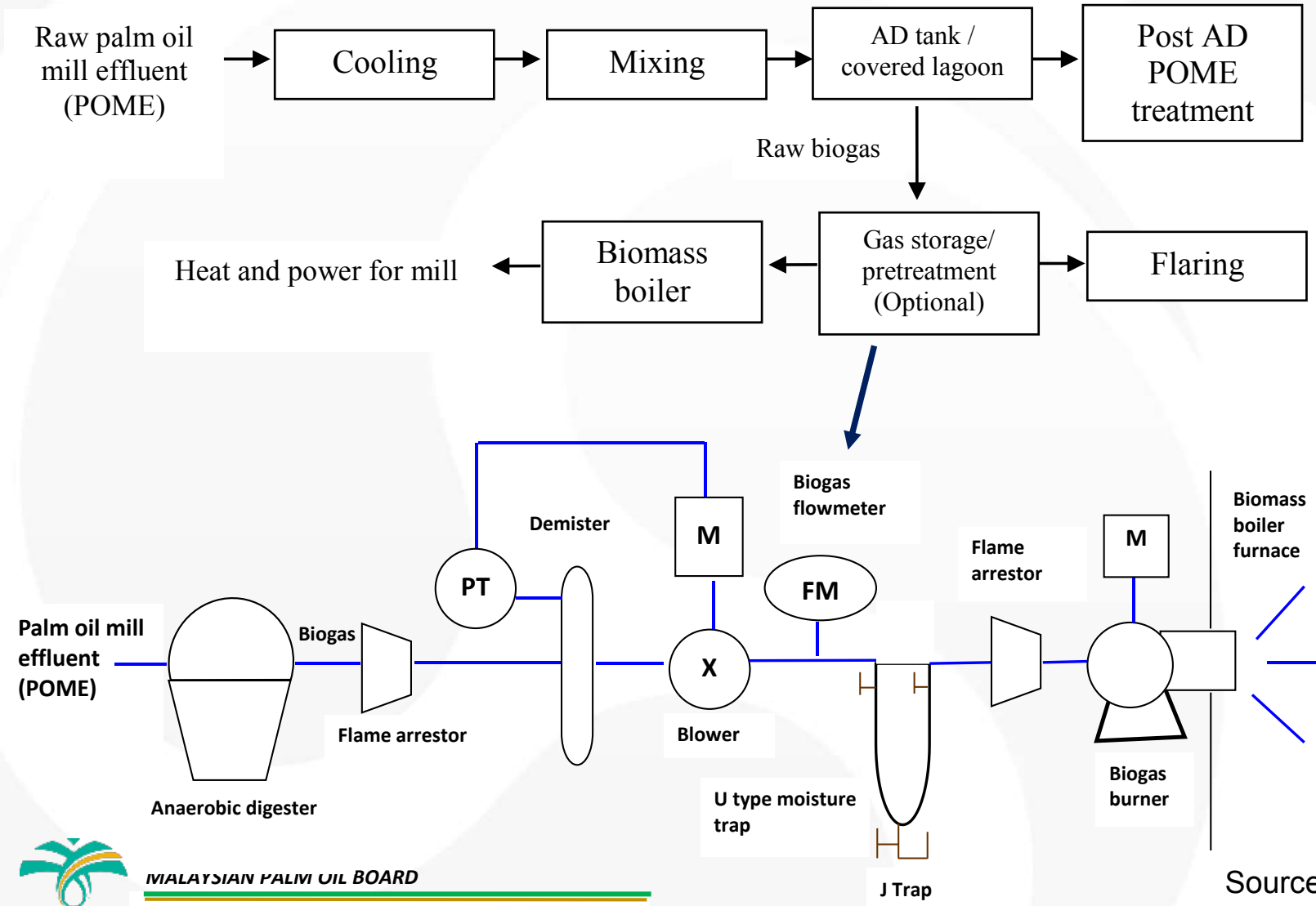
Biogas burners installed at biomass boiler

- Biogas can be co-fired directly into existing palm oil mill biomass boiler (steam & heat generation)
- Provides a safer, cheaper and faster way of biogas utilization (no gas pretreatment required)
- Potential for reduction of dust particulate, slagging/fouling of the boiler tube (less clinker formation)
- Displacement of palm shell (2-5% of shell saving / t FFB) – additional income for the millers

PM Concentration Reduction



- ✓ 60 t/hr palm oil mill, 40 t/hr water tube boiler, 32 barg (high pressure)
- ✓ Particulate matters threshold = 0.150 g m^{-3}
- ✓ Findings, g m^{-3}:
  - **0.1375 (biogas-MF)**
  - 0.2080 (MF only)
  - 0.6050 (biogas-MF-EFB; 70:30)

Source: *Nasrin et al. (2019). https://doi.org/10.1002/ep.13189*

Biogas for Electricity Generation

- Suitable for the mills that require additional electricity for their integrated downstream activities
- On-site electricity generation via:
  - Gas engine,
  - Micro turbine,
  - Co-firing in diesel genset (diesel displacement),
  - Expands through back pressure steam turbines as part of a cogeneration system to produce both electricity and process steam.
- Diesel saving/replacement for mills during start-up, non-processing hours or quarters' uses

Gas engine

Biogas combustion flame generating steam for back pressure turbine

Diesel genset

Biogas for Electricity Generation - Downstream Activities in POM

Kernel Crushing Plant integrated with POM

Tertiary plant of POME

EFB Treatment Plant for Fibre and Solid Fuel

Solvent Extraction Plant

POM staff quarters

Biogas for Steam & Chilled Water Generation

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- Applicable for integrated palm oil mill-refinery complex
- Biogas as a fuel for boiler and chiller of refinery

- Suitable for low and high pressure package boiler/absorption chiller (use the heat for driving refrigerant vapours at low-to-high pressure, creating cooling effect)

- Direct fuel displacement
  - Medium fuel oil (start-up)
  - Diesel (for package boiler)
  - Electricity for auxiliary components of the adsorption chiller

High pressure package boiler

Absorption chiller

Low pressure package boiler

Biogas for Electricity Generation - Grid Connection under FIT

1.25 MW Biogas Plant

Achi Jaya POM, Segamat

500 kW Biogas Plant

Serting Hilir POM

2.0 MW Biogas Plant

Batu Pahat POM (BELL Group)

2.0 MW Biogas Plant

Havys POM

Biogas Plant & Infrastructure (Grid Connection)

Basic Unit :
Biogas Plant & Flaring Unit

Covered Lagoon
(RM 6.5 m)

or

Digester Tank
(RM 8.5 m)

Gas Pretreatment & Gas Engine

Gas Pretreatment
(Scrubber,
Chiller dryer)

Gas Engine & Engine Room/building

Total: RM 4.5 m

Additional Grid Connection Infrastructure & Facilities

1) Low Voltage Line

(RM 1.4 m)

2) High Voltage Line

> RM 1.5 m

3) Pencawang Elektrik (PE)

(RM 200k)

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Main components of grid connection facilities (external)	RM
<u>Low Voltage line (biogas):</u> Switchboard Cabling	 800k 600k
<u>High Voltage line:</u> Transformer Switchgear Cabling	 300k 1.0 mill 300k/km
<u>*PE Building:</u> New set up / Extension of existing PE	 200k 50k
Testing & Commissioning	50k
Estimated cost (Up to 1 km)	3.1 – 3.3 m (excl. GST)
Internal electrical work/ control room/ load bank/safety	500k

Biogas for Rural Electrification

1.2 MW biogas plant (covered lagoon) installed in a 54 t/hr palm oil mill in Felda Umas, Tawau, Sabah

0.6 - 1.2 MW electricity generated from biogas plant supplied to Felda Umas settlers (replacing/reducing diesel for electricity generation)

Commercialized Technology: Bio-CNG

Biogas Offsite, Off Grid

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Raw Biogas (CH_4, CO_2, H_2S) → Pretreatment (H_2S, moist) → Compression → Membrane (CO_2) → Storage (CH_4) /dispensing

Source: *Nasrin et al. (2020). IOP Conf. Ser. 736 022060;*
Nasrin et al. (2018). Eng. Bull. 126: 11-17

World's 1st Bio-Compressed Natural Gas (Bio-CNG) from POME

Launching speech by YB Minister of MPIC

Signing of the plaque by YB Minister of MPIC

MOA exchange ceremony

Flag-off of the 1st delivery of Bio-CNG

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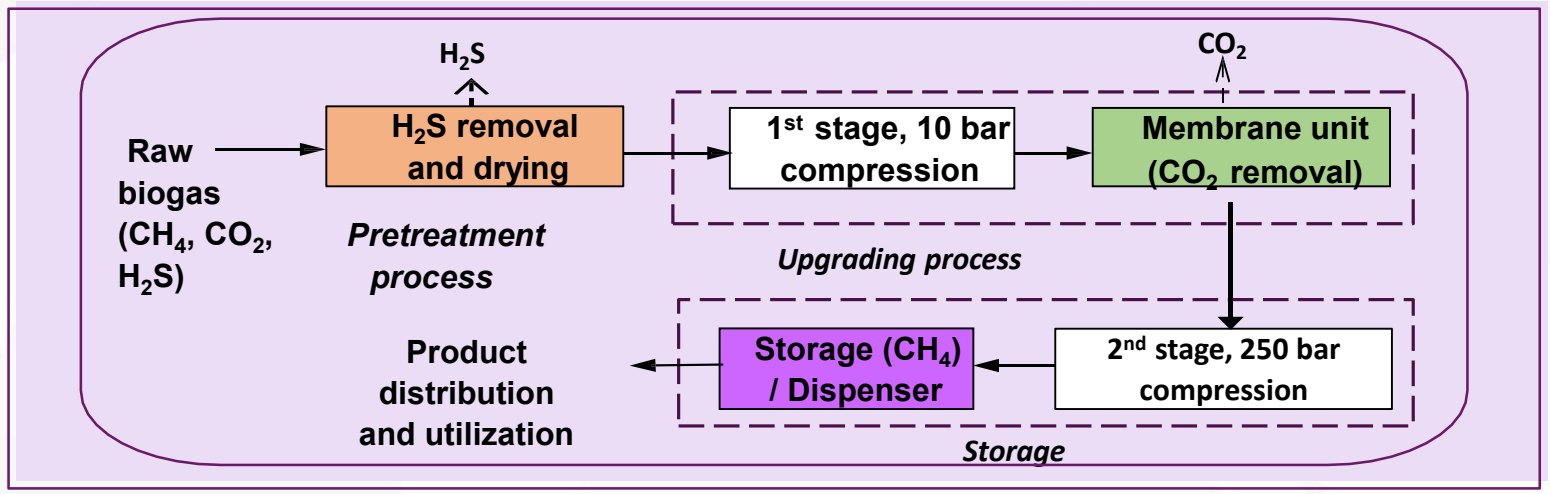
- Launched by YB Minister of MPIC on 28 Oct 2015.
- World's first Bio-CNG commercial plant: MPOB-Felda Palm Industries Sdn. Bhd-Sime Darby Offshore Engineering Sdn. Bhd.
- Location: Felda Sg. Tengi Palm Oil Mill.
- Production: 400 $m^3\ hr^{-1}$ Bio-CNG = 80,000 MMBTu for industrial uses - for heating to manufacture alloy. wheels for motor vehicle

Source: *Nasrin et al. (2020). IOP Conf. Ser. 736 022060;*
Nasrin et al. (2018). Eng. Bull. 126: 11-17

BioCNG Production (1)



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Why compression?
- Improve energy density, reduce storage volume, effective transport, storage and injection.
- System efficiency: Operating condition (desired P, Q̇), gas purity, system design.
→ ~55% thermodynamic efficiency

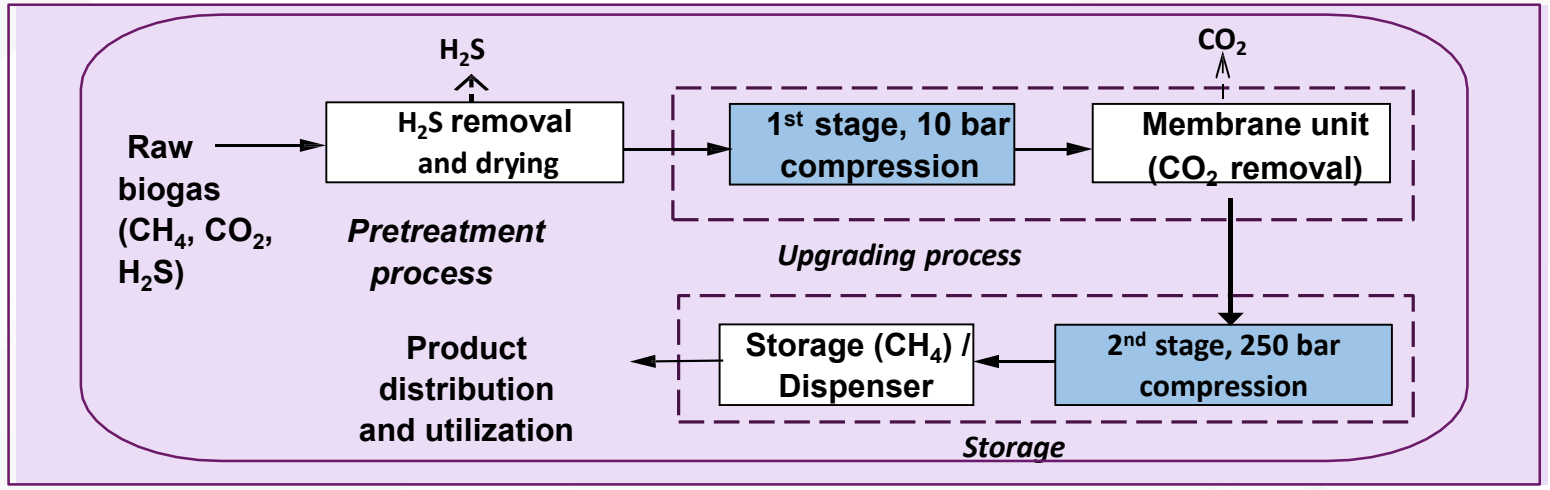
Technical Requirement:
- P range: 2-5 mbar (raw biogas) – 10 bar (1st stage) - 250 bar (2nd stage) – 18-24 barg (NGDS)
- **Safety regulation and standards**
- Application-dependent P range:
  - ❖ Storage, 240-250 bar
  - ❖ Tanker, 276 bar
  - ❖ Pipeline, 20-70 bar
  - ❖ NG grid, ~15-20 bar (local grid) up to 200 bar
- H-P compression: explosion-proof multi-stage reciprocating compressors

Pretreatment
– bioscrubber (<900 ppm) + activated carbon (<10 ppm), > 99% H_2S removal
– H_2O

Upgrading (membrane)
– >80% CO_2 removal,
– ~65% CH_4 to >90%

– Temporary Storage: H-P tank/cylinder
– Dispense to CNG trailer (mobile pipeline)
– Inject directly to existing gas pipeline (replacing fuel oil, LPG, etc.)

BioCNG Production (2)



Source: *Nasrin et al. (2020). IOP Conf. Ser. 736 022060;*
Nasrin et al. (2018). Eng. Bull. 126: 11-17

2nd Stage compressor, gas cylinders and dispenser unit

1st stage compressor unit and membrane separation system

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Implication:

- Stable & consistent feedstock supply;
- High CAPEX & energy demand for upgrading;
- Ensure safe operating pressure to prevent leaks; potent GHG;
- Adhere to strict safety protocols: gas leak detection, flame arrestors, pressure relief systems, etc.;
- Ease of maintenance and servicing;
- CNG requires > space for fuel storage than petrol & LNG;
- Supply chain establishment and creation of market access.

❖ **Environmental sustainability**

- Lower GHG (less NOx), CF, energy security, fuel cost reduction, CE.

Bio-CNG Applications

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Potential

Transportation fuel:
– Diesel-fueled buses, trucks, cars (bioCNG; bioLNG; bioH_2)

Chemical Feedstock:
– Green H_2, MeOH, or NH_3

Test Parameters of Vehicle Testing using Bio-CNG (Petrol Car)

	Test Description	Natural Gas (Before)	BioCNG (After)
1	Engine Ignition	No issue	No issue
2	Engine Power	Good	Good. No difference felt
3	Engine Responsiveness	Good	Good. No difference felt
4	Engine Smoothness	Good	Good. No difference felt
5	Idling RPM	Slightly above 1k	Slightly above 1k

Current

Heating & cooking
– LPG (residential, commercial, and industrial settings)
CHP (cogeneration)
– Electricity (agriculture, industrial)
Grid injection (virtual or gas grid)
– Fuel oil supplement (household, industrial)

Bio-CNG Compositions (Final Product)

Gas Component	Vol. %
CH_4	95.45± 2.00
CO_2	4.4 ±2.44
O_2	0.74±0.54
H_2S, ppm	0.45±0.44
Calorific value, MJ m^{-3}	**35.95**

Source: *Nasrin et al. (2020). IOP Conf. Ser. 736 022060*

Example of BioCNG Application: Replacing LPG at OMI Alloy (M) Sdn. Bhd (45 km away)

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Product Distribution and utilization:

- Install pressure reducing unit (PRU) and trailer bay at OMI's factory
- Fixed storage: 15 mmbtu;
- Mobile storage: 80-90 mmbtu (2 units of trailers)
- Replacing LPG for steam and heat generation
- OMI uses the heat to manufacture alloy wheels for motor vehicle

Source: *Nasrin et al. (2020). IOP Conf. Ser. 736 022060;*
Nasrin et al. (2018). Eng. Bull. 126: 11-17

Economic Feasibility (1)

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Economic analysis of biogas plant for co-firing
(based on 60 t/hr palm oil mill, different biogas technology)

Type of biogas utilization: co-firing	**Economic Value**	
	Digester Tank	**Covered Lagoon**
Capital expenditure, biogas plant + burner (CAPEX), RM (million)	8.0	7.0
OPEX @ 2% of CAPEX, RM (million/yr)	0.2	0.14
Shell displacement, tonne/yr (at 80% of total shell produced)	13,824	
Assumption: • **Sale income of shell @ RM150/tonne = RM2.07 (million/yr)**		
Internal rate of return (IRR), %	23.34	27.57
Payback period (PBP), year	4.3	3.6

Source: *MPOB (2019). Report of Working Group on Biogas*

Economic Feasibility (2)

Economic analysis of biogas plant for grid connection – FiT project (based on 60 t/hr palm oil mill, different biogas technology)

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Type of biogas utilization: on-grid	Economic Value	
	Digester Tank	Covered Lagoon
*Capital expenditure (CAPEX), RM (million) - at **RM10 million/MW** for digester tank, **RM8 million/MW** for covered lagoon	18.0	15.0
OPEX @ 4% of CAPEX, RM (million/yr)	0.72	0.58
Potential power output, MW	1.8	1.8
Annual potential electricity, kWh/yr (70% utilization rate, 7200 hr/yr)	9,072,000	
Assumption: • **Potential of electricity (FiT) sales @ RM0.35/kWh, RM3.16 million/yr**		
Internal rate of return (IRR), %	13.6	18.0
*Payback period (PBP), year	7.4	5.6

*The investment cost or payback period will be reduced if eligible tax exemption or rebate incentive is applied in the project cost or annual business revenue and expenditure

Source: *MPOB (2019). Report of Working Group on Biogas*

Economic Feasibility (3)

Economic analysis of biogas plant for upgrading 600 m^3 hr^{-1} raw biogas into 400 m^3 hr^{-1} BioCNG plant

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Type of biogas utilization: BioCNG 54 t/hr palm oil mill, covered lagoon	**Economic Value**	
	Bio-CNG plant only	**biogas and Bio-CNG plant**
Capital expenditure (CAPEX), RM (million)	7.0	12.0
Annual production, million m^3 @ 7200 hr yr^{-1}	2.46 (~80,000 MMBTu)[1]	
Assumption: • **Bio-CNG selling price @ RM 40.00 - 46.00 $MMBTu^{-1}$,** • **Operation expense (OPEX) @ RM 25.50 $MMBTu^{-1}$**	Natural gas is usually measured in BTUs.	
Net present value (NPV) @ 10% RM (million)	1.82	0.17
Internal rate of return (IRR), %	14.36	10.25
Payback period (PBP), year	6.03	7.50

[1] "MM" = one million; MMBTU = one million British Thermal Units (BTU). A BTU is a measure of the energy content in fuel, and is used in the power, steam generation, heating and air conditioning industries. One BTU is equivalent to 1.06 Joules.

Source: *Nasrin et al. (2018). Eng. Bull. 126: 11-17; Mohtar et al. (2018); Hong et al. (2021)*

Potential Technology Adoption: PSA Bio-CNG

Biogas Offsite, Off Grid

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1. Project Cost Reference (CAPEX) - typical 60 t/hr palm oil mill

- Biogas Plant (Tank-Type): RM 8.0 – RM 8.5 mil. (~ 2 mil USD)
- Upgrading Plant + Compression: ~ 3 mil. USD
- Storage: Tube Trailer (9 cylinders @ 250 barg) : 200k USD
- **Total CAPEX: 5 mil. USD**

2. Revenue Streams

a) **Annual Bio-CNG Sales**: USD 10-14/MMBtu

- Production: 200,000-250,000 MMBTu/yr
- **Annual Revenue: USD 2.25 mil.,** conservative unit price @ USD 10

b) **Carbon Credits**: Additional USD 4-8/t CO_2eq. *(Excluded).*

3. Annual OPEX

a) Labour: 3 Manpower, 2 shifts at monthly wages of 1.5k = **USD 108,000**
b) Power demand: 450 kWh at tariff of USD 0.10/kWh = **USD 360,000**
c) Routine maintenance (estimated at 1.5% of CAPEX) = **USD 75,000**

- **Annual OPEX Projection: USD 543,000 @** USD 2.4/MMBTu

4. Payback & IRR

- **Payback Period: 3-4 years; IRR**: >25% (current Malaysian conditions)

Source: *Hextar Biogas BEE Sdn. Bhd.– MPOB joint collaboration; https://hextarbiogasbee.com/projects/*

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GHG Mitigation & RE Potential

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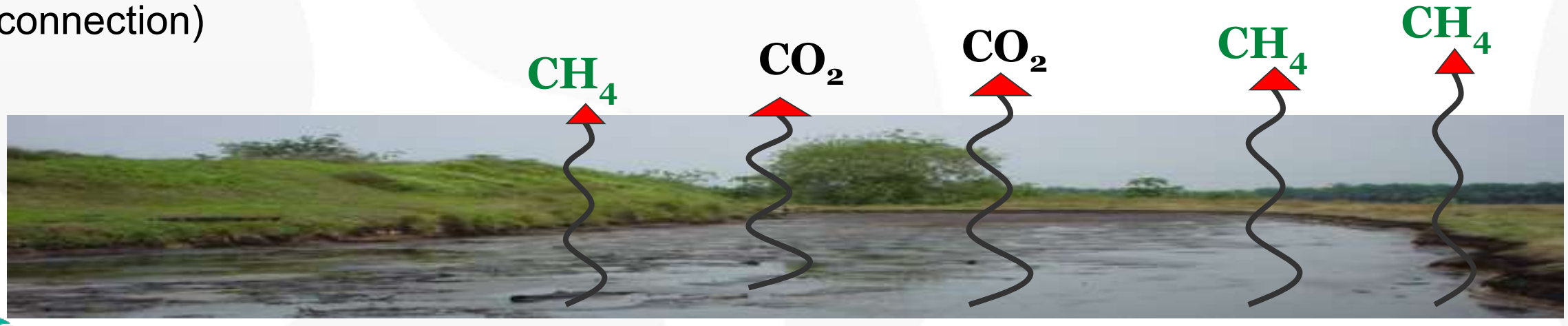
Annual biogas (60-70 % CH_4, 30-40 % CO_2 and traces H_2S) production:
~1781 mil m^3 biogas = 759,333 t CH_4 (based on 28 m^3 biogas/t POME, 65% CH_4, ρ_{CH4} = 0.656 kg/m^3)

RE potential: ~500 MW

GHG emission : ~18 mil. t CO_2 eq. (IPPC 2006 GL)
GHG savings: ~6 million t CO_2 eq. (biogas capture + grid connection)



Decarbonisation Potential

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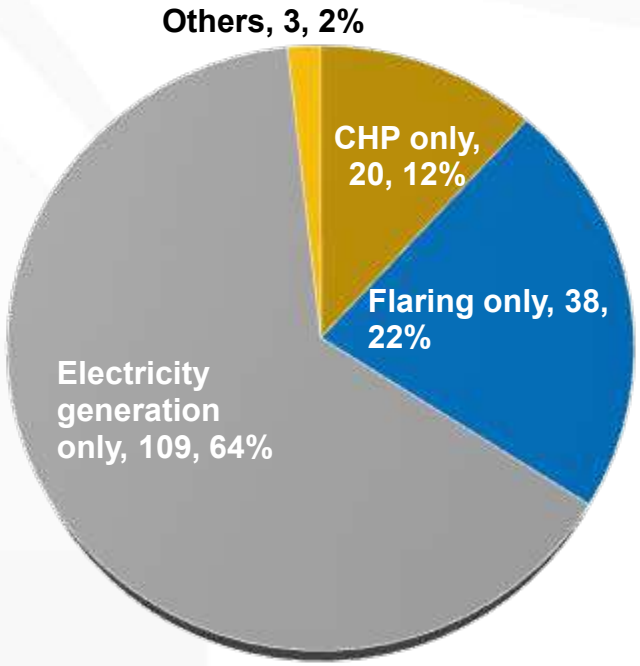
Energy Potential (2023/2024)

Material	Quantity
Fresh fruit bunches	93.40 million t
POME (65% FFB)	60.71 million m^3
Biogas (28 m^3/m^3 POME)	1700 million m^3
Potential electricity (installed capacity)	525 MW[a,b,c]
Potential electricity	4,410,000 MWh
REC – Based on USD2.2/REC 1 REC = 1 MWh	USD 9.7 million
Carbon Credits *60 t/hr (t CO_2eq.)	30,000-40,000

Source: *Loh et al. (2017). Renew. Sustain. Energy Rev. 74:1257-74; Nasrin et al. (2022). J. Clean. Prod.*

[a] Calorific value = 20 MJ m^{-3}, STP
[b] 1 MJ = 1/3600 MWh
[c] 40% power output

Biogas Capture Status, 2024

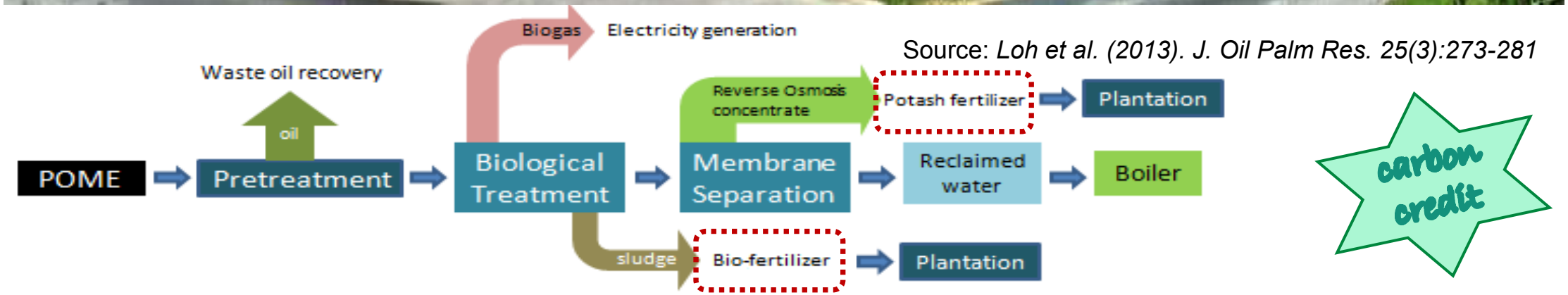


Statistics:

- ✓ 170 mills with biogas trapping
- ✓ 71 grid-connected (FiT)
- ✓ GHG Savings: 13.4 kg CO_2 eq./m^3 biogas
- ✓ Total GHG emissions: ~18-20 mil. t CO_2 eq. (IPCC 2006GL)
- ✓ **GHG Savings: 13.4 kg CO_2 eq./m^3 biogas**
- ✓ Total CH_4 recovery = emission reduction: **~6 mil. t CO_2 eq.**

Source: *MPOB Confidential Data (2024)*

Zero Discharge POME Treatment Technology



Source: *Loh et al. (2013). J. Oil Palm Res. 25(3):273-281*

- Integrated process: pre-treatment-biological processes (anaerobic-aerobic)–reclamation (membrane separation).
- Produce biofertilizer from AD digestate, with organic matters soil amendment & carbon sequestration.

Sustainable Aviation Fuel (SAF)

CORSIA Compliance Market
- Carbon tax / cap-and-trade scheme

SAF Feedstock Pathways

CURRENT Source: *Boyd, 2024. MyAero Symposium* **FUTURE**

HEFA | Alcohol-to-jet | Fischer-Tropsch | Power-to-liquid

Biojet, e-fuel (SAF)

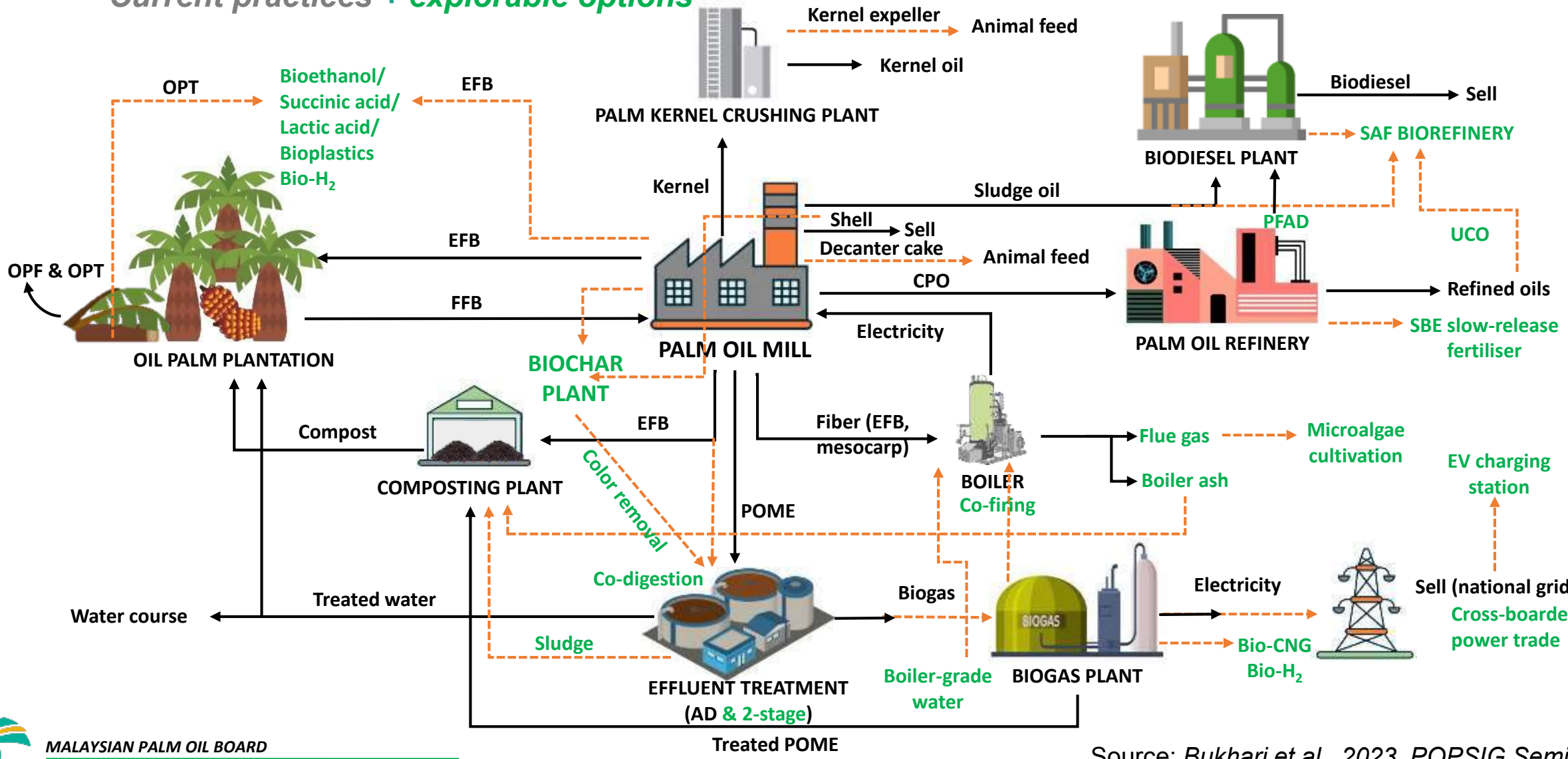
Bioelectricity generation

Eligible & potential palm-based feedstock:

- ✓ UCO
- ✓ PFAD
- ✓ SBE oil
- ✓ Sludge palm oil
- ✓ POME oil, etc.

Circular Economy in the Palm Oil Industry

*Current practices + explorable options



Source: *Bukhari et al., 2023. POPSIG Seminar*

Conclusion

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Commercial adoption depends on:

- Feedstock accessibility
- Financial support, business model
- Domestic & international market support/acceptance
- Sustainability requirements and certifications

  - ✓ **Business oriented, based on global requirement (supply-demand) and existing regulations**

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Muchas Gracias

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