UNIVERSITI KEBANGSAAN MALAYSIA
National University of Malaysia

Sime Darby
Developing Sustainable Futures

BIO-HYDROGEN GENERATION AS NEW BIOGAS FOR OIL PALM INDUSTRY

JAMALIAH MD JAHIM
BIOHYDROGEN GROUP
UNIVERSITY KEBANGSAAN MALAYSIA

UKM: Inspiring Futures & Nurturing Opportunities

- Promotes the **national language in its intellectual tradition** yet gives greater space for proficiency in English
- Encourages its student population to celebrate cultural diversity that promotes **inter ethnic understanding & unity, a** living demonstration to a better future for the nation
- **Adapts global knowledge by** looking at others through our eyes (e.g. Institute of Occidental Studies, Institute of West Asian Studies)

Faculty of Engineering and Built Environment

Established 1 Nov 1984





Departments:

- **Civil and Structure Engineering**
- **Electrical, Electronics and Systems Engineering**
- **Chemical and Process Engineering**
- **Mechanical and Materials Engineering**
- **Architecture**

Research centers

213 academic staff   151 supporting staff
1170 undergraduates 1030 postgraduates





Center for Sustainable Process Technology (CESPRO), Faculty of Engineering and Built Environment, UKM

Research Focus

Research categories; basic, applied, bench scale, lab pilot, industrial pilot, demonstration plant

Sustainable development	Integrating appropriate technologies to achieve sustainable development with zero waste, increase revenue and productivity. Undertaken by the UKM-YSD Chair for Sustainable Development
Bio-refinery	Integrating appropriate technologies to develop bio-refinery to recover valuable products from biomass. Undertaken by the LRGS Bio-refinery Group
Cutting-edge process system	Integrating appropriate technologies to develop cutting-edge process to solve specific issues and problems of industries and communities
Other research programs	Integrating appropriate technologies to provide solutions and develop new knowledge

Focus Technology

Bio-technology	Chemical technology	Separation technology	Nano-technology	Renewable Energy	Processing Technology

Introduction
Why Biohydrogen at Oil Palm Mill

- Good goverment policies, action plans & initiatives on biomass direction strategy by Malaysian Government

- Biological hydrogen process
  - ✓ Cheap technology
  - ✓ Green & sustainable
  - ✓ Natural phenomenon in anaerobic digestion

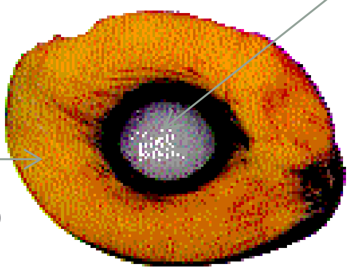
- Hydrogen as biofuel
  - ✓ Clean carbon neutral energy & environmental friendly
  - ✓ near to zero levels of pollution, emits no CO_2 but only water

- Oil Palm biomass resourses
  - ✓ provide carbohydrate as main carbon if biological conversion without light
  - ✓ abundant source of low value feedstock such as POME and OP residues
  - ✓ Carbohydrates are best feedstock: oligosaccharides, hexoses, pentoses, as e.g. coming from (hemi)cellulose

Palm and Palm Kernel Oil

Kernel
Oil content 45-48%

Mesocarp
Oil content 35-45%



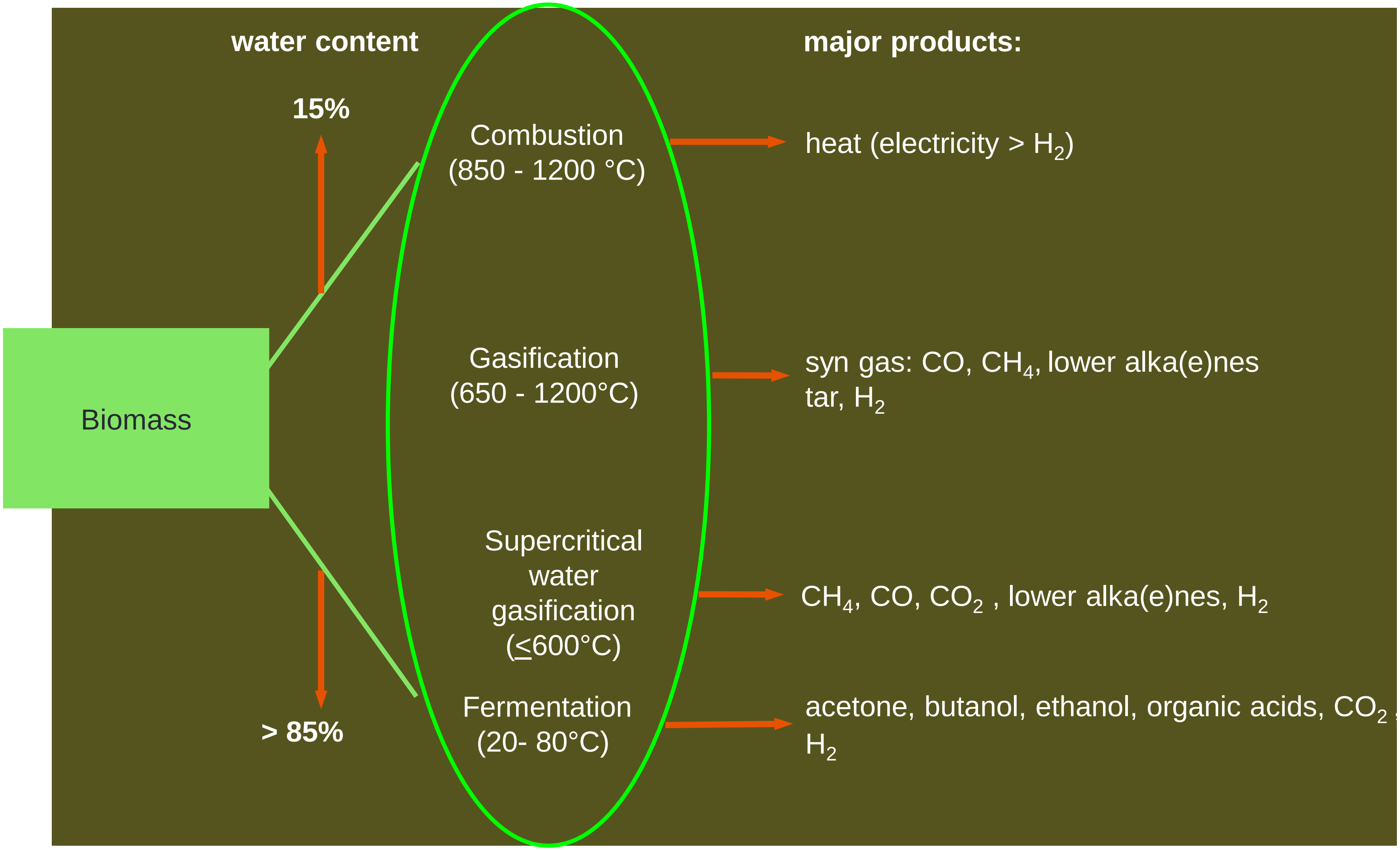
Palm Oil Extraction Rate = 20% FFB
Palm kernel Extraction Rate = 5 % FFB
=> Kernel oil
Oil yield = 3.5-4.0 t/ha
Economic life around 25 years
Oil recovered by pressing

Palm oil mill products

- Basis: Fresh Fruit Bunch (FFB) processed in Malaysia = 99.6 million MT (MPOB, 2015)

No	Products	Quantity (million MT)	%FFB
1	Crude Palm Oil (CPO)	19.9	20
2	Kernel	5	5
3	Shell	7	7
4	Empty Fruit Bunch (EFB)	19.9	20
5	Fiber	11.9	12
6	Palm Oil Mill Effluent (POME)	64.7	65

Hydrogen production from biomass



Fermentative hydrogen production

- Biomass or carbohydrate-based substrate presents a promising route of biological hydrogen production.
- Strict anaerobes and facultative anaerobes chemoheterotrophs, such as Clostridia and Enteric bacteria, are efficient producer.
- Fermentation of glucose by microbiological route can produce theoretically up to 4 mol of hydrogen per mol of glucose

Main challenge in fermentative production of hydrogen

- A conversion efficiency of 33% is theoretically possible for hydrogen production from glucose (based on maximum four moles hydrogen per mole glucose), only half of this is usually obtained under batch and continuous fermentation conditions.
- Four moles of hydrogen could only be obtained from glucose if two moles of acetate are produced, however only two moles of hydrogen are produced when butyrate is the main fermentation product.
- high H_2 pressure inside the reactor caused inhibition thus a low hydrogen pressure of around 10^{-3} atm is necessary for achieving high conversion efficiency.

H_2 yield on carbohydrates

Organism	Domain	T-opt.	Culturing type	Substrate	H_2/glucose
Mesophiles					
Enterobacter aerogenes E.82005	B	38	batch	glucose	1.0
Enterobacter aerogenes HU-101	B	37	chemostat	glucose	0.6
Klebsiella oxytoca HP1	B	38	chemostat	glucose	1.0
Clostridium acetobutylicum	B	34	controlled batch	glucose	1.4
Clostridium sp. No 2	B	36	batch	glucose	2.0
Thermophiles					
Clostridium thermosaccharolyticum	B	55	chemostat	glucose	1.44
Clostridium thermocellum JW20	B	60	batch	glucose	1.8
Clostridium thermocellum JW20	B	60	chemostat	glucose	3.5
Clostridium thermocellum LQRI	B	60	batch	cellobiose	2.86
Extreme/hyperthermophiles					
Thermotoga maritima	B	80	batch	glucose	4
Caldicellulosiruptor saccharolyticum	B	70	controlled batch	sucrose	3.3
Thermoanaerobacter tengcongensis	B	75	chemostat	glucose	4
Pyrococus furiosus	A	90	batch	maltose	3.5
Thermococcus kodakaraensis	A	85	chemostat	starch	3.33

(Classen, 2013)

UKM-YSD CHAIR ON SUSTAINABLE DEVELOPMENT:
ZERO WASTE TECHNOLOGY

RM15 Million Endowment by Sime Darby Foundation since February 2011

Forging Mutually Beneficial Partnerships between UKM- Sime Darby

Sime Darby
Developing Sustainable Futures

Inspiring Futures,
Nurturing Possibilities

Universiti Kebangsaan Malaysia
The National University of Malaysia

To turn palm oil mills into green factories-targeting for carbon neutral

No pollutants to the air

No pollutants to the ground

No pollutants to the water

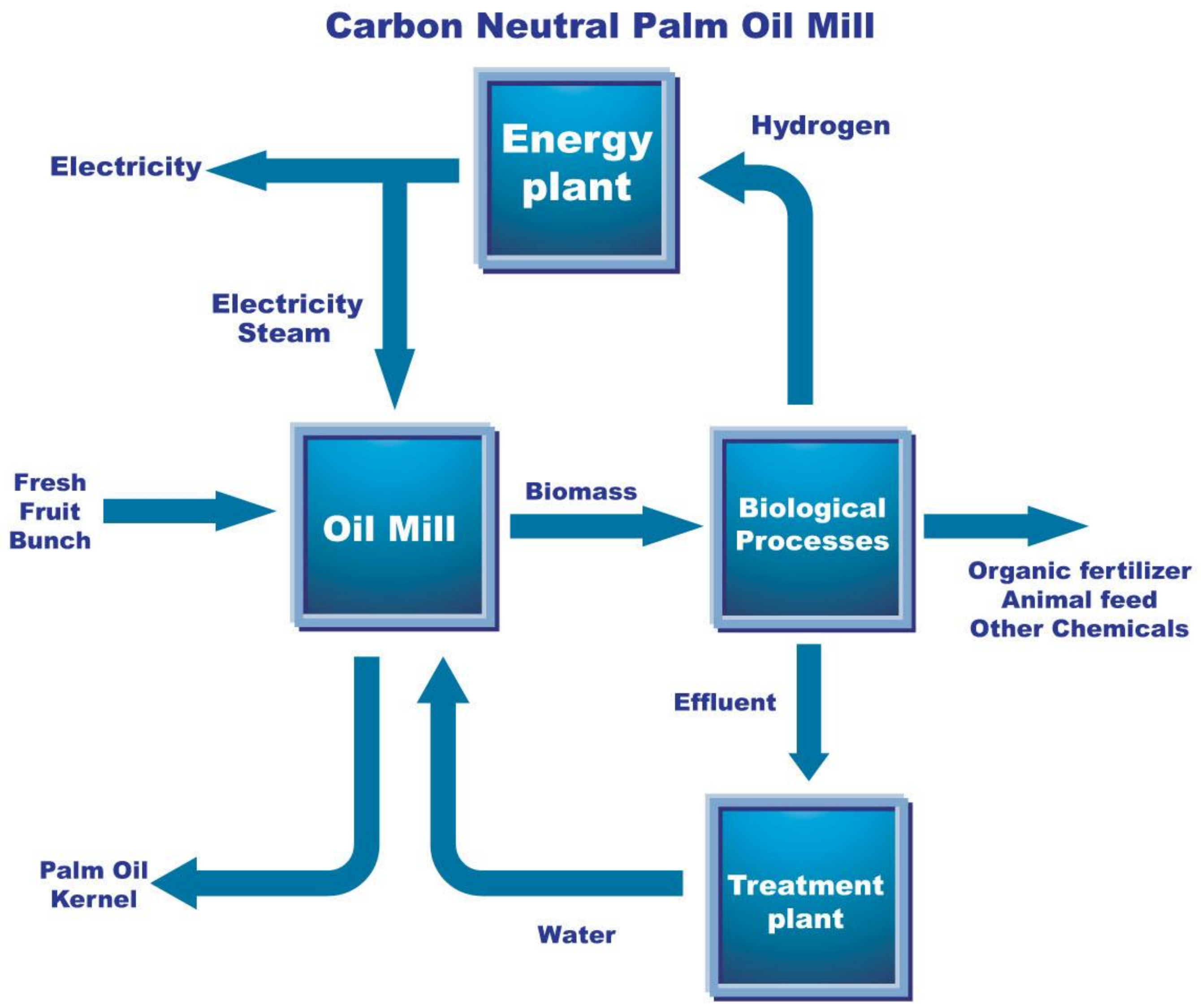
-But yet;

- ❑ Increase of revenue
- ❑ long term productivity and sustainability of the oil palm industry ensured

Sime Darby Developing Sustainable Futures

Universiti Kebangsaan Malaysia *The National University of Malaysia*

Process Model



An integrated approach for zero waste with production of hydrogen fuel, electricity, fertiliser, animal feed and other chemicals

UKM-YSD Chair on Sustainable Development

THRUST AREAS

1 H_2 for Power and Steam Generation

2 In-line composting for organic fertilizer

3 H_2 production from POME and biomass

4 Pretreatment of biomass for H_2 production

5 Algae production to sink CO_2

6 Water recycle and reuse

Key Messages from Tun Chairman

Integrate projects within Sime Darby with UKM-YSD

Key Messages from EVP Plantation & Agribusiness

Short term: Focus on Quick Gain Projects

Long term: DO NOT reinvent the wheel

Sime Darby Developing Sustainable Futures

Universiti Kebangsaan Malaysia The National University of Malaysia

UKM-SDR Thrust Area 3: Hydrogen production from POME and biomass

Objective:

To produce hydrogen gas for electricity generation

2 projects

- TA3A - H2 and CH4 production via biological processes from POME and biomass residue (empty fruit bunch)
- TA3B - Cracking of CH4 into hydrogen for more H2 generation

POME characteristic

Parameters	RAW POME
pH	4.5
Total Chemical Oxygen Demand (COD) (g/L)	99.91 ± 19.89
Soluble COD (g/L)	47.89 ± 3.48
Total carbohydrate (g/L)	22.65 ± 1.71
TSS (g/L)	70.06 ± 14.16
VSS (g/L)	57.64 ± 10.13
TS %	10.69
Water content %	89.31
Total reducing sugar (g/L)	15.7 ± 1.3
Total soluble sugar (g/L)	8.4 ± 4.2
Total sugar (g/L)	20.9 ± 4.6
Oil and Grease (g/L) (%)	<1%
Total nitrogen (mg/L N)	723.33 ± 20.82

- Location: at Bukit Krayong Oil Mill, Kapar;
- Centrifuge POME

Composition Analysis: POME and OPDC

3-phase decanter POME

Component	OPDC	POME*
	(wt %)	
pH	4.5	3.9
Total moisture	73-75	90-96
Solid	20-30	3-5
Lignin	4.89	1.03
T. carbohydrate	9.45	2.20
glucan	5.30	0.60
xylan	3.39	0.23
arabinan	0.93	0.08

POME

Oil Palm Decanter Cake (OPDC)

THERMOPHILIC BIOHYDROGEN PRODUCTION IN FLUIDISED BED COLUMN REACTOR

Volume = 16 L

Column vessel H/D = 8

Temperature = 55 °C

Working volume = 10 L

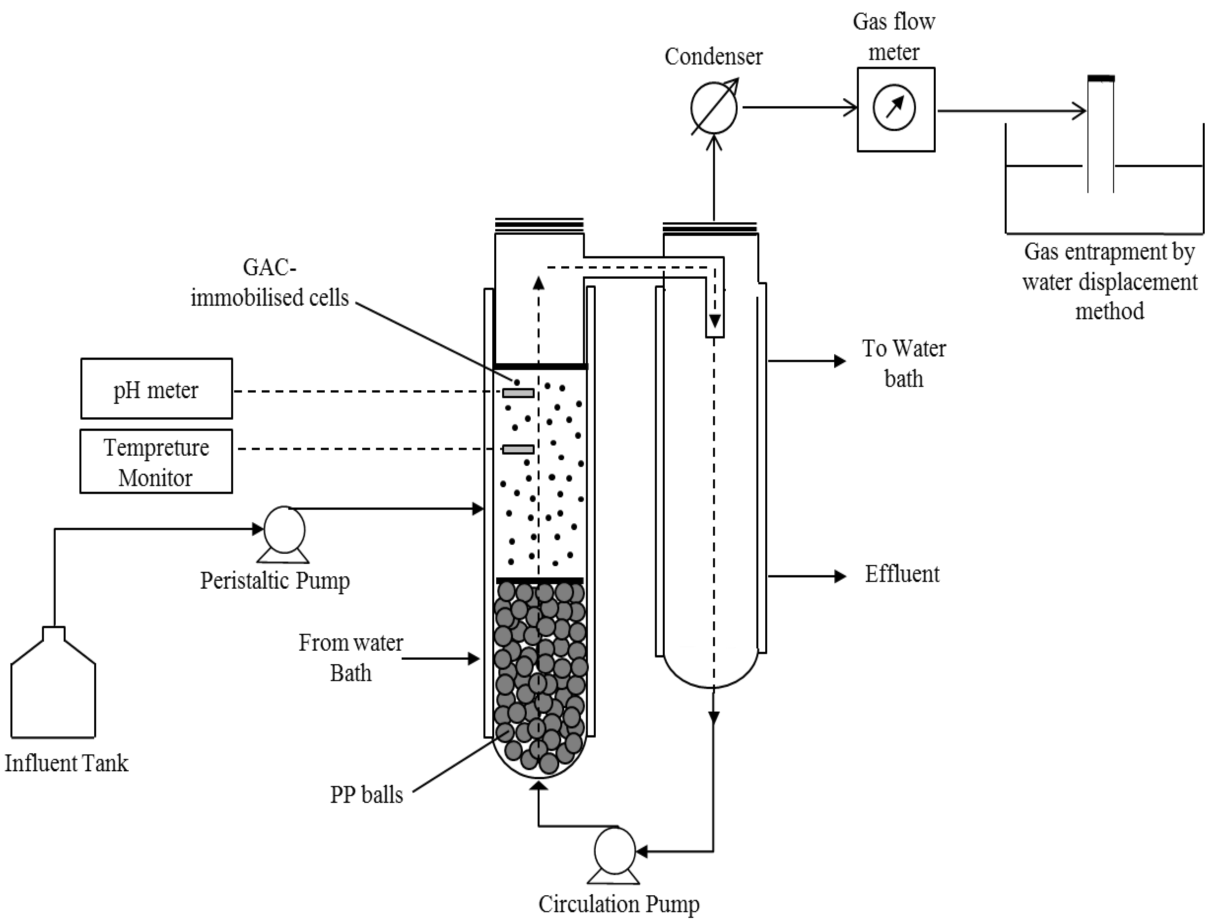
pH = 5.5

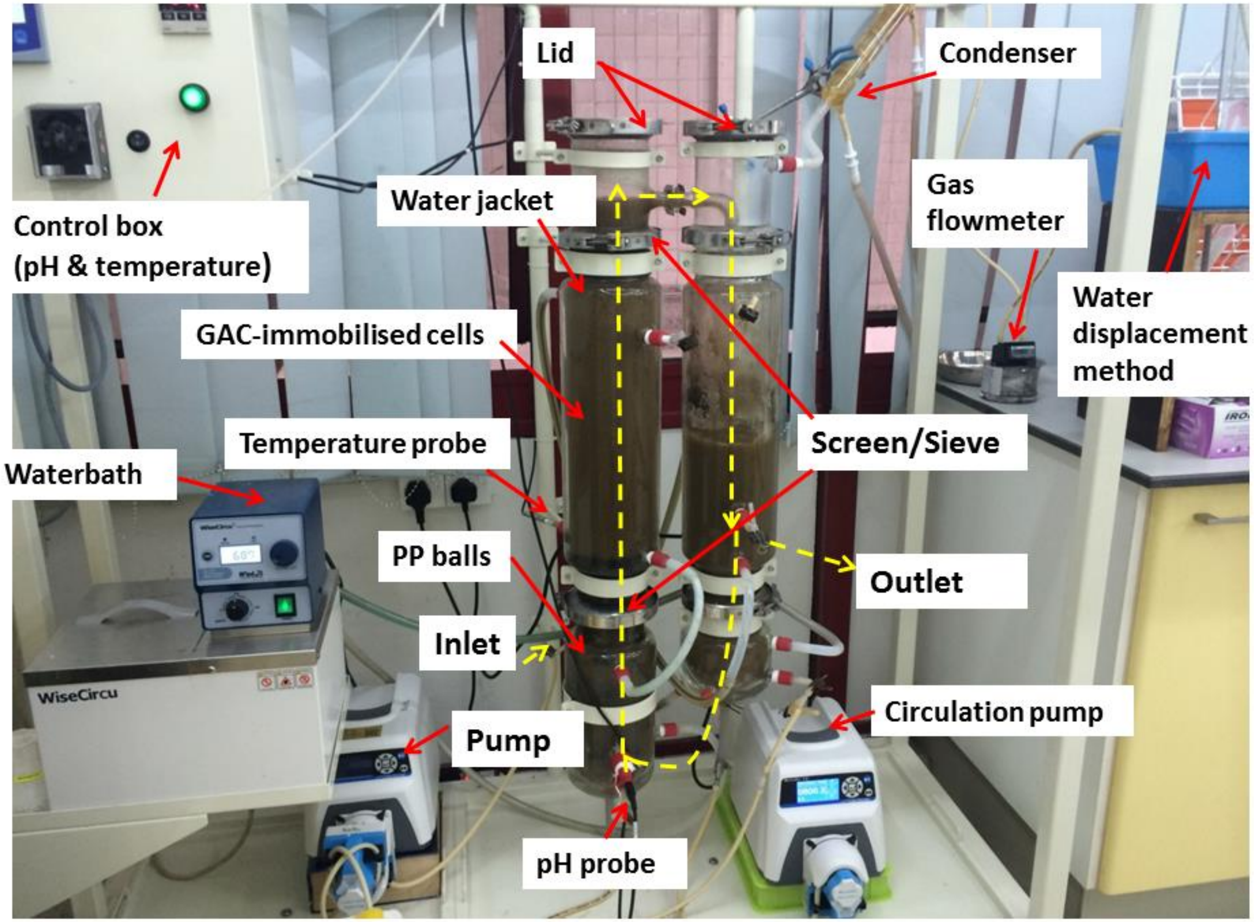
Substrate feed = sucrose and POME (pH adjusted to 7.0)

Inoculum = GAC biofilm (mixed culture)

Mode of mixing = pump recirculation

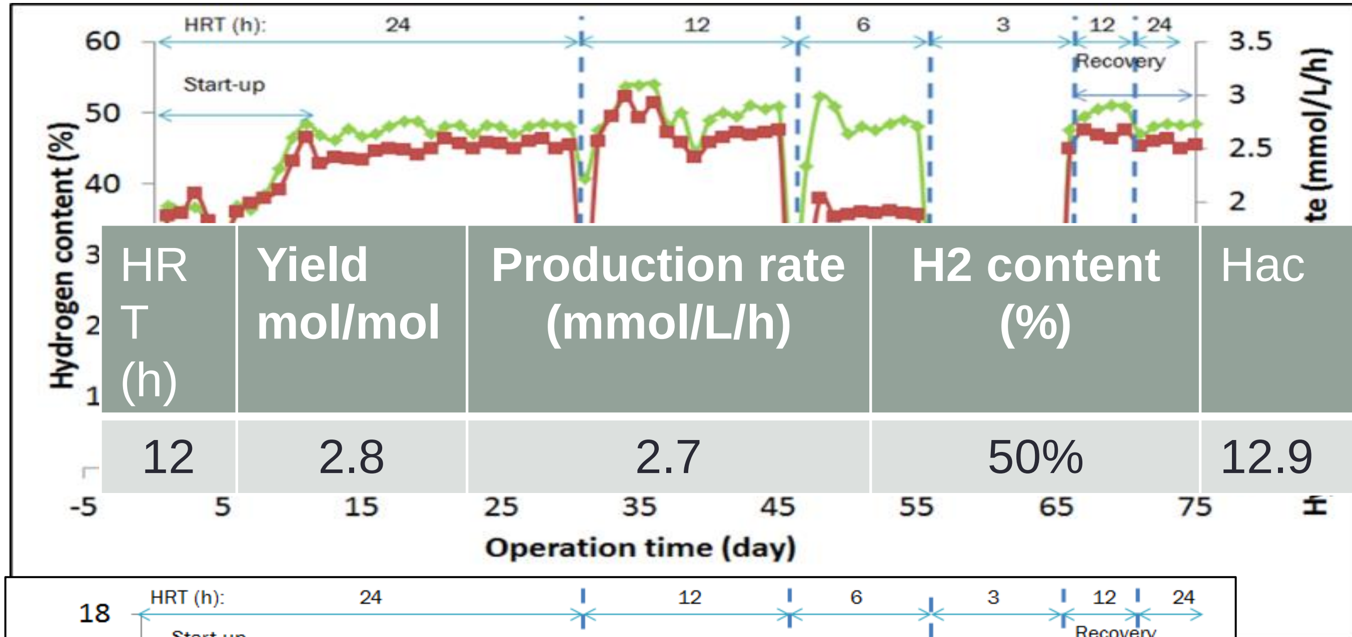
Mode of feeding = Sequential Batch





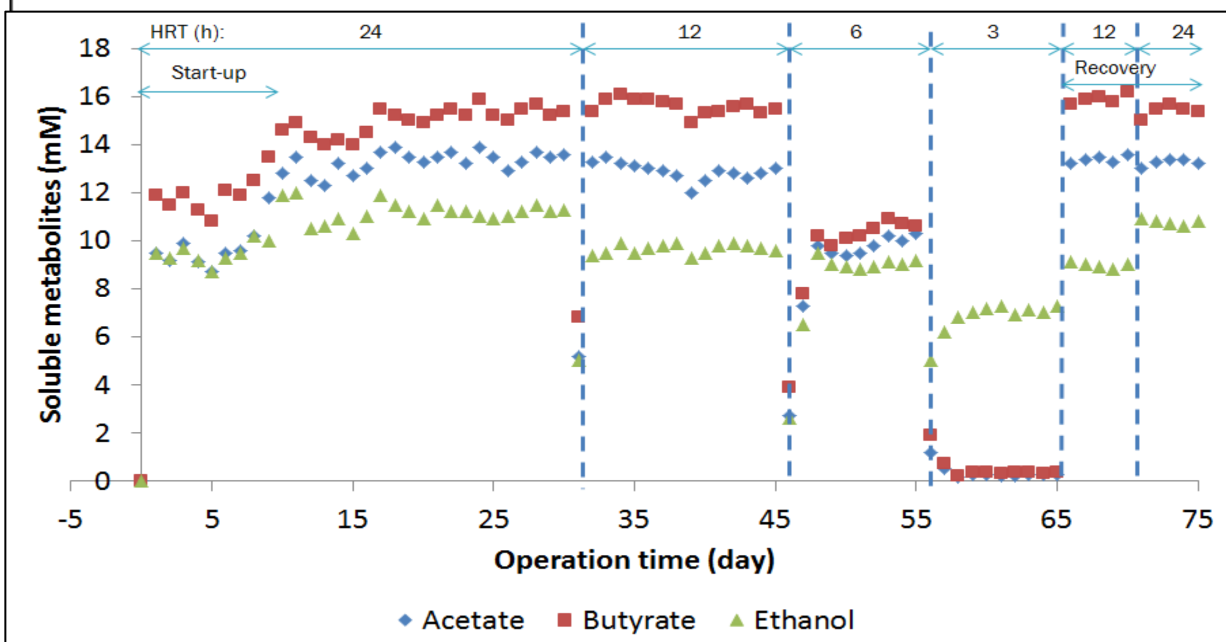
16L packed bed column bioreactor

H2 Profile using synthetic at different HRT

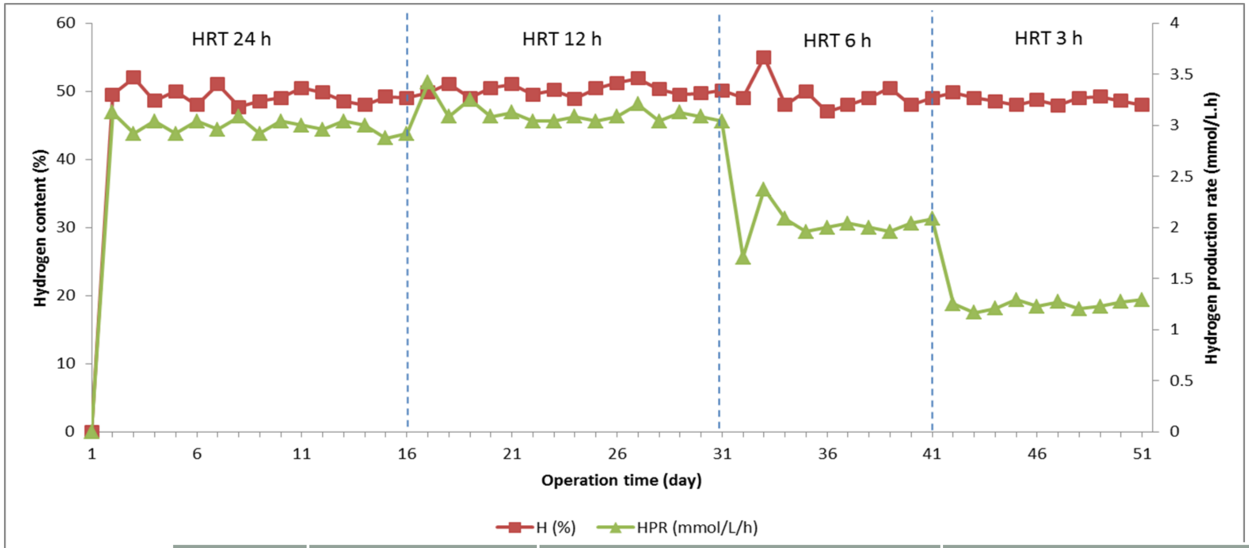


Feedstock: synthetic with 5 g/l sucrose

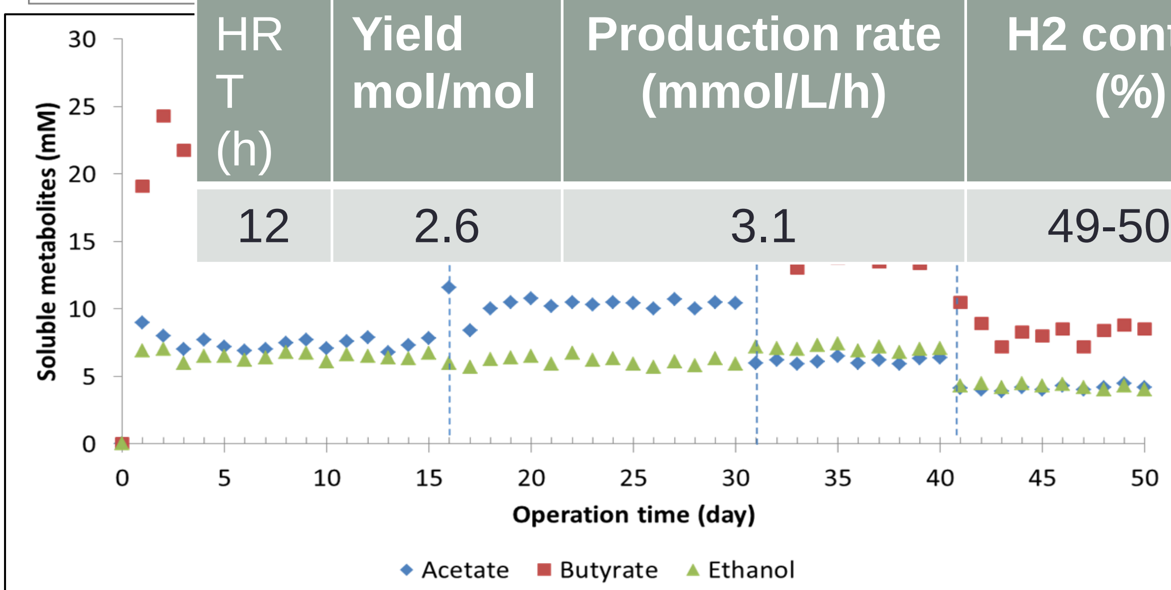
HRT (h)	Yield mol/mol	Production rate (mmol/L/h)	H2 content (%)	Hac	HBu	EtOH
12	2.8	2.7	50%	12.9	15.6	10.0



The use of 10% POME with synthetic media

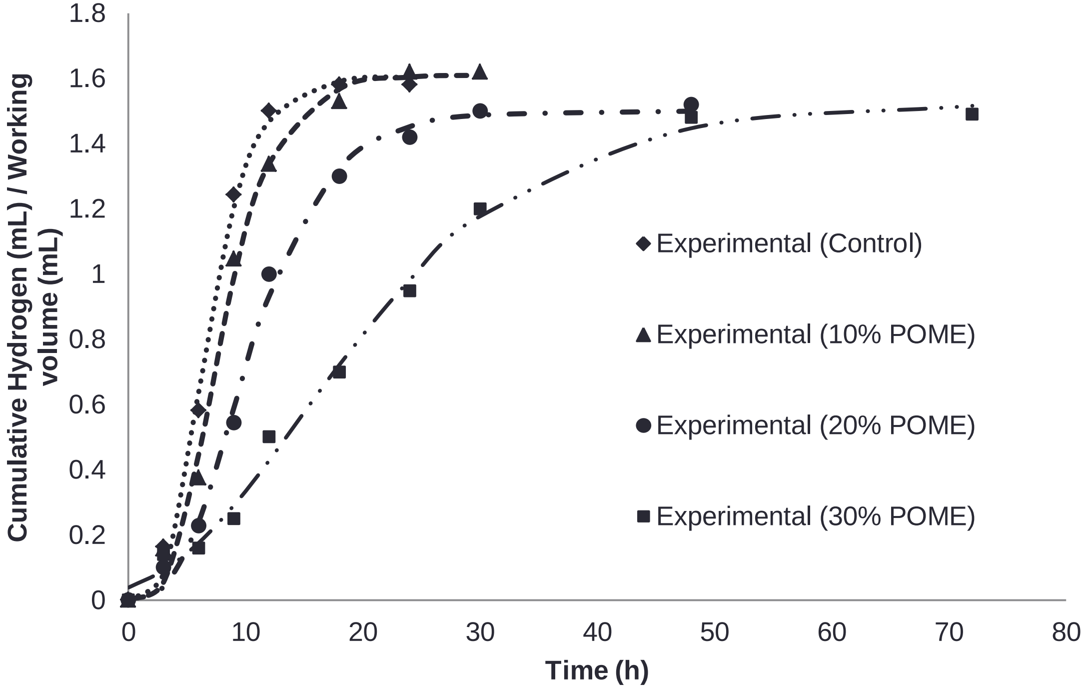


Feedstock: synthetic (glu+xyl) with 10% POME
Total sugar = 11g/l
Temp = 60 C
pH = 5.5



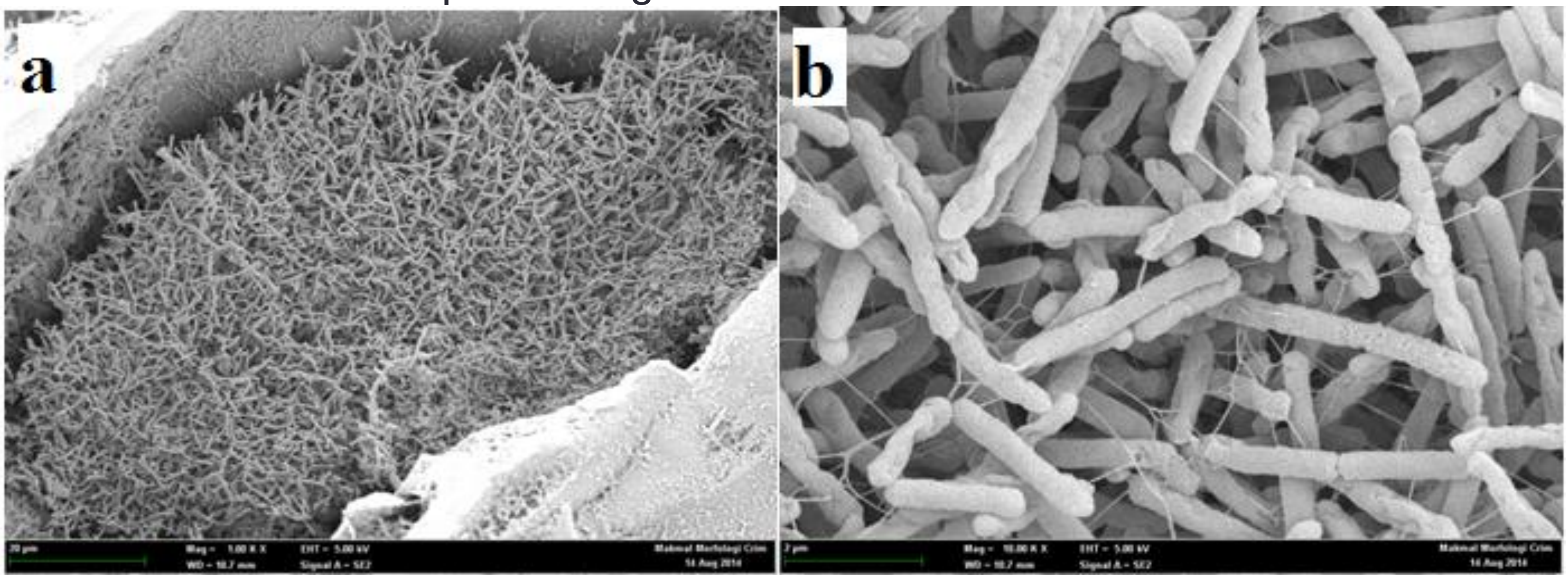
HRT (h)	Yield mol/mol	Production rate (mmol/L/h)	H2 content (%)	Hac mM	Hbu mM	EtOH mM
12	2.6	3.1	49-50%	12.9	15.6	10.0

Comparison of rate of H2 production by GAC-biofilm with different % POME (Batch run)



% POME	Yield mol/mol	HPR mmol (l.h)-1
control	1.90	3.2
10	1.76	2.5
20	1.73	1.9
30	1.56	1.2

GAC- biofilm after performing the run at 10% POME

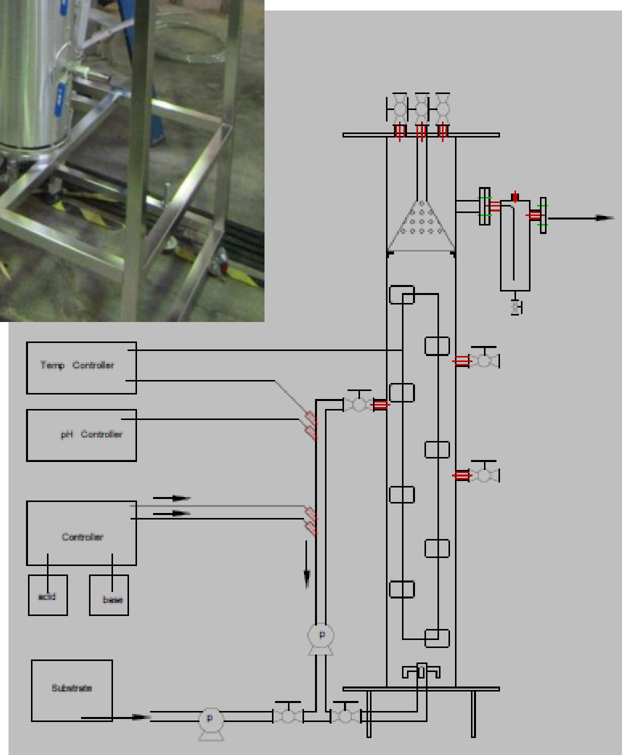


a) Bacterial colonization onto GAC (magnification 1,000×);
b) Close-up view of rod-shaped microorganisms (magnification 10,000×) found to be the predominant species during biohydrogen production at thermophilic conditions (60 °C)

Biohydrogen production in 20L column bioreactor

Experimental setup:

- Mode: continuous
- T = 55 deg C
- Working volume = 20L (5L inoculum + 15L substrate)
- HRT = 1-2 days
- pH = 6.0
- Substrate = 50% diluted POME
- Inoculum = mixed culture



Total biogas (L/day) = 30.8-40
H_2 (%) = 38.5
COD removal(%) = 24.3
Total carbohydrate (TC) consumed (%) = 60
Yield (mol H_2/ mol TC) = 0.89-1.0
H_2 production rate (L-1H2 L^{-1}day-1) = 1.38-1.5

Acknowledgement

- Yayasan Sime Darby
- Sime Darby Research Sdn Bhd
- CESPRO, UKM
- Fuel Cell Institute UKM
- Malaysia Genome Institute
- Research Collaborators: UPM, SIRIM, UM and Monash University
- Dr Pieternel Claassen, ex-Chair Holder of UKM-YSD Chair on Sustainable Development: Zero Waste Technology
- MSc and PhD students

THANK YOU

UNIVERSITI
KEBANGSAAN
MALAYSIA
National University of Malaysia

Sime Darby
Developing Sustainable Futures