Circular Palm Oil Value Chain: from Concept to Modelling

How Bing Shen, Ph.D, MIChemE, C.Eng

20 Sept 2021

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- Circular Economy
- Conversion Technology
- Modelling Technique- P-graph
- Case Study
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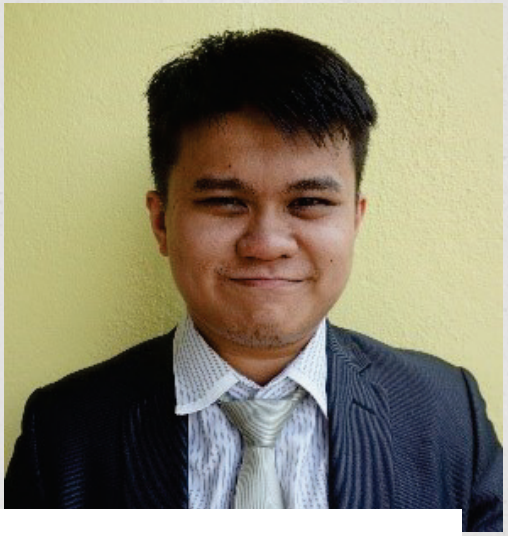
About Speaker

- Lecturer & Researcher in SUTS
- Chartered Engineer (IChemE)
- Active Reviewer
- Associate Editor of *Frontier in Sustainability*



Research Topic

Towards Artificial Intelligence for Chemical Process Synthesis, Design and Optimization

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Overview | Articles | Authors | Impact

About this Research Topic

The Industry 4.0 paradigm requires sustainable improvements to be made within the chemical processing industry that is in tandem with the rapid development in technology and smarter systems. Industry 4.0 has the potential to transform the chemical industry by streamlining operations and promoting sustainable growth. Artificial intelligence (AI), particularly machine learning (ML) has been viewed as an essential tool and driving force to digitally transform operations in the chemical industry. In fact, since the past decades, chemical engineers have shown great interests in the commercial potential of AI in enhancing the sustainability performances of a chemical process. In view of the rapid development of AI, the technology has evolved to be more mature now (e.g. with the developments of deep or convolutional neural nets (CNNs), reinforcement learning, and statistical ML). These developments open up high potential for AI to be incorporated into sustainable process synthesis, design and/or optimization phases.

The aim this collection is to address the following three research questions:

Topic Editors

Bing Shen How
Swinburne University of Technology Sarawak Campus
Kuching, Malaysia

55 publications

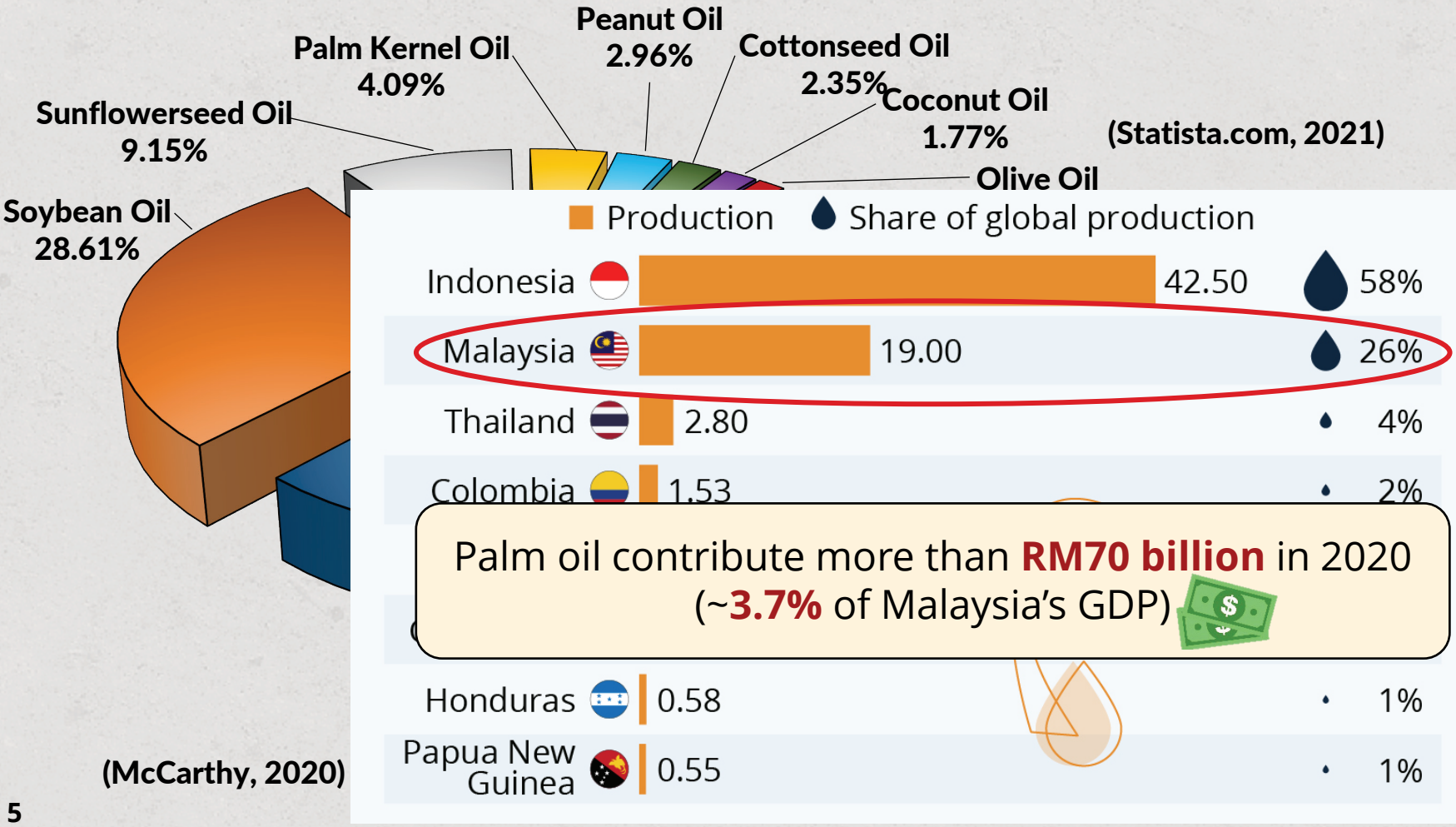
Yasuki Kansha
The University of Tokyo
Bunkyō, Japan

Follow

50 publications

Introduction

- **Palm Oil Statistics**



Introduction

- **Palm Oil Debates/Misconception**

Palm oil-derived biodiesel no longer a "green fuel" in the EU

July 23, 2019

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Introduction

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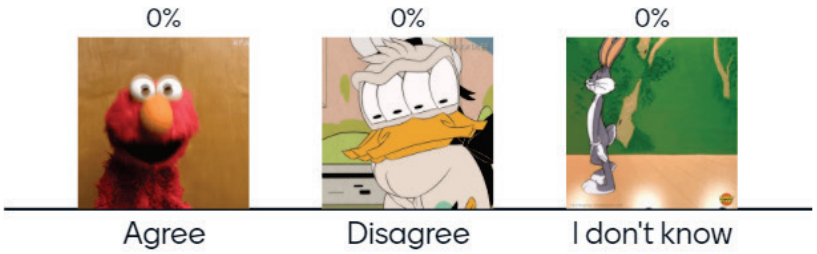
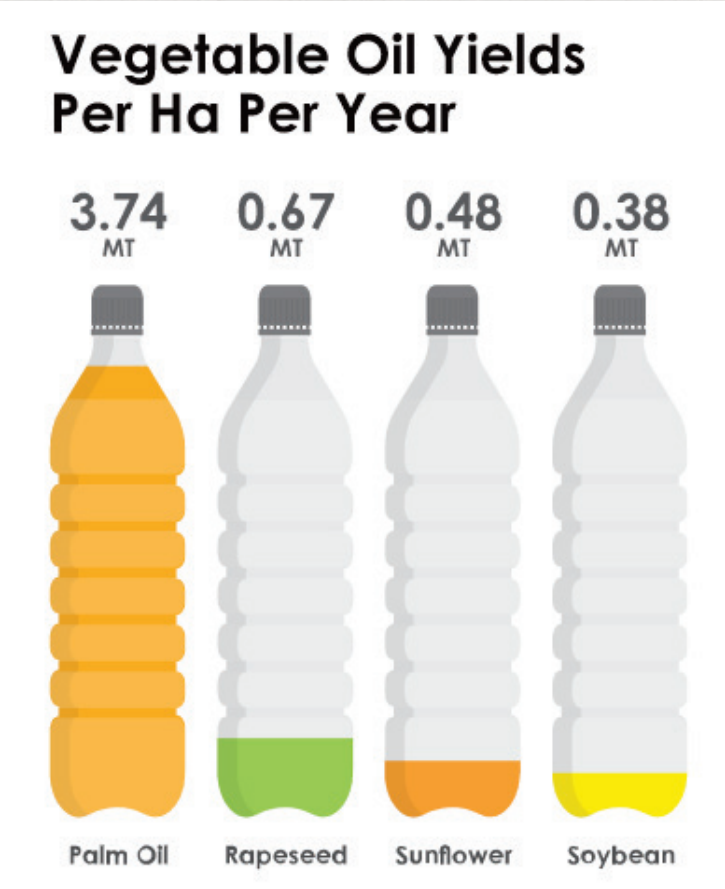
Mentimeter

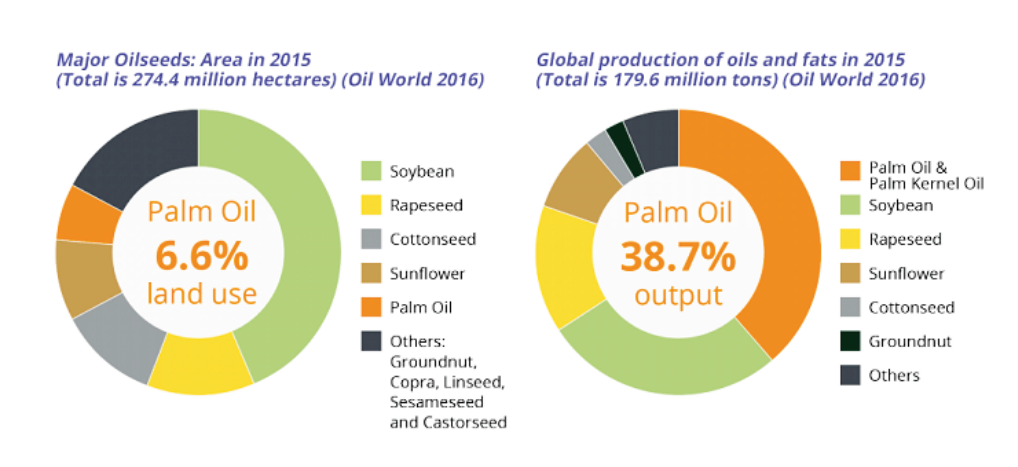
Palm oil creates more environmental damages as compared to other oil crops



Introduction

- **Palm Oil Facts-Sustainability**





The argument that …

oil palm cultivation contributes to deforestation is not only untrue

the palm oil ban may accelerate deforestation!

(Source: GreenPalm)

Introduction

- **Palm Oil Facts- MSPO Implementation**

BORNEO POST online
THE LARGEST ENGLISH NEWS SITE IN BORNEO

HOME SARAWAK SABAH NATION WORLD

YOU ARE AT: Home » News » Nation » MPOA: Malaysians oil palm firms

MPOA: Mala
since 1985

POSTED ON OCTOBER 3, 20

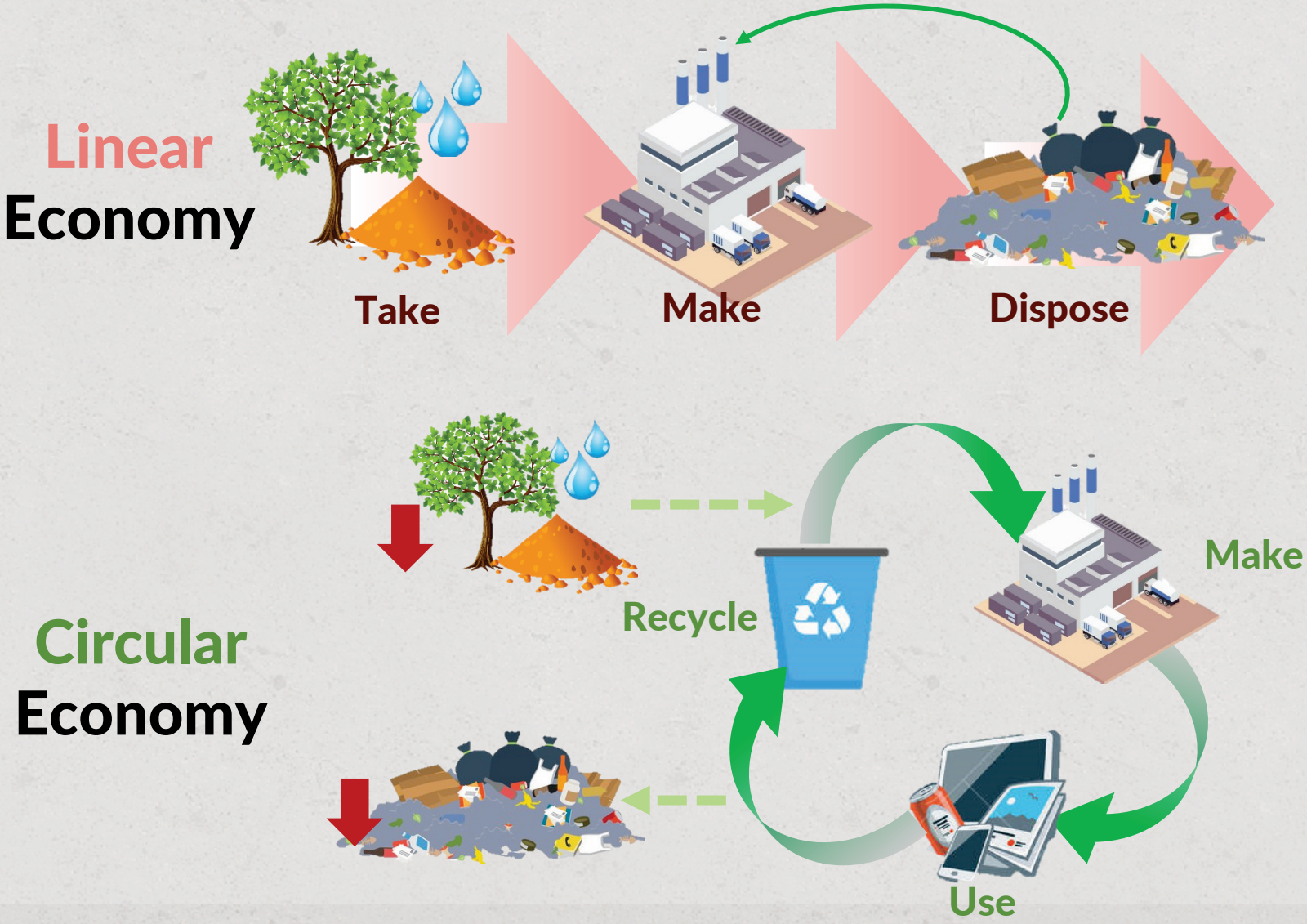
Can the MSPO Enforce and Deforestation?

Malaysia's Federal Minister for Primary Industries, Teres palm oil in Malaysia.

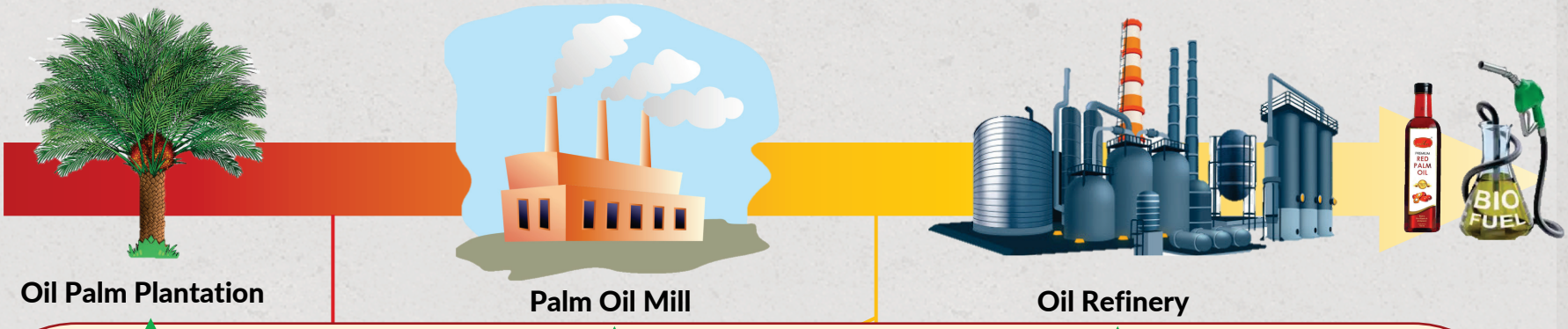
Local media reports including one from The Rakyat Pos

1. Capping of the total oil palm cultivated area to 6.5 milli
2. Stopping planting of oil palm in peatland areas
3. Strengthening regulations concerning existing oil paln
4. Banning conversion of forest reserve areas for oil palm
5. Pledged to make oil palm plantation maps available for public access

Concept of Circular Economy



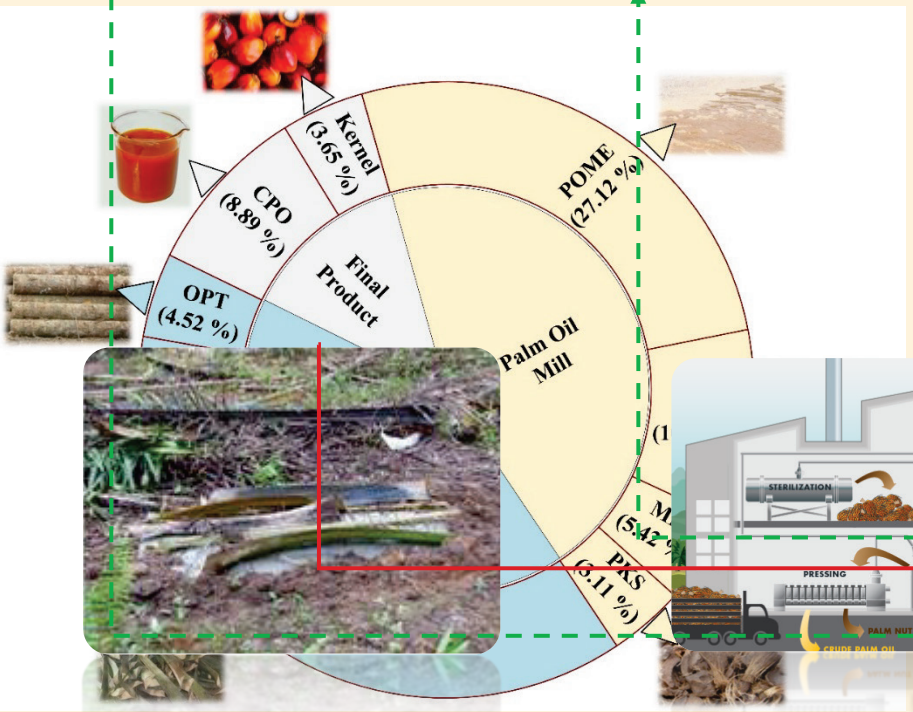
Palm Oil Value Chain



Oil Palm Plantation

Palm Oil Mill

Oil Refinery



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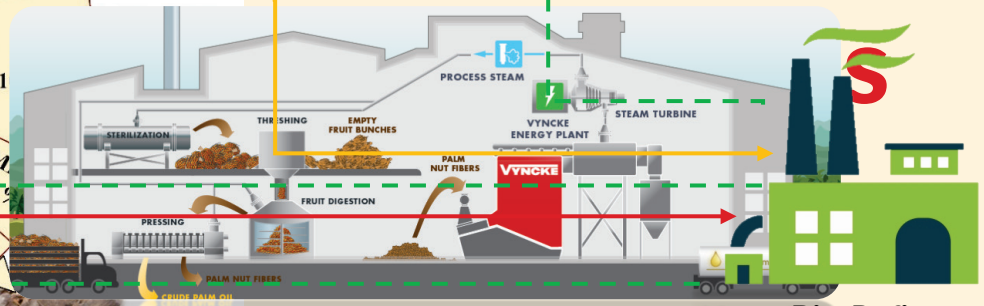


(Yeo et al., 2020)

Bio-Refinery

Conversion Technology

Thermochemical

Biological

- **Combustion**
- **Pyrolysis**
- **Gasification**

	Combustion	Pyrolysis	Gasification
Equivalent Ratio	>1	0	0.25-0.50
Temperature (°C)	700-1400	380-530	500-1300
Catalysts	Not required	Not essential	Not essential

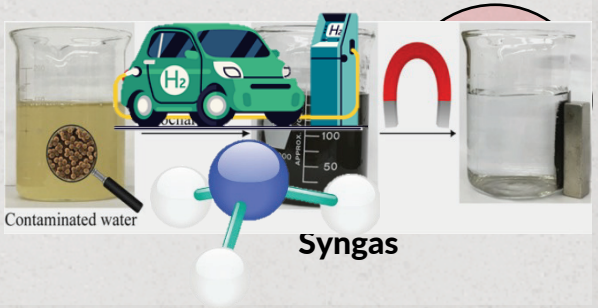
(Demirbas, 2009)

Thermal

Power

Bio-oil

Bio-char

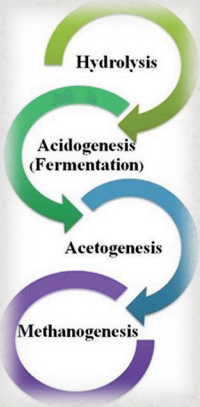


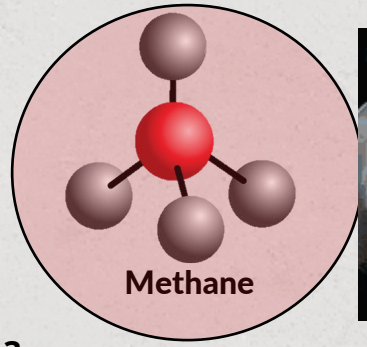
Syngas

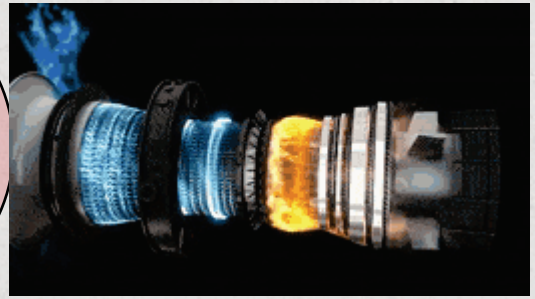
Conversion Technology

Biological

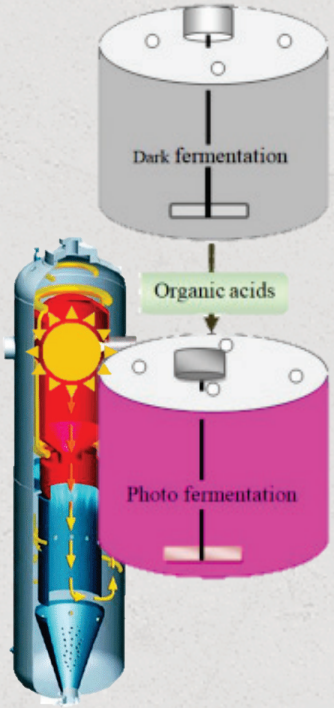
- **Anaerobic Digestion**







- **Sequential Dark-Photo Fermentation**



$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 4\boldsymbol{H_2} + 2CO_2$

Microbe:
Clostridium and Enterobacter

$CH_3COOH + 2H_2O \rightarrow 4\boldsymbol{H_2} + 2CO_2$

Microbe:
Rhodobacter sphaeroides

Modelling approach

- **Mathematical Modelling**

Enhancing the Way, We Make Decisions in Energy Planning with Mathematical Models

A Perspective on Important Tools for the Future

Viknesh Andiappan, PhD CEng MIChemE
Assistant Professor
Heriot-Watt University, Putrajaya, Malaysia

HERIOT WATT UNIVERSITY

IChemE Webinar,
May 19, 2021, Heriot-Watt University Malaysia

AIMMS

GAMS

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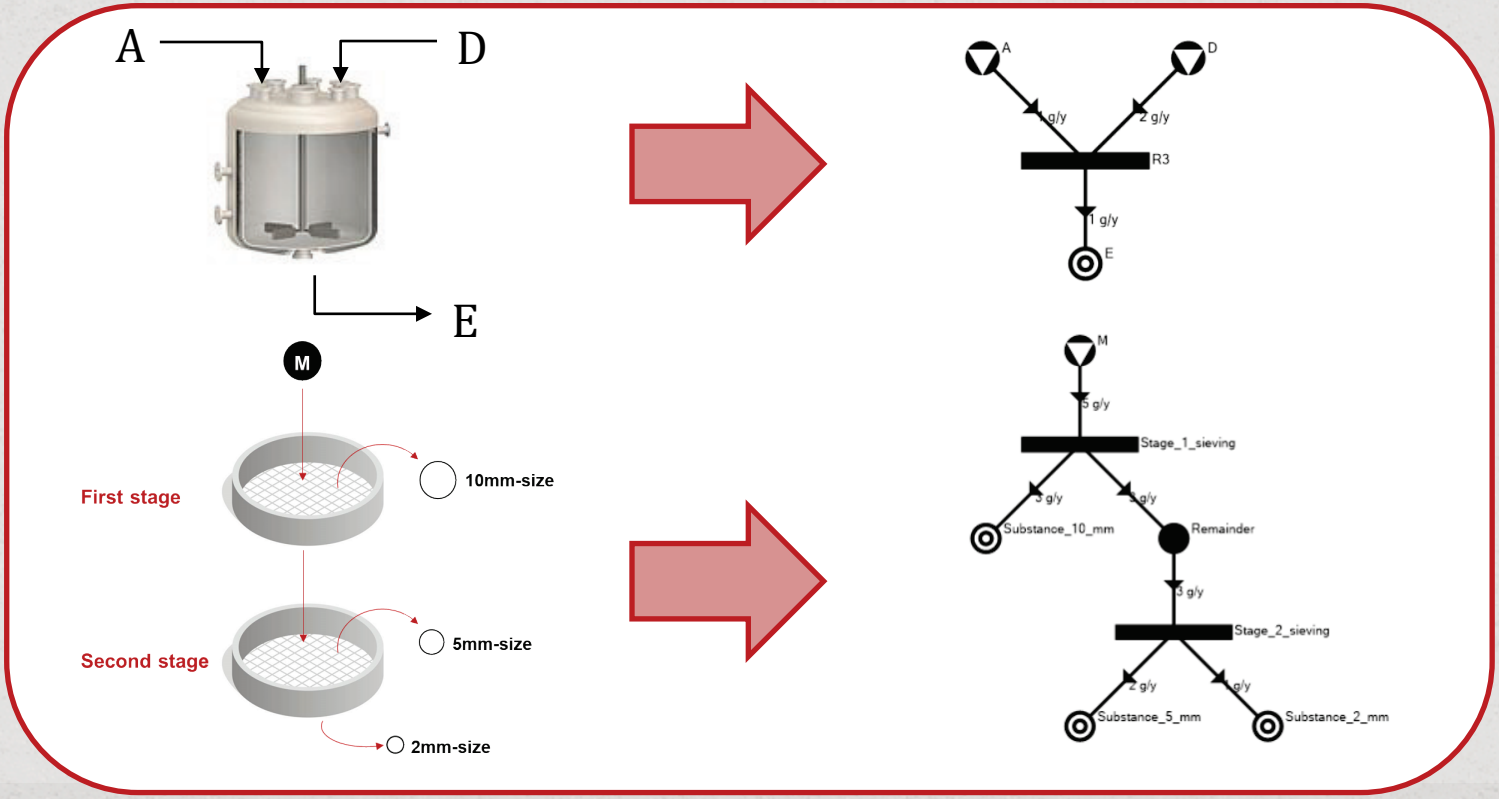
Graph-theoretic

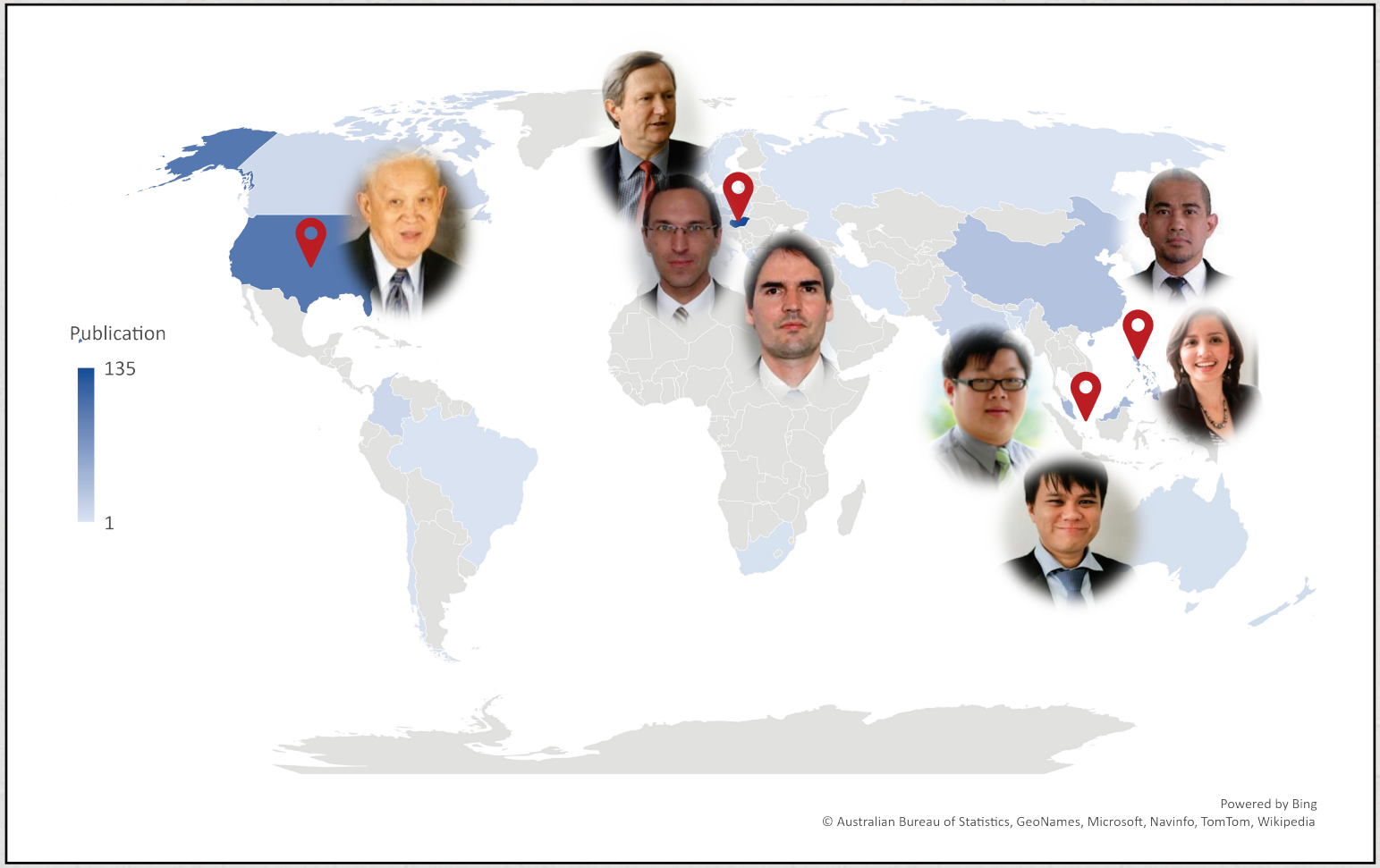
- **P-graph**

Powerful tool that is able to determine all combinatorially feasible solutions and rank these solutions based on the objective function.



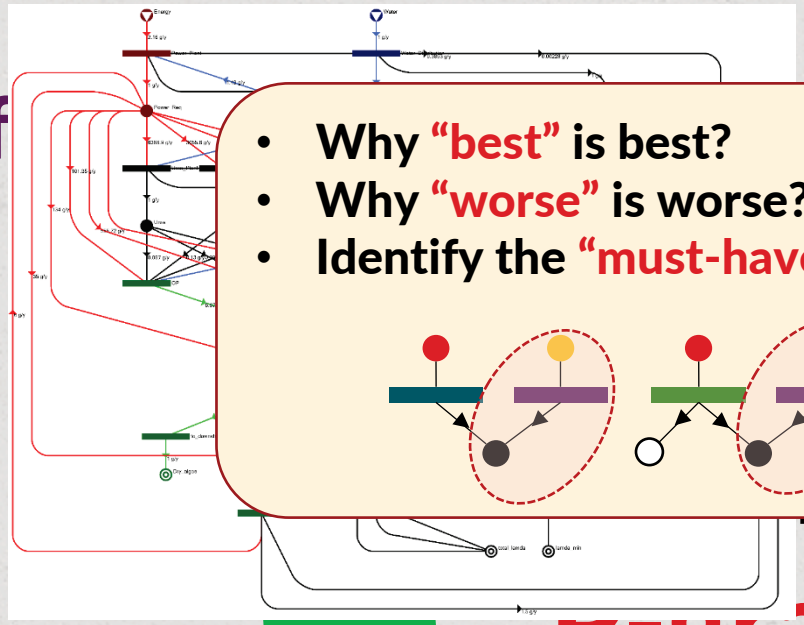
P-graph

- **P-graph Utilization Track**



P-graph

Eff



- Why "best" is best?
- Why "worse" is worse?
- Identify the "must-have" an

P-graph

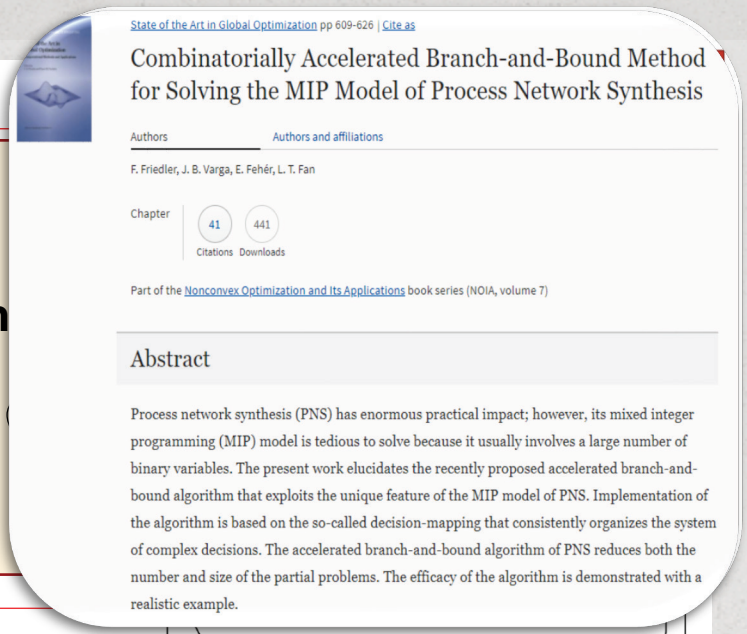
2

Accelerated Branch-

Multi-Solution

2

e



State of the Art in Global Optimization pp 609-626 | Cite as

Combinatorially Accelerated Branch-and-Bound Method for Solving the MIP Model of Process Network Synthesis

Authors Authors and affiliations

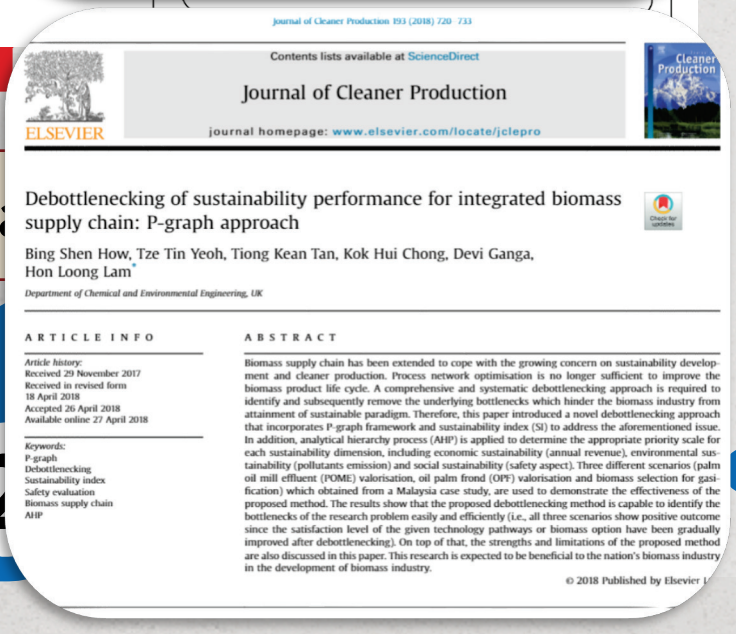
F. Friedler, J. B. Varga, E. Fehér, L. T. Fan

Chapter 41 Citations 441 Downloads

Part of the Nonconvex Optimization and Its Applications book series (NOIA, volume 7)

Abstract

Process network synthesis (PNS) has enormous practical impact; however, its mixed integer programming (MIP) model is tedious to solve because it usually involves a large number of binary variables. The present work elucidates the recently proposed accelerated branch-and-bound algorithm that exploits the unique feature of the MIP model of PNS. Implementation of the algorithm is based on the so-called decision-mapping that consistently organizes the system of complex decisions. The accelerated branch-and-bound algorithm of PNS reduces both the number and size of the partial problems. The efficacy of the algorithm is demonstrated with a realistic example.



Journal of Cleaner Production 193 (2018) 720–733

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Debottlenecking of sustainability performance for integrated biomass supply chain: P-graph approach

Bing Shen How, Tze Tin Yeoh, Tiong Kean Tan, Kok Hui Chong, Devi Ganga, Hon Loong Lam*

Department of Chemical and Environmental Engineering, UK

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Keywords:
P-graph
Debottlenecking
Sustainability index
Safety evaluation
Biomass supply chain
AHP

ABSTRACT

Biomass supply chain has been extended to cope with the growing concern on sustainability development and cleaner production. Process network optimisation is no longer sufficient to improve the biomass product life cycle. A comprehensive and systematic debottlenecking approach is required to identify and subsequently remove the underlying bottlenecks which hinder the biomass industry from attainment of sustainable paradigm. Therefore, this paper introduced a novel debottlenecking approach that incorporates P-graph framework and sustainability index (SI) to address the aforementioned issue. In addition, analytical hierarchy process (AHP) is applied to determine the appropriate priority scale for each sustainability dimension, including economic sustainability (annual revenue), environmental sustainability (pollutants emission) and social sustainability (safety aspect). Three different scenarios (palm oil mill effluent (POME) valorisation, oil palm frond (OPF) valorisation and biomass selection for gasification) which obtained from a Malaysia case study, are used to demonstrate the effectiveness of the proposed method. The results show that the proposed debottlenecking method is capable to identify the bottlenecks of the research problem easily and efficiently (i.e., all three scenarios show positive outcome since the satisfaction level of the given technology pathways or biomass option have been gradually improved after debottlenecking). On top of that, the strengths and limitations of the proposed method are also discussed in this paper. This research is expected to be beneficial to the nation's biomass industry in the development of biomass industry.

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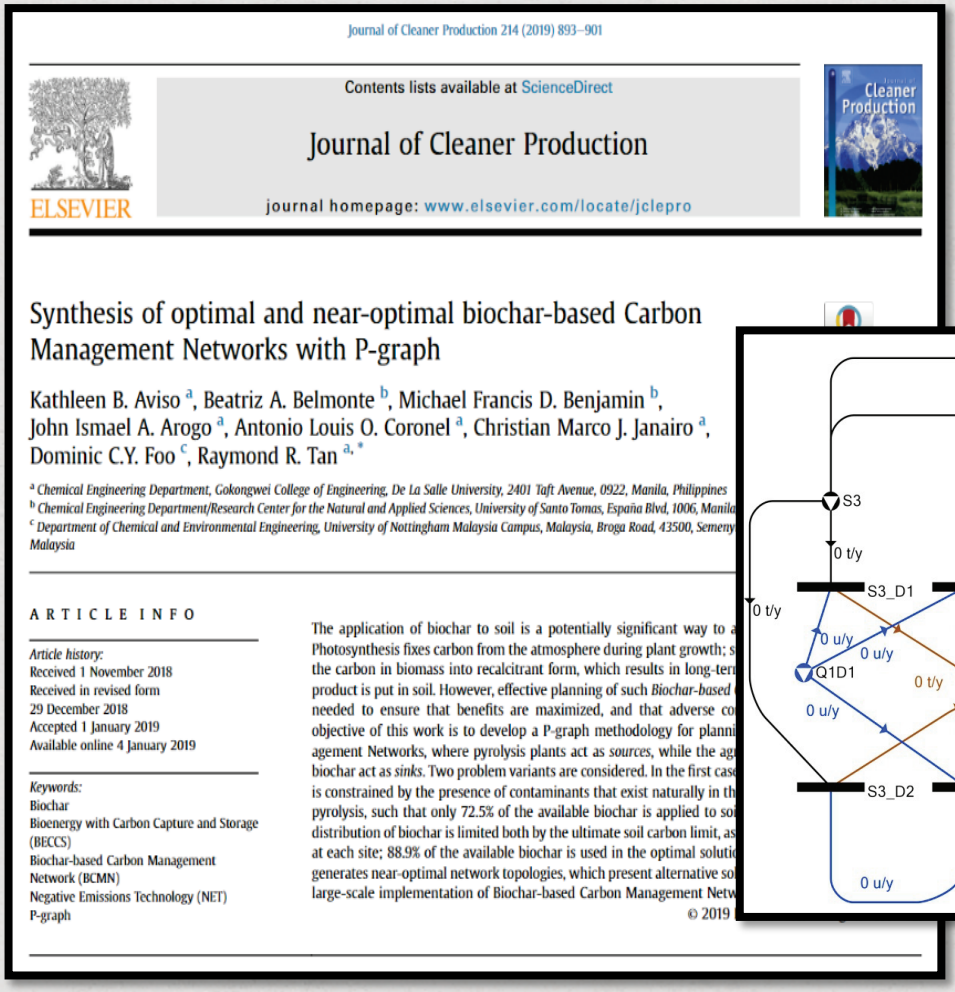
P-graph

- **Energy Planning**



Journal of Cleaner Production 214 (2019) 893–901

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Synthesis of optimal and near-optimal biochar-based Carbon Management Networks with P-graph

Kathleen B. Aviso [a], Beatriz A. Belmonte [b], Michael Francis D. Benjamin [b], John Ismael A. Arogo [a], Antonio Louis O. Coronel [a], Christian Marco J. Janairo [a], Dominic C.Y. Foo [c], Raymond R. Tan [a, *]

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Malaysia

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Available online 4 January 2019

Keywords:
Biochar
Bioenergy with Carbon Capture and Storage (BECCS)
Biochar-based Carbon Management Network (BCMN)
Negative Emissions Technology (NET)
P-graph

The application of biochar to soil is a potentially significant way to a
Photosynthesis fixes carbon from the atmosphere during plant growth; s
the carbon in biomass into recalcitrant form, which results in long-ter
product is put in soil. However, effective planning of such *Biochar-based*
needed to ensure that benefits are maximized, and that adverse co
objective of this work is to develop a P-graph methodology for planni
agement Networks, where pyrolysis plants act as *sources*, while the ag
biochar act as *sinks*. Two problem variants are considered. In the first cas
is constrained by the presence of contaminants that exist naturally in th
pyrolysis, such that only 72.5% of the available biochar is applied to so
distribution of biochar is limited both by the ultimate soil carbon limit, as
at each site; 88.9% of the available biochar is used in the optimal solutio
generates near-optimal network topologies, which present alternative so
large-scale implementation of Biochar-based Carbon Management Netw

P-graph

- **Hydrogen Economy**

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Transitioning of localized renewable energy system towards sustainable hydrogen development planning: P-graph approach

Juin Yau Lim[a], Bing Shen How[b], Gahee Rhee[a], Soonho Hwangbo[c,1], Chang Kyoo Yoo[a,*]

[a] Dept. of Environmental Science and Engineering, College of Engineering, Center for Environmental Studies, Kyung Hee University, Seocheon-dong 1, Giheung-gu, Yongin-Si, Gyeonggi-Do 446-701, Republic of Korea
[b] Chemical Engineering Department, Faculty of Engineering, Computing and Science, Swinburne University of Technology, Jalan Simpang Tiga, 93350 Kuching, Sarawak, Malaysia
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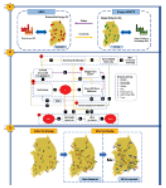
HIGHLIGHTS

- Energy transition of microgrid system into sustainable hydrogen production.
- A mixed-integer linear programming model was applied as debottlenecking framework.
- A mathematically expressed optimization problem was solved with P-graph.
- Feasible configuration of integrated network targeting industrial hydrogen demand.
- Sustainability enhancement by adopting Pareto Frontier Analysis and TOPSIS.

GRAPHICAL ABSTRACT

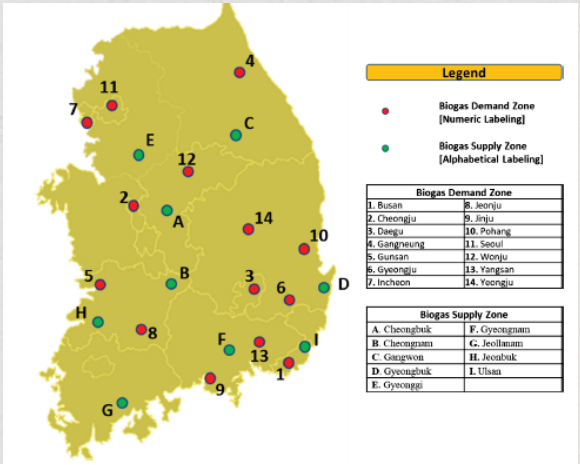


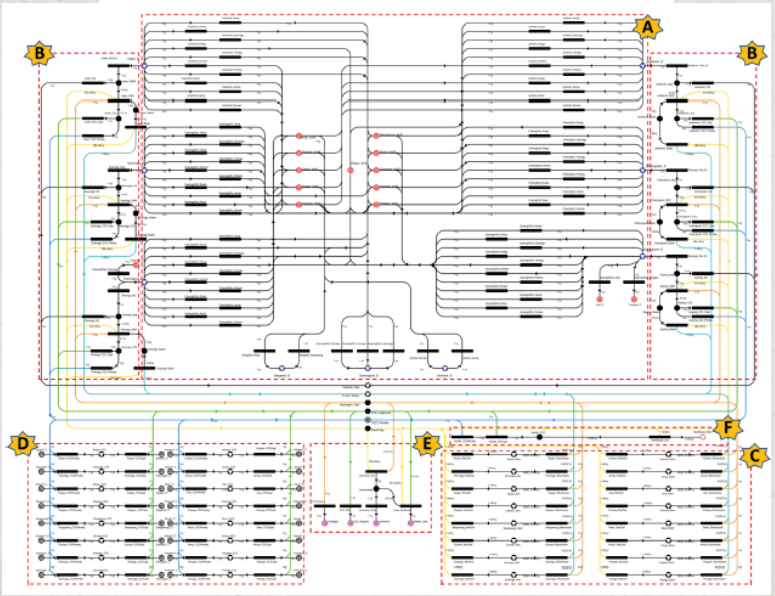
ARTICLE INFO

Keywords:
Sustainability
Integrated optimization network
Mixed-integer linear programming
P-graph
Pareto Frontier Analysis
TOPSIS

ABSTRACT

This study aimed to transition localized hybrid renewable energy microgrid system in multiple regions by integrating excess renewable electricity and carbon dioxide generated with biogas produced in wastewater treatment plant. The integrated optimization network in this contribution addresses the following aspects: (1) biogas supply-demand distribution network, (2) hydrogen production technology allocation involving steam methane reforming and electrolysis, (3) carbon dioxide allocation, and (4) utilization of external resources. The proposed framework is mathematically expressed as a mixed-integer linear programming problem to minimize total annual cost which will be solved by graphical optimization approach, P-graph. A case study of the existing petrochemical industry complex in South Korea has been applied to the developed model. Feasible configuration for meeting base hydrogen demand (7200 tons H_2/year) has been proposed with total annual cost of 75,772,460 US $/year. Apart from base hydrogen demand, the developed model is verified with the increase of hydrogen demand for 10%, 20%, 30%, and 40%. Nonetheless, scenario of tight environmental regulations enforcement has been established among all cases where carbon dioxide emitted within the system will be captured and sequestrated. Pareto Frontier Analysis and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) have been implemented to enhance the overall sustainability by re-ranking the pool of near-optimal solutions to propose new sustainable configuration with the consideration of both economic and environmental





P-graph

- **Hydrogen Supply Network**

Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/he
ELSEVIER
International Journal of HYDROGEN ENERGY

A P-graph approach for the synthesis of national-wide bio-hydrogen network from palm oil mill effluent

Chee Hoong Lee [a], *Darren Yu Lun Chong* [a], *Sadaf Hemmati* [a], *M. Mostafa Elnegihi* [a], *Dominic C.Y. Foo* [a,*], *Bing Shen How* [b], *ChangKyoo Yoo* [c]

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[c] Department of Environmental Science and Engineering, Center for Environmental Studies, Kyung Hee University, Yongin-Si, 446-701, Republic of Korea

HIGHLIGHTS

- A P-graph approach to synthesise the bio-hydrogen network is developed.
- Bio-hydrogen network can be more economic feasible compared to the existing one.
- Two case studies in Malaysia are used to illustrate the proposed method.
- The framework can be used to analyse supply chain uncertainty.
- The framework can be used to benchmark the feasibility of new technology.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 3 February 2020
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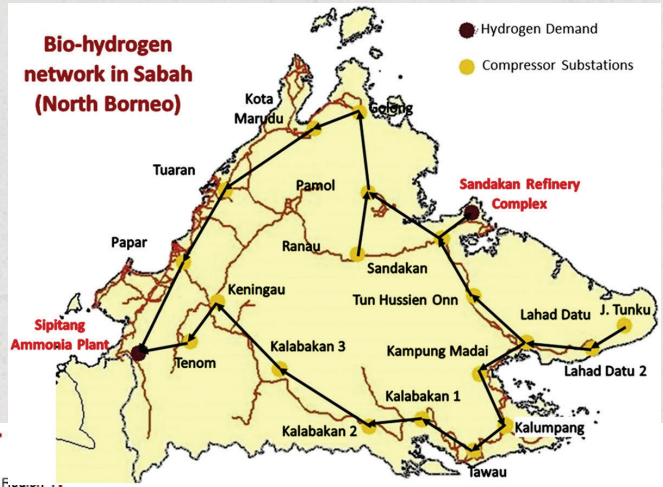
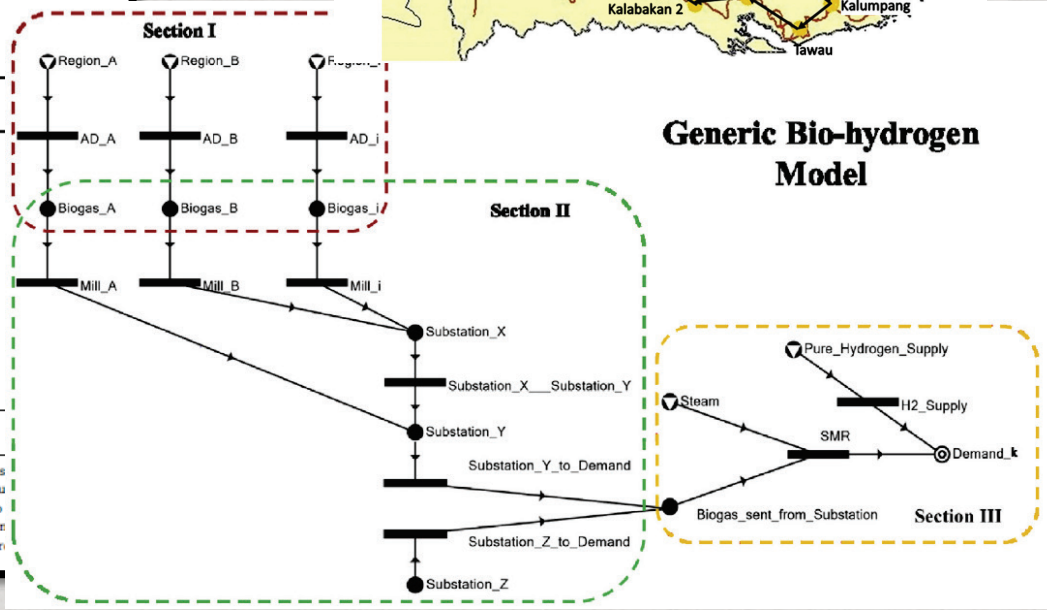
8 April 2020

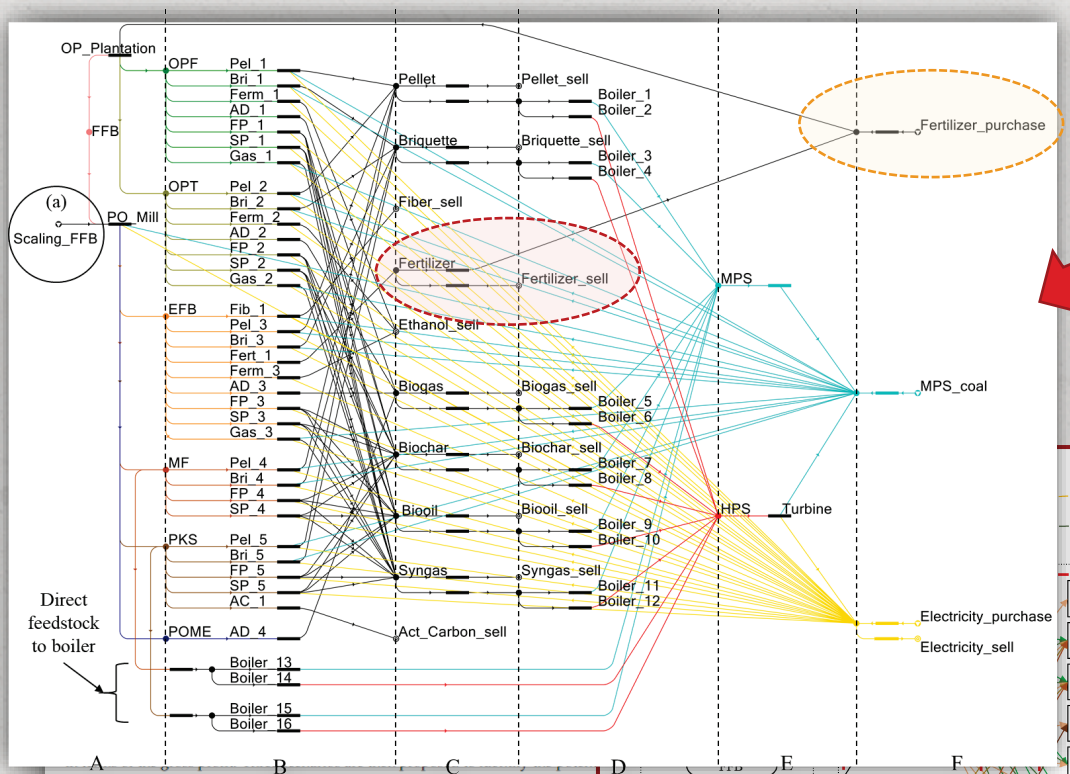
ABSTRACT

The shift from conventional hydrogen production that utilised fossil-bas
a more sustainable practice is essential. Recently, the interest in u
hydrogen sources associated with bio-gas has risen. This work aims to
methodology for bio-hydrogen network synthesis, where oil refineries ar
act as bio-hydrogen sinks, while palm oil mills serve as the bio-hydr



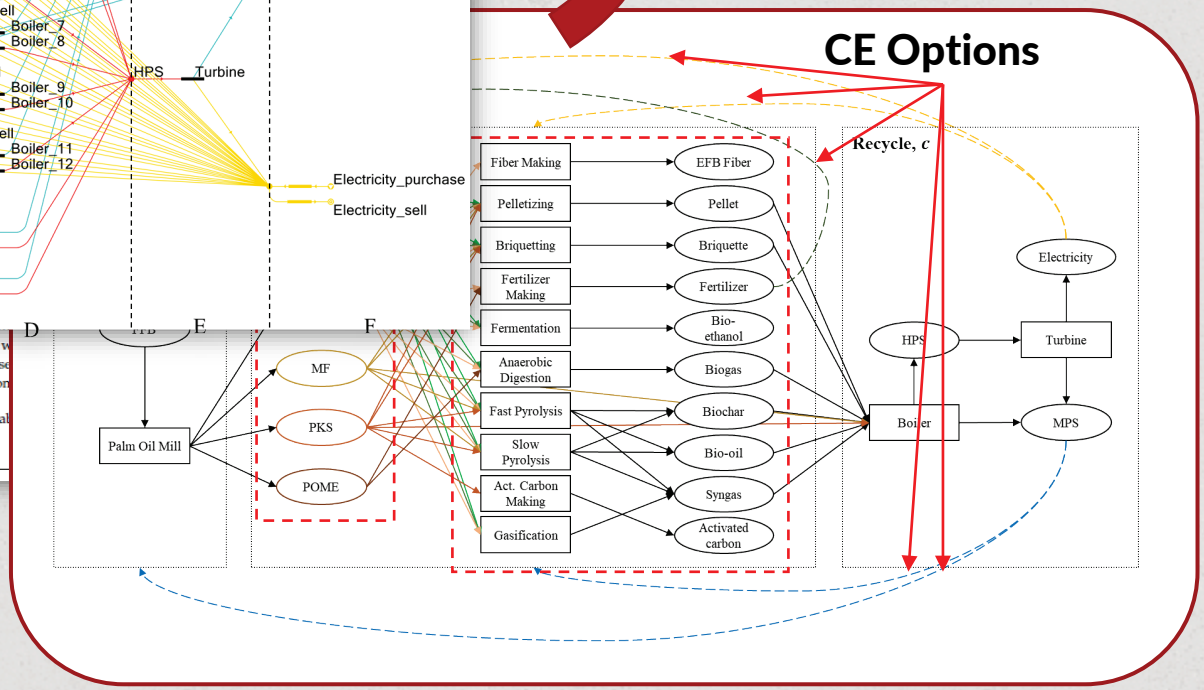


Case Study-Palm Biomass



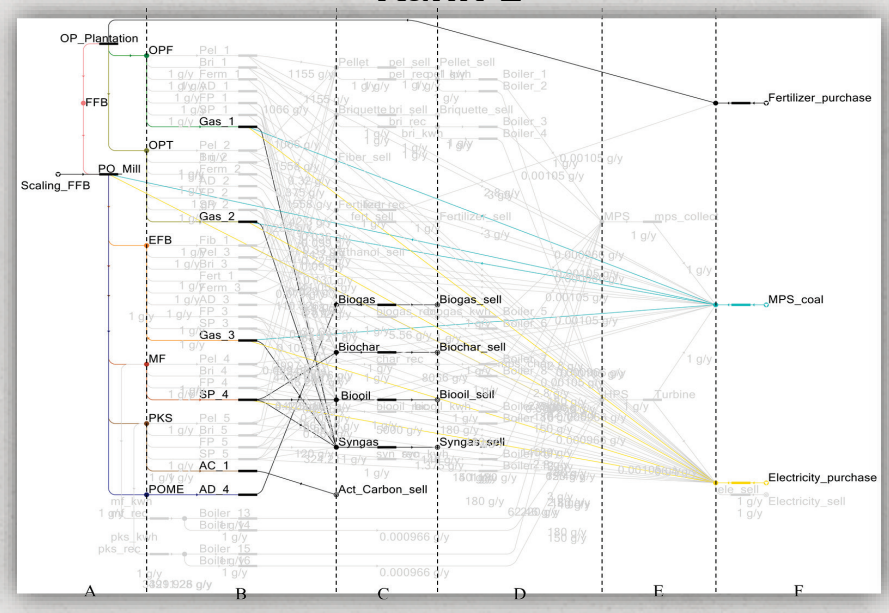
that can hinder the implementation of the sustainable circular economy approach, w
sensitivity analysis. This work is expected to benefit the biomass-based industry se
policymakers on future development and transition to the sustainable circular econon

Keywords: palm oil biomass; integrated biorefinery; circular economy; sustainal
economic analysis; P-graph

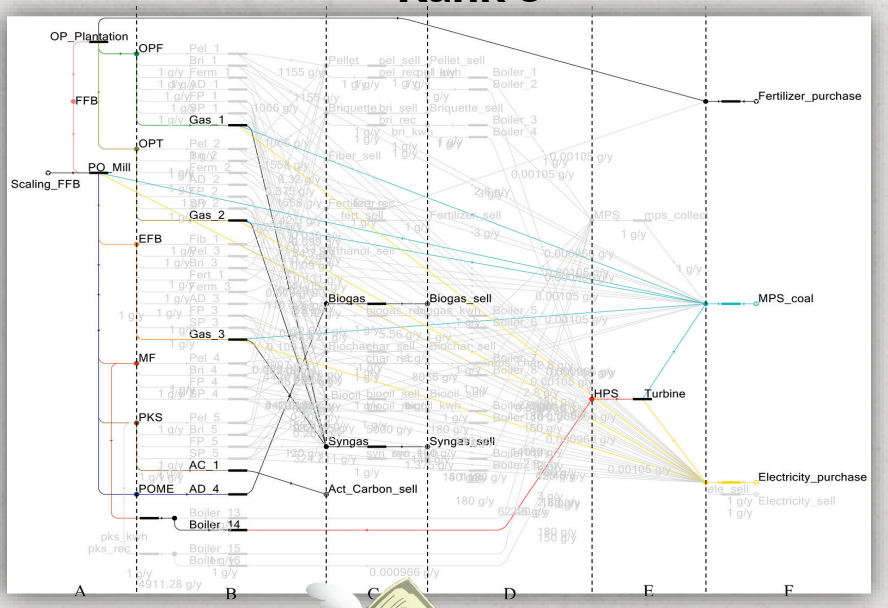


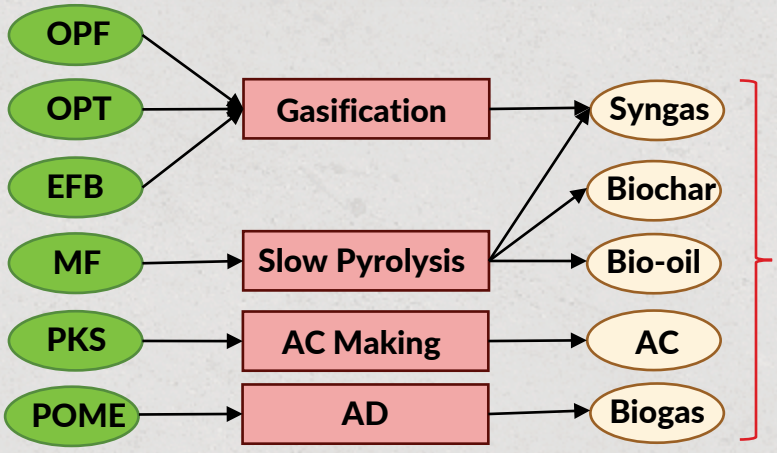
Optimization Result

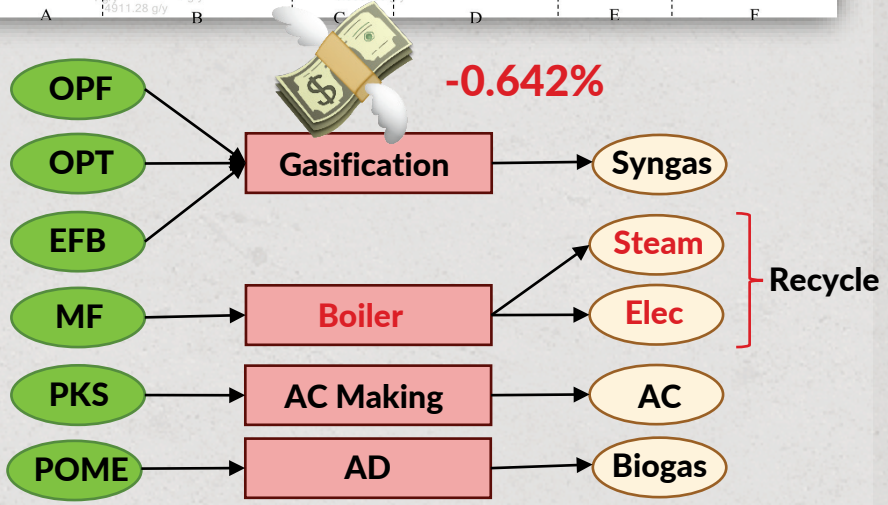
Rank 1



Rank 5







Optimization Result

- **Scenario I—Price Inflation in Imported Resources**

via Refurbishment of Energy Policy

Case	Fertilizer price	Electricity price
Parameter Setting		
Base value	MYR 1630/t	MYR 0.590/kWh
Final adjusted value	MYR 4564/t	MYR 0.708/kWh
Increment, %	+180	+20
Optimized Result		
Imported fertilizer, %	19.880	100
Imported steam, %	89.495	60.708
Imported electricity, %	80.120	86.531
Updated conversion pathway	EFB → Fertilizer	MF → Boiler (HPS)
Recycling pathway	Fertilizer to plantation	HPS → Turbine → MPS + Electricity
Exported product	Biogas, biochar, bio-oil, syngas, activated carbon	Biogas, syngas, activated carbon
Original rank in base case setting	Outside of top 20	5th

Less sensitive

Optimization Result

- **Scenario I—Price Inflation in Imported Resources**

Direct	Indirect
Incentive	Revise Subsidiary
Tax Exemption	
Funding	

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A hybrid approach to prioritize risk mitigation strategies for biomass polygeneration systems

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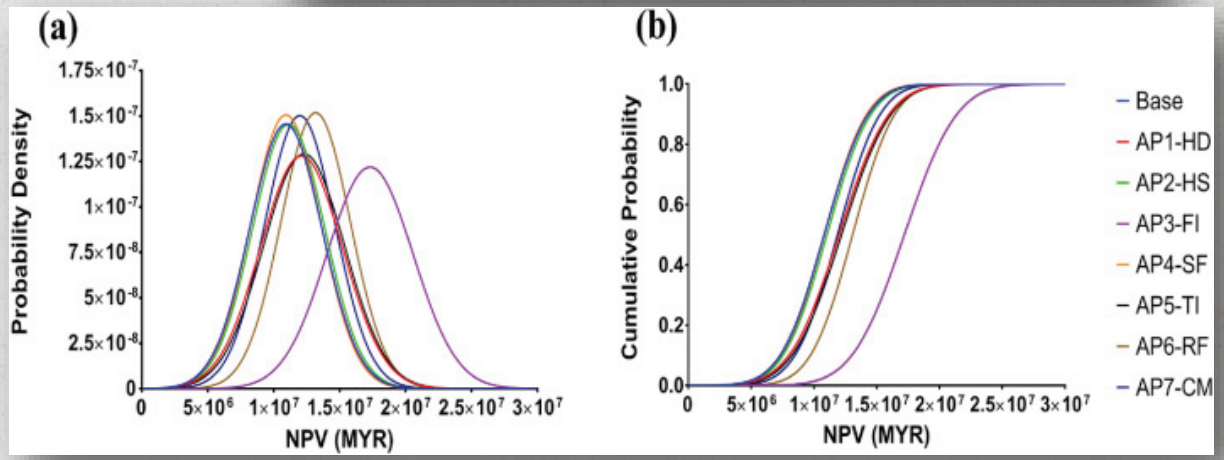
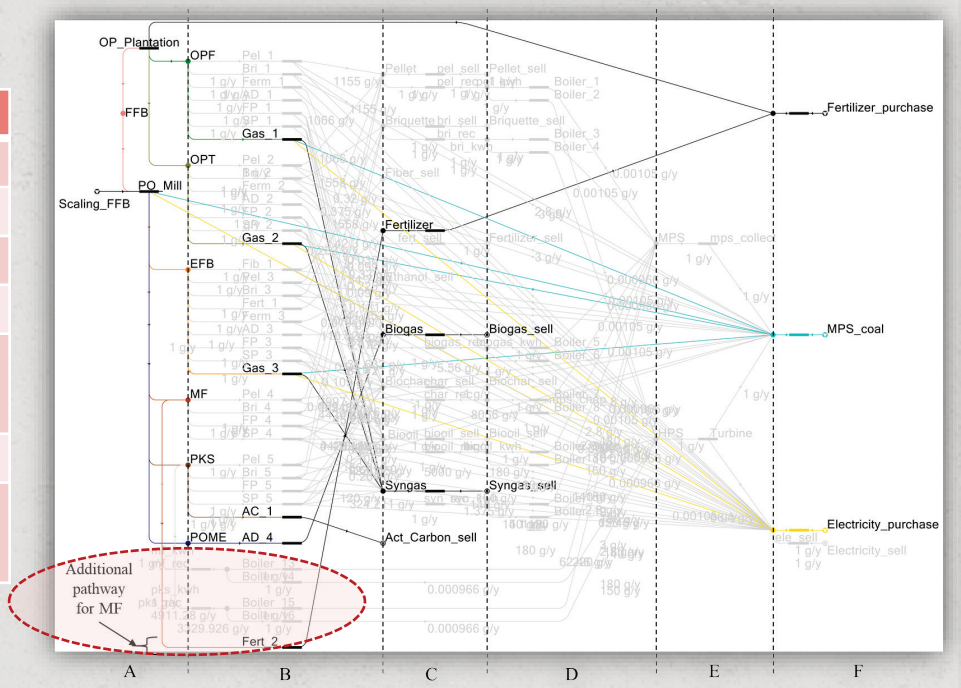


Optimization Result

- **Scenario II—Debottlenecking the Pathway of Fertilizer Production**

Biomass	Conversion ratio, t fertilizer/t MF
EFB	0.330
MF	0.566

Optimized Result	
Gross profit, %	102.899
Imported fertilizer, %	20.323
Imported steam, %	100
Imported electricity, %	94.443
Updated conversion pathway [a]	MF → Fertilizer
Recycling pathway	Fertilizer to plantation
Exported product	Biogas, syngas, activated carbon



Take Away

- Misconception on palm oil: Always benchmark the information received before
- Technologies are available to shift palm oil value chain to circular economy
- Additional efforts in revising the policy and/or improving the technology efficiency are still needed to ensure the economic competitiveness of CE
- Debottlenecking sometime requires researchers/decision-makers to think-out-of-the box

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Thank you!