MANIPAL UNIVERSITY
JAIPUR

Manipal University Jaipur Plastic Waste Reduction Policy

1. Introduction

Manipal University Jaipur acknowledges its responsibility to minimize environmental impact and foster sustainability across all campus activities. Reducing plastic waste is a key area where meaningful change can be achieved. This policy outlines our commitment to reducing plastic waste and establishes a framework for accomplishing this objective.

2. Purpose

The purpose of this policy is to:

- Limit the use of single-use plastics on campus.
- Encourage responsible plastic waste management and recycling practices.
- Raise awareness and involve the university community in efforts to reduce plastic waste.

3. Policy Statements

3.1. Single-Use Plastics Reduction

- Manipal University Jaipur will progressively eliminate the use of single-use plastic items, such as straws, cutlery, cups, and bags on campus.

- Sustainable and reusable alternatives will be available in campus dining facilities, vending machines, and at university events.

3.2. Plastic Recycling

- The university will place recycling bins in accessible locations across the campus to aid in the collection and proper disposal of plastic waste.

- Educational initiatives will be implemented to inform the campus community about the importance of proper plastic disposal.

3.3. Plastic-Free Events

- Manipal University Jaipur will encourage event organizers on campus to adopt plastic-free practices, such as using reusable or compostable materials.
- Event planners will be provided with guidelines and resources to help them reduce plastic waste during events.

MANIPAL UNIVERSITY JAIPUR

3.4. Sustainable Procurement

- The university's procurement policies will prioritize suppliers and products that minimize plastic packaging.
- Vendors and suppliers will be encouraged to offer plastic-free packaging options.

3.5. Research and Innovation

- Manipal University Jaipur will support research initiatives focused on plastic waste reduction, recycling technologies, and sustainable materials.
- Faculty and students will be encouraged to engage in research projects related to plastic waste management.

4. Implementation

4.1. Responsibility

- Office of Registrar Manipal University Jaipur, in collaboration with relevant departments, will oversee the implementation of this policy.
- Each department and unit will be responsible for implementing plastic waste reduction measures within their areas of influence.

4.2. Compliance

- All members of the university community, including students, faculty, staff, and vendors, are expected to comply with this policy.
- Non-compliance may result in disciplinary actions as per university policies.

5. Monitoring and Reporting

5.1. Progress Tracking

- Regular assessments will be conducted to track progress toward plastic waste reduction goals.

5.2. Annual Reports

MANIPAL UNIVERSITY JAIPUR

- The Office of Registrar Manipal University Jaipur will publish annual reports summarizing the university's achievements in plastic waste reduction.
- These reports will be shared with the campus community and made available to the public.

6. Review and Revision

This policy will be reviewed annually to ensure its continued effectiveness in reducing plastic waste on campus. Feedback from the campus community and evolving best practices in sustainability will inform any necessary revisions.

7. Conclusion

Manipal University Jaipur is committed to taking active steps to reduce plastic waste on campus. Through this policy, we aim to inspire our community members to embrace sustainable practices and help create a healthier planet for current and future generations.

Version History

Number	Year	Major Revision
Version 3.0	2023	Focus on awareness
Version 2.0	2022	Including measures as per UGC and Central Government of India
Version 1.0	2020	Initial policy

Approval

IRMRA TALK

At the 24th Rubber Conference & Expo on Sustainability & Circular Economy, held from September 21st to 23rd, 2023, in Chennai!, Dr. Abhishek Sharma's impactful presentation highlighted innovative waste management solutions that entailed conversion of paper and plastic waste into valuable resources. This event gathered global leaders and experts, serving as a pivotal moment for waste management and resource recovery discussions. Dr. Sharma's insights facilitated fruitful discussions on sustainable practices. The presentation reflected the theme of the conference on sustainability and the circular economy. It emphasized the importance of transforming waste into wealth, encapsulating the essence of the event in advancing sustainable and eco-friendly practices within the rubber industry.

Head
Department of Chemical Engg.
Manipal University, Jaipur

Amount of Wate Generated (YoY) at MUJ

Month	Plastic (KG)	Month	Plastic (KG)
Jan-22	21	Jan-23	24
Feb-22	122	Feb-23	119
Mar-22	120	Mar-23	122
Apr-22	384	Apr-23	223
May-22	167	May-23	125
Jun-22	134	Jun-23	233
Jul-22	233	Jul-23	212
Aug-22	244	Aug-23	178
Sep-22	256	Sep-23	289
Oct-22	444	Oct-23	245
Nov-22	376	Nov-23	176
Dec-22	183	Dec-23	198
Total	**2684**	**Total**	**2144**

MANIPAL UNIVERSITY
JAIPUR

FACULTY OF LAW

SCHOOL OF LAW

DEPARTMENT OF LAW

DRUG ABUSE & DRUG TRAFFICKING AWARENESS SESSION

Type of Event: An Enhancement Session

ON

26th June 2022

Content of Report

1. Introduction of the Event
2. Objective of the Event
3. Beneficiaries of the Event
4. Brief Description of the event
5. Geo-tagged Photographs
6. Brochure or creative of the event
7. Attendance of the Event

1. **Introduction of the Event:**

   School of Law with NCC Cadets has organized a session to spread the awareness about drug abuse amongst young people.

2. **Objective of the Event:**

   The primary object of the event was to aware the people about initiatives that can save youngsters to indulge in drug abuse.

3. **Beneficiaries of the Event:**

   The event was conducted to aware the cadets and the students of school of Law have participated in the event.

4. **Brief Description of the event:**

   The international day against Drug Abuse and Illicit trafficking is observed every year on 26 Jun. The NCC cadets on this day take out rallies, organise Nukkad programmes to spread awareness amongst the society. The cadets are themselves made aware about the menace and how it can affect an individual and society at large. Documentaries are screened to convey the message of drug abuse and trafficking. This has now become a worldwide problem. Aim of observing this day is to make a society all around the world free from drugs and drug trafficking.

5. Photograph:

NCC Cadet telling about drug use amongst the young people

School of Law NCC Cadet during the Session at Jaipur NCC Complex

6. Attendance of the Event:

Surbhi Goyal
Neha Kothari
Narmatha Selvam
Gautam Khoiwal
Rohan Singh Faujdar
ravikantg
rohit
Aryan K Sharma
Aditya Jain
kailash
Gagandeep kaur
RITIKA SHARMA
Aayushi Rathi
shwetha J
Jai Rakshita
Aakanksha Badadhe
Deepak Uikey
Arushi Bhatia
Tanya Singh
Bharat Kaushik
Neha Gupta
Garima Sirohi
vaishnavmotsara
jitendra chandrakar
Bankat kumar dholi
Udit Shrivastava
Surbhi Goyal
Neha Kothari
Narmatha Selvam
Gautam Khoiwal
Rohan Singh Faujdar
ravikantg
rohit
Aryan K Sharma
Aditya Jain
kailash
Gagandeep kaur
RITIKA SHARMA
Aayushi Rathi
shwetha J
Jai Rakshita
Aakanksha Badadhe

Yogita Rajput
HEMAA S
Arushi Bhatia
Vinita Srivastava
Rabab Nawab
krupa
Aditi Shekhawat
Tamanna Verma
Shruti Maheshwari

Dr. Sony Kulshrestha
Head, Department of Law
Manipal University Jaipur

MANIPAL UNIVERSITY JAIPUR

School of Architecture and Design

Expert talk
on

'Community Interaction Workshop to Share knowledge on Community Based Solid Waste Management Practices'

Venue: Prithvirajsinghpura, Jaipur, Rajasthan

Time: 11:00 AM onwards

12th May 2023

Index

1. Introduction of the Event:

The School of Architecture & Design at Manipal University Jaipur in association with Mahilla Housing Trust on May 12th, 2023, from 11:00 am onwards, a transformative event unfolded—the "Community Interaction Workshop on Community-Based Solid Waste Management Practices." This gathering served as a platform for knowledge exchange, fostering a collaborative environment where community members shared insights, experiences, and innovative practices in solid waste management. The event aimed to empower participants with practical solutions, strengthening their commitment to sustainable and effective waste management within their communities.

2. Objectives of the Seminar:

- To facilitate the exchange of valuable insights and experiences among community members, promoting a comprehensive understanding of community-based solid waste management practices.
- To provide practical knowledge and tools to empower participants with the skills needed to implement effective and sustainable waste management solutions within their respective communities.
- To foster a collaborative environment to encourage networking and partnership-building among participants, promoting collective efforts towards creating cleaner and healthier communities.

3. Beneficiaries of the Event:

- Common public residing at Prithvirajsinghpura

4. Details of the Expert:

Dr. Madhura is a highly accomplished Architect Planner with 29+ years of experience in Administration, Academics & Research and currently Dean of Faculty of Design at Manipal University Jaipur, and an expert in UPSC, AICTE, CoA and DST Rajasthan & NITI Ayog, Government of India. Her expertise in Sustainable Architecture Design & Planning has been shared through keynotes across universities and governmental bodies. Her scholarly work includes numerous publications and mentoring PhD candidates.

Her research and publications have earned her numerous awards and accolades, including the Indo Pacific Architecture Excellence Award 2021, Education Leadership Award 2019. She is also a UNESCO certified mentor and a member of ICOMOS National Scientific Committee in Working Group of Sustainable Development and in Climate Change and Heritage. She is Fellow Member of various architectural and planning institutes, IGBC etc. contributing to the growth of sustainable and inclusive Design & Planning.

5. Brief Description of the event:

The "Community Interaction Workshop on Community-Based Solid Waste Management Practices" unfolded on May 12th, 2023, from 11:00 am onwards in the rustic setting of Prithvirajsinghpura, a quaint village under the Sanjhariya panchayat in Jaipur, Rajasthan. The event aimed to empower the local community with knowledge and skills for effective waste management. Residents of this rural area actively participated, exchanging insights and experiences. The workshop not only offered practical tools for sustainable waste practices but also facilitated networking and collaboration, fostering a sense of collective responsibility. Amidst the serene surroundings, community members engaged in enriching discussions, contributing to the shared goal of creating a cleaner and healthier environment for Prithvirajsinghpura and its neighboring regions. The event encapsulated a spirit of community collaboration and empowerment, laying the foundation for positive and sustainable changes in solid waste management practices within the rural landscape of Jaipur, Rajasthan.

6. Images

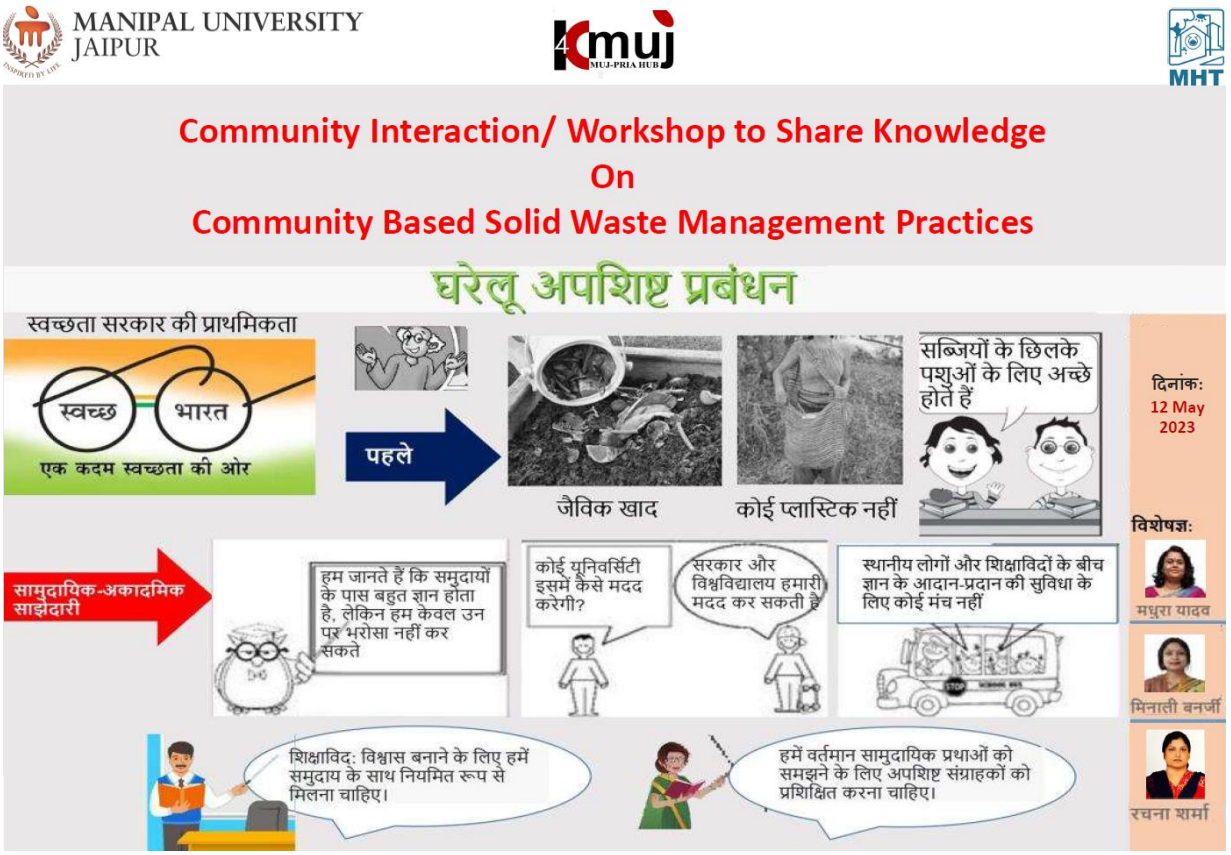
Figure 1: Discussion on Site About Waste Management System

Figure 2: Prof. (Dr.) Madhura Yadav, Delivering about the waste management practice

Figure 3: Prof. (Dr.) Madhura Yadav, Delivering about the waste management practice

Figure 4: Prof. (Dr.) Madhura Yadav, Delivering about the waste management practice

7. Brochure of the Event



8. Schedule of the event

11:00 AM onwards

9. Weblink:

10. Event Coordinators:

Prof. (Dr.) Madhura Yadav (Professor & Dean – Faculty of Design, MUJ)
Ms. Rachna Sharma,
Ar. Akshay Gupta (Assistant Professor, SA&D)

Prof. (Dr.) Sunanda Kapoor
Head, Architecture
School of Architecture & Design, Faculty of Design, MUJ

MANIPAL UNIVERSITY
JAIPUR

MUJ/DSW/Student Clubs/2023/Biotech Club MUJ/28th February

DIRECTORATE OF STUDENTS' WELFARE

Nukkad Natak

ON

Solid Waste Management

Department of Biosciences & Biotech Club, Manipal University Jaipur

Date of Event (28th February, 2023)

(Venue: TMA Pai Auditorium)

Index

Introduction of the Event ,

The Department of Biosciences & Biotech Club, Manipal University Jaipur organized a 'Nukkad Natak' on 'Solid Waste Management' on 28th Feb, 23. It was directed by 2nd year students of Department of Biosciences, Divya and Samrat and it was awe-inspiringly performed by the students. This Nukkad Natak was under the guidance of the convenor – Dr. Mousumi Debnath, Faculty Coordinator, Biotech Club.

The performers interacted with the audience and presented an informatic skit on solid waste management and the do's and don'ts of waste disposal.

This skit was a call to action, urging the audience to take responsibility for their waste and make conscious choices in their daily lives. It was an effective way to educate and engage the public on a crucial environmental issue.

Objectives of the Event

- To increase awareness about solid waste management.
- To bring public awareness about the fatality caused by wastes.
- To educate about the waste disposal methods and its do's and don'ts.

Beneficiaries of the Event

- MUJ Students
- Faculty

Brief Description of the event

Conducted under the guidance of the Founder Faculty Coordinator, Biotech Club, Dr. Mousumi Debnath, Faculty of Biosciences, this Nukkad Natak solely aimed in bringing public awareness on solid waste management. It was well directed by students of Department of Biosciences, Divya and Samrat, who commenced from writing the scripts to directing the performers and eventually operated a successful and inspiring Nukkad Natak.

A group of brilliant and motivated performers presented the Nukkad Natak, bringing attention to the problem of solid waste management through a stirring and thought-provoking performance. The show highlighted the negative consequences of littering and the necessity of effective waste management.

The actors portrayed different characters like a litterbug, a garbage collector, and a responsible citizen who showed how the problem of solid waste management can be tackled. The audience was made conscious of the risks that incorrect garbage disposal poses to both the public's health and the environment.

The play also highlighted the role of the government and the civic bodies in managing solid waste.

In conclusion, the Nukkad Natak on Solid Waste Management held on 28th February on the occasion of National Science Day was a highly successful event that effectively highlighted the issue of solid waste management. The play succeeded in spreading awareness about the importance of proper waste management practices and the role of individuals and the government in tackling this issue.

Photographs

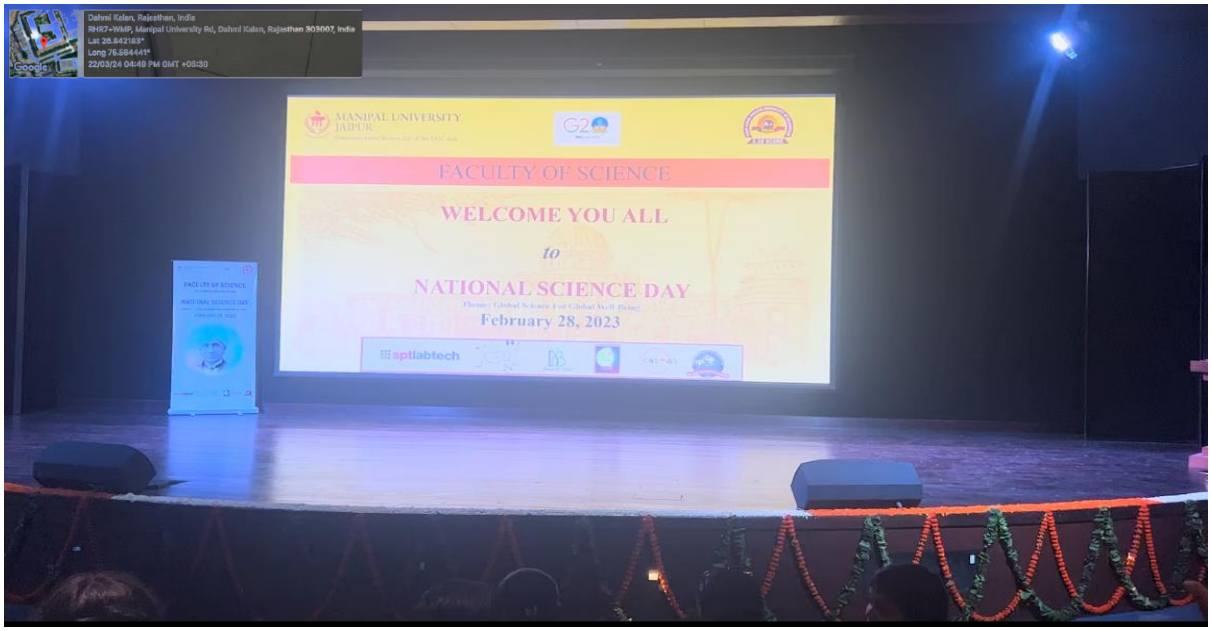


Figure 1 National Science Day; Coordinates: 26.843429; 75.566529; N26°50'36.34" E75°33'59.50"(Manipal University Jaipur)

Figure 2 Nukkad Natak performed by students.; Coordinates: 26.843429; 75.566529; N26°50'36.34" E75°33'59.50"(Manipal University Jaipur)

Figure 3 Nukkad Natak performed by students. Coordinates: 26.843429; 75.566529; N26°50'36.34" E75°33'59.50"(Manipal University Jaipur)

Figure 4 Nukkad Natak performed by students. Coordinates: 26.843429; 75.566529; N26°50'36.34" E75°33'59.50"(Manipal University Jaipur)

Figure 5 Nukkad Natak team and Dr. Mousumi Debnath, Faculty Coordinator, Biotech Club; Coordinates: 26.843429; 75.566529; N26°50'36.34" E75°33'59.50"(Manipal University Jaipur)

Brochure or Creative of the Event

MANIPAL UNIVERSITY
JAIPUR

MANIPAL UNIVERSITY
JAIPUR
(University under Section 2(f) of the UGC Act)

BIOTECH CLUB OF MUJ

Presents

NUKKAD NATAK

on

SOLID WASTE MANAGEMENT

DATE AND TIME

28th February, 2PM onwards

VENUE

TMA PAI auditorium, MUJ

MANIPAL UNIVERSITY
JAIPUR

INSPIRED BY LIFE

Schedule of the event

The event was on the 28th February 2023 from 2:00 PM- 3:00 PM in TMA Pai Auditorium, Academic Block 2.

Attendance of the event: 38

S.No.	Name	Registration No.
1.	Ananya Singh	201002002
2.	Harsh Saxena	201003004
3.	Anvarshu Gopal	211002011
4.	Anshullika Saxena	211002053
5.	Ayushi Gupta	201002029
6.	Divya	211002056
7.	Sylvia Parveen	211003009
8.	Anushka Singh	211002003
9.	Shivani Tiwari	211002002
10.	Aryan Singh	211002038
11.	Muskan Yadav	211002040
12.	Sakshi Nirmal	211002060
13.	Priyasha Paul	211002035
14.	Akash Chandra	211002036
15.	Shashank Goyal	21102043
16.	Nandini	211003001
17.	Mrunal Mangaje	211003007
18.	Sowvhik Parvej	211002007
19.	Aayushi Thakkar	211002061
20.	Manisha Verma	211002009
21.	Rahul Shrivastava	211002050
22.	Debarghya Sarkar	211002015

23.	Samrat Banerjee	211003008
24.	Sneha Srivastava	211002042
25.	Sonali Lalwani	211002041
26.	Suhani Pareek	211002062
27.	Vishnu Priya	211002028
28.	Tarushi Jain	201003001
29.	Dr. Abhijeet Singh	
30.	Dr. Mousumi Debnath	
31.	Dr. Madan Mohan Sharma	
32.	Dr. Rakesh Sharma	
33.	Dr. Nitesh Poddar	
34.	Dr. Monika Sangani	

Ananya Singh

President, Biotech Cub MUJ

Signature of the Student Coordinator

Dr. Mousmai Debnath

School of Basic Science

Signature of the Faculty Coordinator

DIRECTOR STUDENT WELFARE & PROCTOR
MANIPAL UNIVERSITY, JAIPUR

Dr. Arun Kumar Poonia
Asst. Director, DSW Clubs

H/K

भारतीय गैर न्यायिक

भारत INDIA

रु. 500 FIVE HUNDRED RUPEES

पाँच सौ रुपये Rs. 500

सत्यमेव जयते

INDIA NON JUDICIAL

राजस्थान RAJASTHAN K 906334

AGREEMENT

This agreement is executed on the 10 day of April 2019 between, Mr. Kalam, Son of Shri Hachalahulla, Resident of Kachi Basti, Jhag Bus Stand, Bagru, District Jaipur, Rajasthan, (Having PAN No. GESPK6028E and Aadhaar No. 949028222225) hereinafter referred to as first party, and Manipal University Jaipur, having it's campus at Village Dehmikalan, Tehsil Sanganer, Off Jaipur Ajmer Expressway, Near GVK Toll Plaza, Jaipur 303007 hereinafter referred to as second party.

Whereas the first party is engaged in the business of Waste Collection, treatment and disposal activities, materials recovery, collection of non-hazardous waste and manufacturing. First party has got himself registered under the Udyog Aadhaar Memorandum having Aadhaar No. 949028222225.

Whereas the second party is a State Private University.

Whereas the first party approached the second party and made an offer to the second party for collection of the dry garbage generated in the campus of the second party consequent to daily general activities of students and the staff. First party shall pay Rs. 5,000/- in lump sump to the second party on a monthly basis, on or before 7th day of each calendar month for the same. The first party shall use it's own vehicle to collect and transport the collected garbage up to his place for proper disposal and shall not claim anything from the second party against the same. The first party acknowledges that he shall duly adhere all the applicable civil and municipal laws and second party shall not be liable in any manner against any breach committed by the first party.

Hence this agreement is executed at Jaipur on the date mentioned in the beginning.

कलाम

Mr. Kalam, Son of Shri Hachalahulla,
Aadhaar No. 949028222225

Manipal University Jaipur,
Through Authorized Representative.

Witnesses :

1. Dr. Lucky Vijayvargiya
Deputy Registrar
Manipal University Jaipur

2. GAJRAJ SINGH YADAV
P.S. to Registrar
Manipal University Jaipur

Head Office (MUID)

Rajasthan State Pollution Control Board

4, Institutional Area, Jhalana Doongari, Jaipur-302 004

Phone: 0141-5159600,5159695 Fax: 0141-5159697

Registered

File No : F(MUID)/Jaipur(Jaipur)/12(1)/2011-2012/2982-2984

Order No : 2018-2019/MUID/5045

Date: 02/08/2018

Unit Id : 27890

M/s Manipal University, Jaipur

Flat No. 22, Kadamba, Vatika Infotech City near GVK Toll Plaza, Jaipur Ajmer Expressway, Post Thikaria , District:Jaipur

Sub: **Consent to Operate** under section 25/26 of the Water (Prevention & Control of Pollution) Act, 1974 and under section 21(4) of Air (Prevention & Control of Pollution) Act, 1981**.**

Ref: Your application for Consent to Operate dated 24/02/2018 and subsequent correspondence.

Sir,

Consent to Operate under the provisions of section 25/26 of the Water (Prevention & Control of Pollution) Act, 1974 (hereinafter to be referred as the Water Act) and under section 21 of the Air (Prevention & Control of Pollution) Act, 1981, (hereinafter to be referred as the Air Act) as amended to date and rules & the orders issued thereunder **is hereby granted** for your **Manipal University Jaipur plant** situated at **Khasra No 467,469,474,458/1,473,475, 542, 544 village Dehmi Dehmi Kalan Tehsil:Sanganer District:JAIPUR** , Rajasthan, subject to the following conditions:-

1 That this Consent to Operate is valid for a period from **01/06/2018** to **31/05/2028** .

2 That this Consent is granted for manufacturing / producing following products / by products or carrying out the following activities or operation/processes or providing following services with capacities given below.

Particular	Type	Quantity with Unit
Built-up area	Activity	63,352.61 SQ. METER
PLOT AREA	Activity	269,801.80 SQ. METER

3 That this consent to operate is for existing plant, process & capacity and separate consent to establish/operate is required to be taken for any addition / modification / alteration in process or change in capacity or change in fuel.

4 That the quantity of effluent generation along with mode of disposal for the treated effluent shall be as under:

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Unit Id : 27890

Type of effluent	Max. effluent generation (KLD)	Recycled Qty of Effluent (KLD)	Disposed Qty of effluent (KLD)and mode of disposal
Domestic Sewage	56.000	NIL	56.000 On Land For Plantation/Horticulture etc

5 That the sources of air emmissions along with pollution control measures and the emission standards for the prescribed parameters shall be as under:

Sources of Air Emmissions	Pollution Control Measures	Prescribed	
		Parameter	Standard
TWO D.G. SET (500KVA)(500KVA)	ACOUSTIC ENCLOSURE , WITH ADEQUATE STACK HEIGHT	--	--

6 That the domestic sewage shall be treated before disposal so as to conform to the standards prescribed under the Environvent (Protection) Act-1986for disposal **Into Inland Surface Water**. The main parameters for regular monitoring shall be as under.

Head Office (MUID)

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Order No : 2018-2019/MUID/5045

Date: 02/08/2018

Unit Id : 27890

Parameters	Standards
Total Suspended Solids	Not to exceed 100 mg/l
Oil and Grease	Not to exceed 10 mg/l
Total Residual Chlorine	Not to exceed 1.0 mg/l
Ammonical Nitrogen (as N)	Not to exceed 50 mg/l
Total Kjeldahl Nitrogen (as N)	Not to exceed 100 mg/l
Biochemical Oxygen Demand (3 days at 27°C)	Not to exceed 30 mg/l
Phosphate as P	Not to exceed 1.0 mg/l
pH Value	Between 6.5 to 9.0
Chemical Oxygen Demand	Not to exceed 250 mg/l

7 That the entire treated sewage shall be utilized within premises for flushing, horticulture/plantation etc or and zero discharge status shall be maintained outside the premises.

8 That the unit shall not abstract ground water more than 491 KLD without prior permission from CGWA

9 That the unit shall obtain all necessary permission from JDA, Nagar Nigam and district administration Jaipur related to the University Campus

10 That the unit shall obtain separate consent to establish and consent to operate under the provision of Water Act 1974 and under the Air Act 1981 from the Board, for construction activities of expansion of academic block of University campus.

11 That the project proponent shall comply with the conditions imposed through Environmental Clearance grated by State Level Environment Impact Assessment Authority, Jaipur vide letter no. 08-09 dated 29/12/2009.

12 That the unit shall comply all the conditions of NOC imposed by CGWA vide letter no 1826 dated 15/03/2010 and subsequent renewal.

13 That the unit shall maintain and operate the STP of 150 KLD capacity to treat the waste water generated from the utilities.

14 That the total water consumption in phase-I, shall not exceeds 70 KLD without prior permission of the Board.

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Order No : 2018-2019/MUID/5045

Date: 02/08/2018

Unit Id : 27890

15 **That the water flow meters shall be provided at all suitable points to measure quantity of daily water consumption, waste water generation, waste water treated and treated waste water recycled and utilized for plantation/gardening purposes. Daily record of the same shall be maintained and to be submitted to the Board.**

16 **That the industry shall comply with the standards as prescribed vide MOEF notification no. GSR 826(E) dated 16th November, 2009 with respect to National Ambient Air Quality.**

17 **That this consent to operate is valid for (Phase-I) Academic block – A (G +03), University administration block & Library (G + 03) and Workshop, Food court (G + 03) having total Built-up area – 63,352.61Sq. Meter and Plot Area – 2,69,801.80 Sq. Meter only. For any change in capacity of the services & area, the unit has to seek fresh consent to operate.**

18 **That the unit shall ensure not to discharge treated/untreated waste water into any drain/Nallah which is terminating to any water body in nearby area.**

19 **That the unit shall install adequately designed rain water harvesting structure for prevention and recharge of ground water in and around the area.**

20 **That the unit shall not allow making any obstacles to any natural water flow i.e. natural nallah/stream carrying rain water to any water body**

21 **That the unit shall maintain adequate height of stack along with acoustic enclosures on two D.G.Sets of 2 x 500 KVA. Further unit shall not allow to install any other air pollution source i.e. Boiler/Hot Water generator etc without prior permission of the Board under the Air Act 1981.**

22 **That the unit shall dispose the sludge of STP in scientific manner**

23 **That if the project cost (for Phase-I) exceeds Rs.188.38 Crores, the unit shall take/obtain modification in consent to operate after paying fee as applicable.**

24 **That the unit shall ensure proper utilization and reuse of domestic waste water after adequate treatment for gainful purposes.**

25 **That energy conservation measures like installation of CFLs/FLs for lighting the areas outside the building should be integral part of the project design and should be in place before project commissioning.**

26 **That used CFLs/FLs should be properly collected and disposed off/sent for re-cycling as per the prevailing rules/guidelines issued by the regulatory authority. Use of solar panels also may be done to the extent possible.**

27 **That this consent to operate shall be subject to compliance of any direction or order passed by Court of Law in the matter.**

28 **That the unit shall provide and maintain the Oil & Grease trap in good condition, so that oil & grease coming with waste water from kitchen/laundry will retained in the trap.**

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Date: 02/08/2018

Unit Id : 27890

29 **That the unit shall demolish the R.M.C.Plant after completion of college building and report to the Board.**

30 **That the unit shall take separate consent to operate for other phases (excluding phase-I) under the provision of Water Act 1974 and under the Air Act 1981 from the Board as and when commissioned.**

31 That, not withstanding anything provided hereinabove, the State Board shall have power and reserves its right, as contained **under section 27(2) of the Water Act and under section 21(6) of the Air Act** to review anyone or all the conditions imposed here in above and to make such variation as it deemed fit for the purpose of **Air Act & Water Act**.

32 That the grant of this **Consent to Operate** is issued from the environmental angle only, and does not absolve the project proponent from the other statutory obligations prescribed under any other law or any other instrument in force. The sole and complete responsibility to comply with the conditions laid down in all other laws for the time-being in force, rests with the industry/ unit/ project proponent.

33 That the grant of this **Consent to Operate** shall not, in any way, adversely affect or jeopardize the legal proceeding, if any, instituted in the past or that could be instituted againt you by the State Board for violation of the provisions of the Act or the Rules made thereunder.

This **Consent to Operate** shall also be subject, besides the aforesaid specific conditions, to the general conditions given in the enclosed Annexure. The project proponent will comply with the provisions of the **Water Act and Air Act** and to such other conditions as may, from time to time , be specified, by the State Board under the provisions of the aforesaid Act(s). Please note that, non compliance of any of the above stated conditions would tantamount to revocation of **Consent to Operate** and project proponent / occupier shall be liable for legal action under the relevant provisions of the said Act(s).

This bears the approval of the competent authority.

Yours Sincerely

Group Incharge[MUID]

Head Office (MUID)

Rajasthan State Pollution Control Board

4, Institutional Area, Jhalana Doongari, Jaipur-302 004

Phone: 0141-5159600,5159695 Fax: 0141-5159697

Registered

File No : F(MUID)/Jaipur(Jaipur)/12(1)/2011-2012/2982-2984

Order No : 2018-2019/MUID/5045

Date: 02/08/2018

Unit Id : 27890

Copy To:-

1 Regional Officer, Regional Office, Rajasthan State Pollution Control Board, Jaipur requested to verify the compliance of CTO conditions and forward the detailed inspection report for further necessary action within 03 month.

2 Master File.

Group Incharge[MUID]

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REVIEW ARTICLE

A review on co-pyrolysis of agriculture biomass and disposable medical face mask waste for green fuel production: recent advances and thermo-kinetic models

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Abstract The Association of Southeast Asian Nations is blessed with agricultural resources, and with the growing population, it will continue to prosper, which follows the abundance of agricultural biomass. Lignocellulosic biomass attracted researchers' interest in extracting bio-oil from these wastes. However, the resulting bio-oil has low heating values and undesirable physical properties. Hence, co-pyrolysis with plastic or polymer wastes is adopted to improve the yield and quality of the bio-oil. Furthermore, with the spread of the novel coronavirus, the surge of single-use plastic waste such as disposable medical face mask, can potentially set back the previous plastic waste reduction measures. Therefore, studies of existing technologies and techniques are referred in exploring the potential of disposable medical face mask waste as a candidate for co-pyrolysis with biomass. Process parameters, utilisation of catalysts and technologies are key factors in improving and optimising the process to achieve commercial standard of liquid fuel. Catalytic co-pyrolysis involves a series of complex mechanisms, which cannot be explained using simple iso-conversional models. Hence, advanced conversional models are introduced, followed by the evolutionary models and predictive models, which can solve the non-linear catalytic co-pyrolysis reaction kinetics. The outlook and challenges for the topic are discussed in detail.

Keywords biomass, COVID-19 waste, catalyst, pyrolysis, kinetics

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1 Background

1.1 Bioenergy from biomass as a crucial renewable energy source

Association of Southeast Asian Nation (ASEAN) projected its population to grow by 100 million from 2014 to 2025, with an annual growth of 5%, and 4% in energy demand per year. Hence, the association has set the goal to increase its renewable energy share from 9.4% to 23% of the primary energy supply in the ASEAN region [1]. In order to meet the target, member countries has strategise several policies, laws, and regulations [2], as summarised in Table 1, which includes ASEAN member countries and their strategies [3].

Following this, ASEAN countries are known as the top agriculture producers. Hence, there are significant prospects for bioenergy as a strategy to help realise the ASEAN renewable energy generation and consumption goals. For example, Indonesia and Malaysia are the major players in the oil palm industry, followed by Thailand as

Table 1 ASEAN member countries renewable energy policies

Country	Policies/strategies	Ref.
Cambodia	**Energy Sector Development Policy and Rural Electrification Policy, 2007** Rural electrification fund subsidy and investment incentives are provided as support to the policy • Providing reliable, affordable quality supply of electricity to the consumers • Promoting private-owned facilities in the renewable energy sector to instigate competition between the companies • Providing electricity to 70% of the rural households by the year 2030	[4]
India	**The Electricity Act, 2003** • To encourage the co-generation of electricity with renewable sources • Specify the terms and conditions for the determination of tariff, which forms the National Electricity Policy and the Tariff policy **Tariff Policy, 2006** • States that renewable energy shall be distributed with a preferential tariff determined by the appropriate commission • Bidding process within suppliers offering renewable energy from the same source **National Rural Electrification Policies, 2006** • Provision of access of electricity to all households by the year 2009 • Quality and reliable power supply at affordable rates • Providing off grid solutions for rural areas **Integrated Energy Policy Report (Planning Commission), 2006** Recommends a solution to meet the energy demand of India in an integrated process up to 2031–2032	[5]
Indonesia	**Government Rule No. 3 on Supply of Electricity, 2005** To ease the private-own power producers to set up renewable energy plants **Blueprint of National Energy Implementation Program 2005–2025** • To outline plans for energy supply security • To provide guidelines for various sectors involving renewable and non-renewable energies • To provide subsidies to enhance energy efficiency **Presidential Regulation No. 5 on National Energy Policy, 2006** • To set goals to promote diversification of energy sources • To reduce energy consumption by 1% per year as target **Presidential Decree No. 1 on Supply and Use of Biofuels, 2006** Setting targets and guidelines for biofuels utilisation and development **Ministerial Regulation No. 2 on Medium Scale Power Generation from Renewable Energy Sources, 2006** To set pricing guidelines for projects ranging from 1 to 10 MW **Energy Law, 2007** Providing renewable energy developers with investment incentives **Electricity Law, 2010** To encourage private companies to participate in energy supply To provide priority in the utilisation of renewable energy To promote small scaled distributed power generation from renewable sources **Ministerial Regulation No. 4/2012, 2012** To set the Feed-in-Tariff for electricity generated from biomass **Ministerial Regulation No. 27/2014, 2014** • To set goals to increase the renewable energy portion to 23% by the year 2025, and 31% by 2050 • Feed-in-tariffs for renewable energy • To encourage the government and private sectors to utilise biofuels for power generation	[6]
Malaysia	**Five-Fuel Diversification Policy, 2001** To include renewable energy in the energy supply mix of power generation **National Biofuel Policy, 2006** • To reduce dependency on fossil fuels • Providing subsidies to promote the demand for alternate sources of energy **National Renewable Energy Policy and Action Plan, 2010** • Increase the renewable energy contribution in the energy supply mix • Promote growth of the renewable energy sector • Maintaining the renewable energy at an affordable price • Instigate awareness to the community on renewable energy	[7]
Thailand	**Committee on Biofuel Development and Promotion (CBDP), 2008** Government subsidies from the State Oil Fund biodiesel price reduction **Second Alternative Energy Development Plan (2008–2022), 2008** • To increase the proportion of alternative energy to 20% of the national total energy consumption by 2022 • To utilise renewable energy as a substitute for imported oil • To increase energy security of Thailand • Promote integrated green energy utilisation in communities • Enhance the development of alternative energy industry • Research and development of efficient technology to harvest renewable energy	[8]
Vietnam	**Renewable Energy Action Plan, 2001** Government intervention to promote renewable energy **The Law of Electric, 2004** Support electricity generation from renewable sources by providing investment incentives, preferential electricity prices and taxes **Decision 1855/QD-TTg: 27 Dec 2007** • National Energy Development Strategy up to 2020 with outlook to 2050 • To encourage the development of new and renewable energies, bioenergy to meet the socioeconomic requirements • To meet the target of 5% of primary commercial energy by 2020 and 11% by 2050 **Decision No. 177/QD-TTg:20 Nov 2007** • To develop biofuel, as an alternative for fossil fuels • To build a legal framework for biofuel development • To develop materials for biofuel production • To enhance biofuel extraction **National Program for Biofuels Development, 2011** • Develop biofuel to partly replace fossil fuels • Create the legal framework for biofuel development • Develop relevant materials for biofuel production • Develop biofuel extraction technologies	[9]

(*Continued*)

Country	Policies/strategies	Ref.
Myanmar	**Myanmar Energy Master Plan, 2015** • To study the energy demand development from 2014 to 2035 • To set a goal to achieve 15%–20% share of renewable energy in 2020 • To improve the rural renewable energy usage • To achieve 57% hydropower, 5% solar and wind by 2030	[10]
Laos	**The Electric Law, 1997** Setting standards for the administration, production, distribution, transmission and the import and export of electricity **The Power Sector Policy Statement, 2001** • To increase the electricity supply rate to 90% by 2020 • Promotes the public and private partnerships in hydropower development (500 kV grid) **The 8th National Socio-economic Development Plan (NSEDP), 2016–2020** Promotes sustainability and diversification of renewable energy sources **The Renewable Energy Development Strategy** To increase the renewable energy share to 30% and substitute 10% of the transport fuel with biofuels by 2025	[11]
Philippines	**R. A. No. 9367: The Biofuels Act, 2006** Encourage the utilisation of biofuel-blended transport fuels by providing fiscal incentives **R. A. No. 9513: The Renewable Energy Act, 2008** • Enhance the renewable energy development by providing fiscal and non-fiscal incentives • To reduce the country's reliance of fossil fuels • Adopts renewable portfolio standards, feed-in-tariffs, net-metering, and Green Energy Option policy instruments	[12]

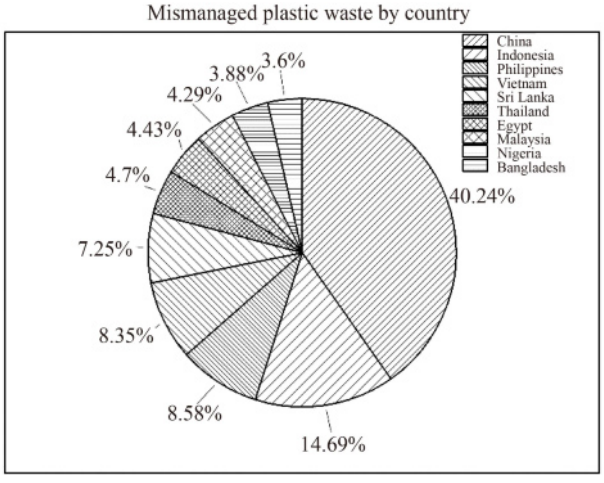

Fig. 1 Mismanaged plastic waste generated by countries. Reprinted with permission from Ref. [24], copyright 2015, American Association for the Advancement of Science.

shown in Fig. 1. In Indonesia, the production volume reached 45.86 million tonnes in 2019 [13]. Meanwhile, Malaysia produced 18.5 million tonnes in the same year [14]. However, the palm oil produced only represents 10% by weight of the total harvest; and the remainder contributed to the oil palm biomass, i.e., oil palm empty fruit bunch (EFB), palm kernel shell (PKS), palm pressed fibres (PPF), and oil palm frond [15]. To accommodate the rising population, food demand such as rice and wheat production in India has grown dramatically. In 1960, rice and wheat production was 34.6 and 11 million tonnes, respectively, and had risen to 118.9 and 107.6 million tonnes respectively in 2019 [16]. The rapid generation of biomass poses sustainability issues and waste management complications. Fortunately, this agriculture biomass is made up of lignocellulosic constituents, which include cellulose (23.3–44.9 wt %), hemicellulose (17.3–34.0 wt %), and lignin (12–53.5 wt %) [17]. Cellulose is a complex polymer of glucose held by β-1,4-glycosidic bonds, intramolecular and intermolecular H-bonds. Hemicellulose is a heterogeneous polysaccharide, consisting of hexoses (i.e., glucose, mannose, galactose, xylose, arabinopyranose, arabinofuranose, and glucuronic acid). Lignin is made up of guaiacyl propane, syringyl propane and *p*-hydrophenyl propane [17,18]. These constituents serve as the basic precursors for the conversion into fuel, fibres, and aromatics [19]. Other properties from the proximate and ultimate analysis are depicted in Table 2, which shows that the biomass contains 50 to 70 wt % of volatile matter. In comparison, the carbon and hydrogen contents are 36–53 and 5.0–7.3 wt %, respectively.

Besides that, plastic or polymer waste generation has increased over the years. According to Geyer et al. [23], the study reports that cumulative plastic waste generation of primary and secondary plastic has reached 6300 million tonnes from 1980 to 2015. Only 12% of these plastic wastes were incinerated, while 9% were recycled. Furthermore, according to Jambeck et al. [24], ASEAN member countries such as Indonesia, Philippines, Vietnam, Thailand, and Malaysia contributed approximately 41% of the mismanaged plastic waste as illustrated in Fig. 1. Moreover, according to Abnisa and Alaba [25], the global composition of plastic wastes comprises of 26.67% low density polyethylene (LDPE), 25.33% polypropylene (PP), 18.67% high density polyethylene (HDPE), 14.67% polyethylene terephthalate (PET), 8% polystyrene (PS), and 6.67% polyvinyl chloride (PVC). Furthermore, with the rapid rise of confirmed cases of the novel coronavirus disease (COVID-19), the need for personal protective equipment (PPE) is high, resulting in the rapid generation of COVID-19 related wastes, exacerbating the current plastic waste management issue. According to Liang et al. [26], there are two categories of COVID-19 related wastes which are (1) wastes generated

Table 2 Proximate and ultimate analysis of different agriculture biomasses [20–22]

Sample	PKS	PPF	EFB	Rice husk	Rice straw (RS)	Bagasse
Proximate analysis/(wt %)						
Moisture	5.73	6.56	8.75	4.50	–	–
Ash	2.21	5.33	3.02	12.40	13.60	6.50
Volatile matter	73.74	75.99	79.67	58.60	70.10	72.70
Fixed carbon	18.37	12.39	8.65	24.40	16.30	20.80
Ultimate analysis/(wt %)						
C	53.78	50.27	48.79	43.20	37.10	36.30
H	7.20	7.07	7.33	5.00	5.20	5.80
S	0.51	0.63	0.68	0.00	0.10	0.00
N	0.00	0.42	0.00	0.30	0.50	0.30
O	36.3	36.28	40.18	51.4	43.5	51.10

from within hospitals or healthcare facilities, which are considered medical wastes and are collected and disposed of with appropriate measures (i.e., identification, collection, separation, storage, transportation, treatment, and disposal) [26], and (2) the wastes generated outside those facilities, which include disposable medical face masks (DMFM) and gloves. These wastes do not have proper waste management and are often treated as municipal solid, and plastics wastes. Besides that, according to the World Health Organisation (WHO) [27], the demand for these PPE, i.e., DMFM, and gloves, is expected to rise 20% by the year 2025. If these wastes are not managed properly, it will lead to major environmental complications. In some parts of the ASEAN region (i.e., Cambodia, Philippines, India, and Indonesia), poor waste management issues such as landfills and illegal dumping were present even before COVID-19. These uncontrollable landfills would escalate into space limitations and release toxic pollutants to the environment [28]. Moreover, the random disposal of these wastes could also lead to microplastic pollution, accumulating in the food chain, especially in aquatic life [29].

1.2 Biomass and polymer waste conversion pathways: pyrolysis

Therefore, strategies to recover energy from these wastes are keys to minimize the waste accumulation and their impacts to the environment. To convert these high-energy feedstocks into valuable fuel, there are two main pathways to convert the lignocellulosic biomass and plastic wastes into biofuels or green fuels, i.e., bio-chemical conversion and thermochemical conversion. In bio-chemical conversion, the larger and complex compounds are broken down into simpler molecules, with bacteria and enzymes. However, this method has limited feedstock options, and is not suitable to convert synthetic polymers like plastic wastes [30]. Besides that, thermochemical conversion includes low-temperature carbonisation, intermediate-temperature pyrolysis, and high-temperature gasification. Among these thermochemical processes, pyrolysis represents a promising technology in terms of high fuel-to-feed ratios [31]. In addition, the pyrolysis process is favoured as the process that can be carried out at atmospheric pressure and faster conversion rates (<1 s) [32]. Moreover, the pyrolysis process is compatible with a wide variety of feedstocks aside from lignocellulosic biomass, i.e., plastics, and waste tires [33–36]. The pyrolysis process involves-production of biofuel in the form of bio-oil, as well as producing valuable bio-chemicals such as alcohols, aldehydes, ketones, acids, furans, anhydrosugars, and phenols from biomass [37]. Fast pyrolysis yields the highest amount of bio-oil (65–75 wt %), while slow pyrolysis produces less bio-oil (20–50 wt %), with a larger proportion of bio-gas (20–50 wt %) and biochar (25–35 wt %) [38]. A detailed information on the different pyrolysis modes can be found in these references [38–43].

This paper focuses on the issues of the growing generation of biomass in ASEAN region, as well as the single-use plastics (i.e., DMFM) generated due to the COVID-19 pandemic. Following this, this review outlines the potential of co-pyrolysis of the biomass with plastic wastes as a technique to produce value-added bio-oil. Besides that, this review also looks into the technologies, (i.e., catalyst selection) and technical aspects (i.e., pyrolysis parameters) of the co-pyrolysis process. In addition, the kinetic models, and the advancements to describe the catalytic co-pyrolysis of biomass and plastic wastes are also outlined. Finally, the outlook detailing the significance and the limitations of the co-pyrolysis technique is discussed.

2 Bibliometric analysis

Bibliometric analysis is defined as the analysis of scientific publications using statistical methods to provide an outline of the research area [44]. Several publications have adopted this method in research areas of bio-diesels [45], municipal solid waste management [44], invest-

ments [46], and even COVID-19 [47]. This method of analysis provides a systematic way to sort and analyse a great number of publications, in terms of citations, co-citations, author keywords, and countries.

In this project, the bibliometric analysis of the field of pyrolysis of biomass was conducted in VOSviewer1.6.11. The utilisation of the software has been widely employed in this study, providing a visualisation of the relationships between publications in a research area or topic. The online publication database platform, Scopus, was utilised in the collection of the database for this study. The search phrase and Boolean Operators for this study were "pyrolysis AND biomass AND plastic AND bio-oil OR oil palm OR catalyst", the publication year was limited from 2019 to 2023, and limited to journal articles only. A total of 1448 publications were fitted into VOSviewer to analyse the co-occurrence of author keywords more than 20 times and are visualised in Fig. 2. The top-ranked link strength keywords, excluding the search phrases, include catalytic pyrolysis, co-pyrolysis, biochar, oxygen reduction reaction, and hydrogen. Based on this study, the current research trend involves around catalytic pyrolysis or co-pyrolysis, and focuses on the oxygen reduction, hydrogen and biochar formation from the process. Furthermore, another analysis of the bibliographic coupling of countries was carried out and the results were visualised in Fig. 3. The result suggests that China, United States, South Korea, Malaysia, and Australia are the active countries involved in this research area.

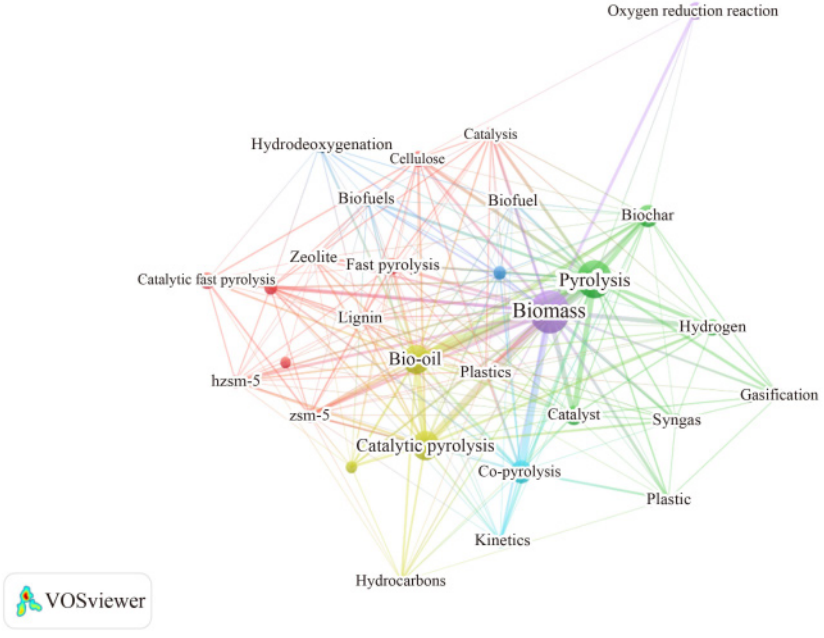

Fig. 2 Co-occurrence of author's keywords > 20 times by publication year.

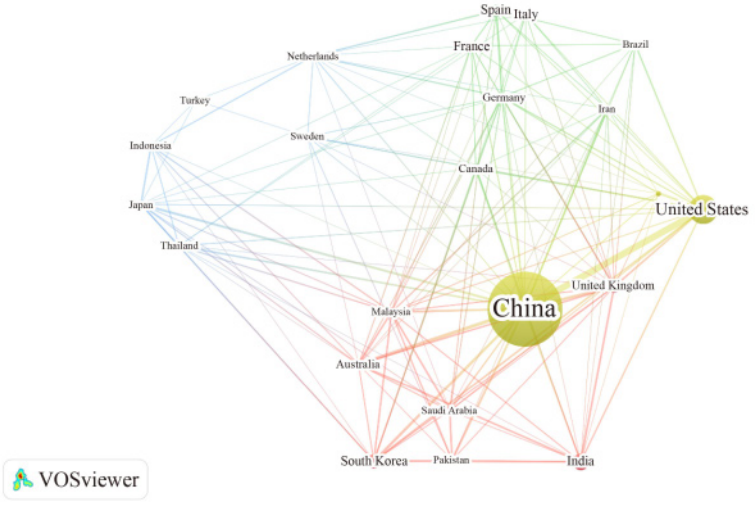

Fig. 3 Bibliographic coupling of countries by year.

3 Pyrolysis technologies/techniques for bio-oil production

Initially, most of the research studies focus on mono-component such as biomass [20,48–54] or plastic waste [55–60] in the pyrolysis process for bio-oil production. However, the pyrolysis of lignocellulosic biomass produces low quality bio-oil and yield [61]. Biomass-derived pyrolysis oil is high in oxygen content, corrosive in nature, and thermally unstable. Bio-oil generally requires upgradation using a hydrogen source and a catalyst, which makes the process complicated and expensive [37]. For plastic pyrolysis, the volatile products contain harmful compounds, i.e., polycyclic aromatic hydrocarbons (PAHs) [62–64]. PAH is a macromolecular aromatic compound with carcinogenic and mutagenic characteristics that pose health concerns upon exposure [65]. Hence, there is a growing interest in improving the pyrolysis process to produce bio-oil with enhanced properties, i.e., co-pyrolysis of two or more feedstock, and the utilisation of catalysts for product upgrading.

3.1 Mechanisms of co-pyrolysis with polymers

Hence, it is crucial to understand the reaction mechanism of co-pyrolysis of biomass and plastic wastes. Several studies have explored the co-pyrolysis of biomass with polymer wastes, i.e., RS and sugarcane bagasse with PP, and PS [34]; corn stover, ipil, and narra, with HDPE, LDPE and PP [35]; RS with waste tires [36]; sawdust with LDPE [66]. These studies show that the co-pyrolysis technique is promising in improving the bio-oil quality and calorific value, reducing energy costs by lowering the activation energy. According to Lin et al. [67], the widely accepted mechanism of co-pyrolysis of biomass with plastics can be summarised in a two-step mechanism: (1) the free radicals generated from the pyrolysis of biomass initiate the β-scission of the polymers, inhibiting the intermolecular and intramolecular H transfer, producing aliphatic hydrocarbons and reduced alkadienes; (2) the H transfers from the polymers reacting with the biomass-derived radicals to form stable compounds. This mechanism allows an increase in the decomposition rate of the biomass, greatly reducing the char yield as reported by Önal et al. [68]. The addition of a hydrogen-rich plastic waste to biomass influenced the energy recovery efficiency of bio-oil by affecting the real-time power output, reaction time, and changes in the bio-oil composition [69]. Besides that, the biomass decomposes first at a lower temperature forming free radicals, i.e., OH radicals. These radicals react with the pyrolysis products of plastic, larger molecular weight organics (C_{12}) were formed with the co-pyrolysis of biomass and LDPE [70]. According to Navarro et al. [34], this mechanism reduces the selectivity for the secondary reaction to occur, reducing the char yield (i.e., 8.6 and 10 wt % reduction of char with the co-pyrolysis of B and PS, B and PP, respectively). Besides that, according to a study by Ojha et al. [71], the formation of C_8–C_{20} alcohols was observed, which was explained by the reaction of hydrocarbon free radicals from PP, with water from the dehydration reaction from cellulose. According to Uzoejinwa et al. [72], synthetic polymers are derived from petroleum products with high carbon and hydrogen contents, low oxygen content, and contains high calorific values. Hence, making it suitable potential as a co-feedstock for the biomass pyrolysis. Furthermore, these polymer wastes also showed similar properties of high volatile matter, higher heating value (HHV) and lower heating value (LHV) than biomass, as observed in Table 3.

3.2 Pyrolysis reaction parameters that influence the bio-oil yield

During pyrolysis, multiple factors affect the outcome of the process, which are, reactor temperature, heating rate, feedstock particle size, and residence time. Studies on these parameters are crucial to improve the pyrolysis process in terms of bio-oil product yield and quality. Generally, the operating parameters are adjusted, to impede the secondary tar cracking reactions, which reduces the bio-oil yield.

3.2.1 Pyrolysis temperature

The role of temperature is to provide sufficient thermal energy for the decomposition of the biomass. It is important to note that for the main constituents of biomass, cellulose, hemicellulose, and lignin, their temperature degradation ranges are 225–325, 325–375, and 250–500 °C, respectively. Hence, an optimal temperature of 500 °C is sufficient to encompass these temperature ranges. Nevertheless, the optimal temperature differs with the compositions of varying feedstock [74]. Furthermore, according to Dai et al. [75], bio-oil yield peaks at the

Table 3 Proximate and ultimate analysis of polymers [22,34,60,73]

Sample	PP	PS	LDPE	HDPE	Waste tires
Proximate analysis/(wt %)					
Moisture	0.20	–	–	0.00	1.10
Ash	0.10	0.00	–	0.00	8.10
Volatile matter	99.80	99.50	99.98	100.00	62.50
Fixed carbon	0.00	0.50	0.02	0.00	28.20
Ultimate analysis/(wt %)					
C	85.40	89.50	85.47	85.34	84.60
H	14.50	8.50	14.21	12.22	7.70
S	0.00	0.00	0.11	0.00	1.40
N	0.00	0.00	0.08	0.00	0.40
O	0.00	2.00	0.13	2.44	4.30
HHV/(MJ·kg^{-1})	46.00	40.10	–	46.40	36.80
LHV/(MJ·kg^{-1})	43.10	–	–	43.10	35.10

temperature range of 450–550 °C; a further increase of temperature (> 600 °C), the bio-oil yield reduces, corresponding to an increase in non-condensable gas, or biogas. Moreover, a higher temperature (530–830 °C) promotes the reduction of complex compounds (i.e., acetaldehyde, methanol, propanol, and acetone), while increasing stable compounds (benzene, naphthalene, cresols, and phenols). For the case of polymer wastes, the degradation temperature ranges generally overlap or are higher than biomass, which varies between types of polymers. According to Miandad et al. [33], PP showed a single-stage degradation, which starts at a lower temperature of 240 °C with the maximum degradation at 425 °C, PS also showed a single-stage degradation but starts at a higher temperature of 330 °C, with the maximum degradation at 470 °C. While polyethylene (PE) exhibits a two-stage degradation, the first stage starts at the temperature of 270 °C and reaches 400 °C with a conversion rate of 12%, which followed by the second stage degradation starting at 400 °C, with the maximum conversion rate of 95% at 480 °C. Hence, these differences in thermal decomposition behaviours must be considered for the co-pyrolysis of biomass and polymers. According to Salvilla et al. [35], the study studied the effect of co-pyrolysis of corn stover with different polymers, i.e., LDPE, PP, and HDPE. Thermogravimetry analysis (TGA) experiments of the biomass-plastic blends result in a two-stage decomposition. The first stage involves the degradation of hemicellulose, and cellulose of the corn stover, while the second stage degradation overlaps with the decomposition of lignin. The results from this study conclude that the biomass and plastic blends exhibit the most synergistic effect occurs at temperature near 500 °C, i.e., corn stover and PP blend (5:3), and corn stover and LDPE blend (5:3) observed the greatest decomposition rate between 8% and 10% per minute respectively between the temperature ranges of 480–505 °C.

3.2.2 Heating rate

The heating rate is another important parameter that could determine the product distribution of the biofuels. According to Akhtar and Saidina Amin [31], fast heating rates cause rapid fragmentations of biomass and produces more bio-oil yield. This is possible as at higher heating rates (1000 °C·min^{-1}), there is short amount of time for the secondary reactions (i.e., tar cracking and repolymerisation). However, once the heat and mass transfer limitations have been overcome, higher heating rates would not increase the bio-oil yield further. Besides that, heating rates also affect the quality of the bio-oil, at lower heating rates, the water content of the bio-oil increases, as it impedes the dehydration reaction. It is also observed that at low heating rates (< 15 °C·min^{-1}) the bio-oil components have a higher weight range of 500–1000 Da, while increasing the heating rate to 15 °C·min^{-1}, it significantly reduces the weight to 200–500 Da. However, continuing to increase the heating rate does not reduce the weight further [75]. In the case of polymer waste, the study found that LDPE, PP, and PVC, the thermogravimetry or derivative thermogravimetry curves shifted to the higher temperatures when the heating rate was increased. This phenomenon was explained by the thermal lag, due to the increased thermal gradient between the furnace temperature and the sample. Hence, the lower 100 °C·min^{-1} heating rate favoured the degradation of the plastic wastes [60].

3.2.3 Particle size

To reduce heat transfer limitations caused by the poor heat conductivity of biomass, feedstock particle size or shape is another important criterion for bio-oil production. Larger particles (> 0.5 mm) tend to have poor heat transfer to the inner surfaces of the feedstock particle, this will lead to a lower yield of volatiles associated with the great temperature differences between the inner and outer surfaces of the feedstock particle. However, it is documented further increase in particle size (> 1 mm) does not have any effect on the bio-oil yield, which indicates minor impact of the internal heat or mass transfer to the process [76]. It was also reported that larger particle size, results in lower heat transfer to the feedstock [31,75]. For the pyrolysis of bamboo biomass with particle size, 0.45–0.75 mm, the bio-oil peaked at 54.03 wt %, while for smaller particle size 0.25–0.45 mm lowers the bio-oil yield to 50.85 wt % but increases biogas yield from 18.42 to 23.46 wt % [77]. Larger particle size of 0.8–1.2 mm, on the other hand, also lowered bio-oil yield of 51.61 wt %, with increased biogas and biochar yield of 20.62 and 27.74 wt %, respectively.

3.2.4 Residence time

Likewise, since the pyrolysis vapour is susceptible to secondary reactions, it is important to note that, the vapour residence time must be kept short to maximise the bio-oil yield. However, at very short residence times, the heat transfer limitations may restrict the feedstock from undergoing complete fragmentation [32,74,75]. Hence, the parameter is restricted by the characteristic of the feedstock itself. Instead, optimisation of the vapour residence time is a more feasible direction, i.e., feedstock particle size, heating rate, and design of the reactor and heater configuration to maximise the heat transfer [31].

3.3 The role of catalysts in the pyrolysis process

Catalysts play an important role in enhancing the quality of the bio-oil. This section categorised the existing catalysts employed in the pyrolysis process into three

main groups, commercial zeolite catalysts, metal-based catalysts, and renewable waste catalysts.

3.3.1 Commercial zeolite or acid catalyst

The commercial zeolite catalysts, i.e., ZSM-5, HZSM-5, MCM-41, zeolite Y, SBA-15, and zeolite BEA are the commonly utilised catalysts for the pyrolysis of biomass [78]. These catalysts have the active sites of the catalysts and reduce the dissociation energy of C–O, C=O, and –OH functional group, which allow the ability to remove oxygen atoms from the bio-oil via dehydration, decarboxylation, decarbonylation reactions [42,79]. Besides that, according to Ratnasari et al. [80], the key attributes of the zeolite as a suitable catalyst are the micropores (0.4–1.0 nm) or mesopores (1.5–30 nm) sizes. In a study on MCM-41, a zeolite catalyst with a mesoporous structure; the bigger pores allow hydrocarbons with higher molecular weight to enter the active sites, produce less oxygenates, and yield less aromatics. While smaller pore sized zeolites, such as ZSM-5 and Y-zeolite favour the production of aromatics. However, due to its smaller pore size, it is more likely to cause coking on the surface of these zeolites, thereby deactivating them. Therefore, studies have incorporated hierarchical catalyst structure to maximise the conversion performance [78,81]. Besides that, the acidity of the zeolites refers to the Si/Al ratio of the zeolite, it is a direct representation of the Brønsted acid (–OH group) and Lewis acid (Al sources in the Al_2O_3/SiO_2) sites available [74]. Comparing with zeolites, the silicalite catalyst with the same pore size but without acidity produces less aromatics and increases char formation [32]. Besides that, a study on the catalytic co-pyrolysis of RS and B with plastic wastes concluded that HZSM-5 promoted the deoxygenation, cleavage of the aromatic rings, reforming, isomerisation and Diels−Alder reaction of the bio-oil [22]. Hence, product upgradation was achieved, and thereby producing valuable compounds, such as aromatics (i.e., styrene, ethylbenzene, *o*-xylene, and trimethyl-benzene) and aliphatic hydrocarbons (i.e., 2,4-dimethyl heptane). Zhao et al. [82] found that, with the bamboo to PP ratio of 1:2 over HZSM-5, high bio-oil yield of 61.62 wt % can be achieved, which is higher compared to that obtained for single feedstock bamboo pyrolysis of 29.91 wt %. Besides that, the aromatic and naphthenic hydrocarbons in the bio-oil were improved, which was in agreement with the study by Suriapparao et al. [22], where with the addition of a catalyst, the biomass−plastic mixture has a lower selectivity for oxygenates, while an increase in aliphatic and aromatic hydrocarbons were observed. The findings summarising the commercial acid catalysts utilised in literature can be found in Table 4.

3.3.2 Commercial metal-based catalyst/support

The metal-based catalysts in the catalytic pyrolysis of biomass majority refers to the metal oxides, alkali earth metals, metal salts, and transition metals. Metal oxides are prominent catalysts in this case, i.e., the basic MgO, CaO, and the acidic ZnO in the study of the pyrolysis of RS. The catalytic behaviour of MgO is similar to ZSM-5, as it favours the ketonization and aldol condensation reactions, which help to reduce oxygenates from the bio-oil [75]. According to Cao et al. [83], MgO has high ionic properties, which inhibits the repolymerisation reaction, hence greatly reduces the biochar formation while increasing the bio-oil yield. Furthermore, CaO was determined to have unique properties, as it behaves differently at different mass ratio incorporated in the feedstock, at less than 0.2 mass ratios; the CaO is a reactant, that reacts with the carboxyl groups to produce ketones. Carboxyl groups are undesirable bio-oil products due to their acidity, i.e., acetic acid. At 0.2 to 0.4 mass

Table 4 Acid zeolite catalyst application in the pyrolysis process examples

Biomass	Catalyst	Bio-oil yield/(wt %)	Reactor	Scale, feed weight/g	Ref.
RS	HZSM-5	21.50	Microwave pyrolysis	200–800	[22]
Bagasse		22.40			
PP		74.20			
PS		92.30			
Baggase: PS		43.80			
B:PP		35.70			
RS:PS		31.20			
RS:PP		24.50			
RS	ZSM-5	47.40	Fixed bed reactor	10	[83]
	Y zeolite	55.20			
	Mordenite	49.10			
	SBA-15	37.30			
Rice husk and WGPF	HZSM-5/MCM41	67.90% hydrocarbon relative content	Tubular reactor	0.001	[81]
	HZSM5	60.20% hydrocarbon relative content			
Seaweed biomass	ZSM-5	51.48	Hydro-pyrolysis	10	[32]
	MCM-41	41.84			
Bamboo	HZSM-5	49.14	Bubbling fluidised bed	100 $g \cdot h^{-1}$	[77]

ratio, CaO exhibits absorbent properties, absorbing CO_2 to $CaCO_3$, which contributes to the mass increase in the char yield. A further increase of CaO (> 0.4 mass ratio), the catalytic effect dominates, reducing the ester content in the bio-oil into simpler hydrocarbons and H_2 [84]. Besides that, while ZnO has less deoxygenation properties compared to CaO and MgO, it does not increase biochar yield [32,75,85]. On the other hand, studies have also found that metal salts have effectively improved the bio-oil yield. In a study of metal salt catalysts, $MgCl_2$ produced the maximum bio-oil yield of 48.4 wt % [83], comparing to the transition metal salt $FeCl_3$, which has a lower bio-oil yield of 32.2 wt %. According to the study, the ionic behaviour of the alkali earth metal salt, $MgCl_2$ minimises the repolymerisation reaction compared to the partial covalent transition metal salts. In recent studies of the plastic pyrolysis process, the metal catalysts such as carbon-supported platinum (Pt/C), and palladium (Pd/C) were studied in the pyrolysis of PET plastic. The study aims to reduce the polycyclic compounds and biphenyls which are harmful compounds to the environment and public health. The study concludes that Pt/C aided in the reduction of polyclyclic compounds such as 2-napthalenecarboxylic acid by 102% at 800 °C, and reduction of biphenyls such as biphenyl-4-carboxylic acid by 27% at 700 °C [86]. Furthermore, metal oxides have been employed to study the co-pyrolysis process of PP with poplar wood (i.e., ZnO, CaO, MgO, and Fe_2O_3). The researchers found that CaO has the best deoxygenation results, removing carboxylic acids and phenols from the final products. It also increases cyclopentanones and alkenes compositions, but has reduced total volatile compounds, due to its strong basicity to cause coking on the catalyst surface. ZnO has the highest alkene yield, and increased ketone and phenols yields, and reduced carboxylic acid but has the weakest deoxygenation activities among all four catalysts. MgO behaves similarly to CaO, but has weaker deoxygenation properties, as it is less basic than CaO. Moreover, in the presence of the Fe_2O_3 catalyst, formation of aromatics such as *p*-xylene and 2-methyl-1-butenylbenzene were formed [87]. Following this, the studies of metal-based catalysts are summarised in Table 5, CaO is widely utilised in many studies due to its abundance and low cost, which can be found in renewable sources such as limestone and eggshells [88], and the niche in the utilisation of metal catalysts in the co-pyrolysis process.

3.3.3 Renewable waste catalyst

Renewable waste catalysts received much attention as an economic and sustainable alternative to commercial catalysts, i.e., red mud, ash catalysts, activated carbon, biochar derived catalyst, and palm oil sludge [90–94]. Red mud has attained much research interest as it has the potential to replace commercial catalyst. It is an alkaline

Table 5 Metal based catalyst application in the pyrolysis process examples

Biomass	Catalyst	Category	Bio-oil yield/(wt %)	Reactor	Scale, feed weight/g	Ref.
EFBF	CaO	Basic metal oxide	39.90 (5 wt % CaO); 40.40 (10 wt % CaO)	Fixed bed reactor	15	[85]
	MgO	Basic metal oxide	39.30 (5 wt % MgO); 42.30 (10 wt % MgO)			
	ZnO	Acidic metal oxide	44.70 (5 wt % ZnO); 42.20 (10 wt % ZnO)			
Cotton stalk	CaO	Basic metal oxide	50.00	Fixed bed reactor	–	[84]
RS	$MgCl_2$	Metal salt oxide	48.40	Fixed bed reactor	10	[83]
	$FeCl_3$	Metal salt	32.20			
	$CuCl_2$	Metal salt	41.50			
	$MnCl_2$	Metal salt	45.30			
	CaO	Basic metal oxide	38.70			
	$CaCO_3$	Basic metal oxide	30.50			
	MgO	Basic metal oxide	52.10			
	$MgCO_3$	Basic metal oxide	42.40			
	CeO_2	Acidic metal oxide	52.30			
	ZnO	Acidic metal oxide	46.20			
	ZrO_2	Acidic metal oxide	48.30			
	TiO_2	Acidic metal oxide	48.20			
EFB	CaO	Basic metal oxide	58.49	Fixed bed reactor	50	[89]
PET	Pt	Metal catalyst	–	Tube furnace	1	[86]
	Pd					
PP-poplar wood composite	ZnO	Acidic metal oxide	–	Pyrolysis-gas chromatography/mass spectrometry	0.5 mg	[87]
	CaO	Basic metal oxide				
	Fe_2O_3	Acidic metal oxide				
	MgO	Basic metal oxide				

solid by-product from the Bayer process in alumina production. According to Ly et al. [77], the components within the red mud include a great amount of metal oxides, i.e., MgO, CaO, SiO_2, Fe_2O_3, Al_2O_3, and TiO_2. From the study, red mud has a comparable bio-oil yield than HZSM-5 at temperature of 475 °C and residence time of 1.8 s. Upon characterisation of the bio-oil produced from red mud, the catalyst promoted the depolymerisation of cellulose and hemicellulose to produce furan derivatives. Besides that, the formation of saturated phenols in the bio-oil indicates red mud favours the demethylation and demethoxylation reactions. Furthermore, researchers have also studied the catalytic effect of the pyrolysis biochar. According to Dong et al. [95], the experiment on the catalytic pyrolysis of bamboo waste with different ratios of biochar, concluded that, the bio-oil had been upgraded; simpler C_2–C_6 compounds have been greatly increased with reduction in the heavy C_7–C_{11} compounds. Moreover, Chen et al. [96] proposed upgrading the biochar from the pyrolysis process such as N-doped biochar, found high yields of bio-oil (61.0–63.0 wt %) were obtainable. A study on the Fe incorporated activated carbon reduces the bio-oil yield to achieve increased phenols 60.85–86.98 wt % of the bio-oil [97]. For the pyrolysis of plastic wastes, most research utilises the low-cost fly ash and naturally occurring kaolin as renewable catalyst sources [98–100]. Furthermore, in the case of co-pyrolysis, renewable waste catalysts such as Ni-doped biochar from waste pine sawdust, and activated carbon made from coconut husks were utilized [101,102]. The summary of renewable waste catalysts is depicted in Table 6, shows that renewable waste in the literature has much lower bio-oil yields or has a higher selectivity to syngas production than commercial catalysts.

4 Kinetic analysis

Kinetic analysis is an important aspect in describing the chemical kinetics of the pyrolysis process in the form of mathematical models. Traditionally modelling the chemical kinetics of biomass pyrolysis considers cellulose, hemicellulose, and lignin, based on the TGA experimental data. These kinetic models include the iso-conversional models, the Vyazovkin method, distributed activation energy model (DAEM), and the utilisation of predictive tools, i.e., artificial neural network (ANN).

4.1 Iso-conversional models

Iso-conversional method is the simplest form of kinetic model to explain the conversion of biomass to volatiles and biochar as a one-step first-order reaction. Examples of the iso-conversional method include the Kissinger–Akahira–Sunose (KAS), Flynn–Wall–Ozawa (FWO), and Starink's method, which are integral methods ($g(a)$). In contrast, the Friedman method is an example of a differential method ($f(a)$) [104]. In this paper, Friedman and Starink's methods are chosen to demonstrate the difference between the differential and integral versions of the iso-conversional method.

4.1.1 Friedman method

Friedman method is based on the differential method as the following expression in Eq. (1). This method requires the information on the conversion rate $\frac{d\alpha}{dt}$, and T. The kinetic plots between $\ln\left(\frac{d\alpha}{dt}\right)$ and $\frac{1}{T}$ produce the slope of

Table 6 Renewable waste catalyst for pyrolysis process examples

Biomass	Catalyst	Bio-oil yield/wt %	Reactor	Scale, feed weight/g	Ref.
Bamboo	Biochar	20.20 (5 wt % biochar) 18.70 (10 wt % biochar) 16.34 (20 wt % biochar)	Microwave pyrolysis	50	[95]
Bamboo	N-doped biochar	61.00 (10 wt % biochar) 63.00 (30 wt % biochar) 62.00 (50 wt % biochar)	Fixed bed reactor	3	[96]
PKS	Fe/activated carbon	7.96	Microwave pyrolysis	10	[97]
Rice husk	Rice hull ash	–	Fixed bed reactor	0.0055	[92]
Rice husk	Coal bottom ash	–	Fixed bed reactor	0.0055	[93]
PKS	Red mud	37.37–39.95	Fixed bed reactor	2	[103]
Bamboo	Red mud	50.34	Bubbling fluidised bed	100 $g \cdot h^{-1}$	[77]
EFB	Palm oil sludge	–	Fixed bed reactor	15	[90]
LDPE	Calcinated fly ash (900 °C) Calcinated fly ash (800 °C) Natural fly ash	76.22–80.02 70.96–71.36 68.20–71.70	Semi batch reactor	50	[98]
HDPE (plastic tub pieces)	Fly ash (10 wt %)	50.84	Lab scale pyrolyzer unit	1 kg	[100]
LDPE	Kaolin (1350 mesh)	64.66% aliphatics, 93.91% hydrocarbons, 30.07% H_2	Quartz furnace tube	100	[99]
Pine sawdust and PE (50 wt %)	Ni-pine sawdust biochar	70.40 wt % (gas yield)	Fixed bed reactor	1	[101]
Corn stalk-HDPE mixture	Activated carbon	–	Tubular reactor	2	[102]

$\frac{E}{R \cdot T}$ and the intercept of $\ln[Af(\alpha)^n]$. The benefit of this model is that it makes no approximations, and can be adopted in any temperature settings [105],

$$\ln\left(\frac{\mathrm{d}\alpha}{\mathrm{d}t}\right) = \ln[Af(\alpha)^n] - \frac{E}{R \cdot T}, \quad (1)$$

where $f(\alpha)$, T, A, R, E are the differential form of the kinetic dependence function, absolute temperature (K), exponential factor (s^{-1}), universal gas constant (8.314 $J \cdot mol^{-1} \cdot K^{-1}$), activation energy ($kJ \cdot mol^{-1}$).

4.1.2 Starink's method

Starink's method is an extension of the Coats–Redfern equation (Eq. (2)), which is similar to the FWO method, an integral method for estimating kinetic parameters [105]. Since $2RT/E \leq 1$, and has minimal variation with T, results in Eq. (3),

$$\ln\left(\frac{\beta \cdot g(\alpha)}{T^2}\right) = \ln\left[\frac{A \cdot R}{E}\left(1 - \frac{2R \cdot T}{E}\right)\right] - \frac{E}{R \cdot T}, \quad (2)$$

$$\ln\left(\frac{\beta \cdot g(\alpha)}{T^2}\right) \cong \ln\left(\frac{A \cdot R}{E}\right) - \frac{E}{R \cdot T}, \quad (3)$$

where β, $g(\alpha)$ are the heating rate ($°C \cdot min^{-1}$), and the integral form of the kinetic dependence function. The generalised form Eq. (4) is

$$\ln\left(\frac{\beta \cdot g(\alpha)}{T^m}\right) = B - C\left(\frac{E}{R \cdot T}\right). \quad (4)$$

Starink's equation utilises the constants, where m = 1.92, B = $\ln(AR/E)$ + 3.7545411 – 1.92ln E, and C = 1.0008, which can be rewritten as Eq. (5),

$$\ln\left(\frac{\beta}{T^{1.92}}\right) = C_s - 1.0008\left(\frac{E}{R \cdot T}\right), \quad (5)$$

where C_s is the constant. This method is a simple direct method to obtain the expression E/R from the slopes by plotting $\ln\left(\frac{\beta}{T^{1.92}}\right)$ vs. $1/T$. Starink's method is widely employed as a comparison against other iso-conversional methods [48,106]. However, these methods are flawed, as proposed, with an addition of a secondary feedstock and the utilisation of a catalyst, the reaction mechanisms become much more complex [107]. Hence, a modified iso-conversional method is introduced, the Vyazovkin method.

4.2 Vyazovkin method

The iso-conversional methods assume a reaction ideally has a constant value of E_α. This assumption is the main source of errors, which explains the differences obtained from different iso-conversional methods [105]. Hence, to overcome these drawbacks, an advanced alternative non-linear iso-conversional Vyazovkin method is proposed. This method assumes the reaction is independent of the heating rate, and accounts for the variation of E in the computation of the temperature integral, $I(E_\alpha, T_\alpha)$ from Eq. (6). The E_α, which is the effective activation energy ($kJ \cdot mol^{-1}$) is obtained from the minimisation of the function $\varnothing(E_\alpha)$ from Eq. (7),

$$I(E_\alpha, T_\alpha) = \int_0^{T_\alpha}\left(-\frac{E_\alpha}{R \cdot T}\right)\mathrm{d}T = \frac{E_\alpha}{R}p(x), \quad (6)$$

$$\varnothing(E_\alpha) = \sum_i^n \sum_{j=i}^n \left(\frac{I(E_\alpha, T_{\alpha,i})}{I(E_\alpha, T_{\alpha,j})} \cdot \frac{\beta_j}{\beta_i}\right), \quad (7)$$

where n, E_α, T_α are the number of heating rates in the experiment, activation energy and temperature for each α, while i and j represent the heating rates corresponding to n. For $p(x)$, it is the approximation equation obtained from using Yang equation, Eq. (8):

$$p(x) = \frac{\exp(-x)}{x} \cdot \frac{x^3 + 18x^2 + 88x + 96}{x^4 + 20x^3 + 120x^2 + 240x + 120}, \quad (8)$$

where x is the simplified expression of E/RT. Hence, due to its complex structure, this model requires a numerical approach to solve for the kinetic parameters. Recent studies have started adopting this method to compute the kinetic parameters [48,54].

4.3 Distributed activation energy model

In a complex process such as co-pyrolysis, the E_α would not be constant. Instead, it varies as an indication of a much more complex reaction in place, which is unable to explain over a single-step kinetic model. The DAEM is an accurate and versatile model to represent complex pyrolysis processes. It is the best mathematical method to show the physical and chemical heterogeneity of biomass during a devolatisation process [34]. According to Hameed et al. [107], DAEM takes into consideration of the decomposition of species over a large number of independent parallel reactions with different activation energies, represented by a continuous distribution function (i.e., Gaussian distribution, $f(E)$), Eq. (9):

$$f(E) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{E - E_M}{\sigma}\right)^2\right], \quad (9)$$

where σ, E_M are the standard deviation and the mean activation energy, respectively. Furthermore, studies have simplified the DAEM based on the assumption that the solid feedstock is a complex mixture of compounds. During the pyrolysis process, a great number of independent consecutive or simultaneous, irreversible reactions take place, each characterised by its corresponding activation energies and pre-exponential factor, given by Eq. (10):

$$1 - \alpha = \int_0^\infty \exp\left(-A\int_0^t \exp\left(\frac{E}{RT}\right)\mathrm{d}t\right) \cdot f(E)\,\mathrm{d}E = \varnothing, \quad (10)$$

where, according to Cano–Pleite et al. [108], $\varnothing$ = 0.58,

which can be simplified as Eq. (11):

$$\ln\left(\frac{\beta}{T}\right)=\ln\left(\frac{A\cdot R}{E}\right)+0.675-\frac{E}{R}\cdot\frac{1}{T}. \tag{11}$$

However, this model is restricted to a constant heating rate. In the applications of DAEM, it has been utilised to estimate the behaviour of different combinations of lignocellulosic biomass (pine wood) and polymer wastes (i.e., waste tyre, polylactic acid, PS, PET, PP, and HDPE) [34]. Besides that, this method has been incorporated into an ANN model to predict the pyrolytic properties of *Staghorn sumac* [106].

4.4 Optimisation methods

Optimisation methods or often referred to as heuristic models, such as genetic algorithm (GA), and particle swarm optimisation (PSO), shuffled complex evolution (SCE) are algorithms that could solve global optimization problems, i.e., for the pyrolysis process, the optimisation of the kinetic parameters to find the best fit using the data from the TGA. These optimisation methods generally solve problems by subjecting it to an objective function to determine the fitness of the iterations [109]. The objective functions or optimisation targets for a thermal degradation problem are the mass loss $\varnothing_{\mathrm{m}}$ and the mass loss rate $\varnothing_{\mathrm{mlr}}$ in Eqs. (12)–(14) as follows:

$$\varnothing=\varnothing_{\mathrm{m}}+\varnothing_{\mathrm{mlr}}, \tag{12}$$

$$\varnothing_{\mathrm{m}}=\sum_{j=1}^{N}\left[W_{CML,j}\frac{\sum_{k=1}^{n}\left(CML_{\mathrm{mod},k}-CML_{\mathrm{exp},k}\right)^2}{\sum_{k=1}^{n}\left(CML_{\mathrm{exp},k}-\frac{1}{n}\sum_{p=1}^{n}CML_{\mathrm{exp},p}\right)^2}\right], \tag{13}$$

$$\varnothing_{\mathrm{mlr}}=\sum_{j=1}^{N}\left[W_{MLR,j}\frac{\sum_{k=1}^{n}\left(MLR_{\mathrm{mod},k}-MLR_{\mathrm{exp},k}\right)^2}{\sum_{k=1}^{n}\left(MLR_{\mathrm{exp},k}-\frac{1}{n}\sum_{p=1}^{n}MLR_{\mathrm{exp},p}\right)^2}\right], \tag{14}$$

where CML_{mod} and CML_{exp} are the model and experimental cumulative mass loss, respectively; MLR_{mod} and MLR_{exp} are the model and experimental mass loss rate, respectively; N is the number of experiments, n is the number of data points for each experiment; and W_{CML} and W_{MLR} are the weighted value which can be defined as 1.

4.4.1 Genetic algorithm (GA)

The GA is based on an evolutionary concept to find the optimal solution to a complex problem globally. Firstly, the algorithm is initialised by carrying out a range search from a set of randomised candidate solutions referred to as a population. Each candidate solution is defined as an individual or a chromosome, containing the target parameters to be optimised (i.e., for the pyrolysis process, A, E_α and $\varnothing$), where the parameters are defined as genes in the GA [109]. Following the natural survival of the fittest, the population experience evolution forming subsequent generations according to the fitness of the objective function. Besides that, the new generation is produced by the chromosomes crossing over, exchanging information, and allowing mutation, this method helps to prevent the local optimal solution. Finally, by the process of elimination of relatively "unfit" candidate solution and reproducing generations that are "fit". The application of GA in thermal degradation experiments are quite common, it is applied to solve the hybrid pyrolysis scheme of combining both parallel and convective first order reaction. Besides that, recent studies have combined it with different algorithms to improve the performance of the model, according to Aghbashlo et al. [110], the study combines GA with Adaptive Neuro–Fuzzy Interference System (ANFIS) achieving predictions of the kinetic parameters with better fitting compared to traditional ANFIS model; GA-least squares fitting procedure [111], where GA is applied to generate the initial guess for the least square function to solve for the optimal solution. This reduces the number of iterations required for the least square.

4.4.2 Particle swarm optimization (PSO)

The PSO algorithm follows the velocity and position search model. It contains a certain number of particles, their positions, and velocity. The particles in a particular position represent a candidate of solution of space, and the velocity of this particle updates the position of these particles [112]. In addition, these particles have a memory ability which, retains its historical best position vector and its global best position found [109]. Initially, the particles are assigned a random position and velocity in a proposed range. The solution then improves with iterations via Eqs. (15) and (16):

$$v_{id}^{k+1}=\omega v_{id}^{k}+c_1r_1\left(p_{id}-x_{id}^{k}\right)+c_2r_2\left(p_{\mathrm{g}d}-x_{id}^{k}\right), \tag{15}$$

$$x_{id}^{k+1}=x_{id}^{k}+v_{id}^{k+1}, \tag{16}$$

where k is the iteration number, i is the particle number, and d is the search direction from 1 to D, w is the inertia weight, p_{id} and $p_{\mathrm{g}d}$ are the local particle position and the global best position of all particles, respectively. c_1 and c_2 are the two positive acceleration constants for the local and global nature of the swarm. r_1 and r_2 are the stochastic values in the range of [0,1], respectively [113,114].

According to Ding et al. [109], the study compares the performance between PSO and GA, and the results indicate that PSO showed closer global optimum convergence, 0.053 at the population size of 2500 compared to GA, with the best value at 0.075 at the population size of 2000. Besides that, PSO showed less

fluctuation, 0.05 to 0.08 in fitting values regardless of population size, compared to GA, which fluctuates between 0.07 and 0.29. In literature, PSO is often coupled with other algorithms, such as global sensitivity analysis, to find the parameters with the greatest effect on the prediction outcome. According to Ding et al. [112], the sensitivity order is ranked from the largest to the smallest value which are representing the activation energy of lignin, the reaction order of cellulose, and the pre-exponential factor for lignin in the pyrolysis process of pinewood. While for the co-pyrolysis of microalgae *Chlorella vulgaris* and HDPE, the activation energy of cellulose, pre-exponential factor for cellulose and the activation energy of protein, followed by the reaction order of cellulose, showed significant influence on the prediction results, indicating these parameters should be paid much attention for the pyrolysis process [115]. Besides that, Monte Carlo simulations were applied to perform uncertainty analysis, to probabilistically assess the effects of stochastic uncertainties in the predictor values (n = 100000) from the ANN and PSO framework [113]. In addition, a recent study proposed a neuro-evolution algorithm, progressive deep swarm evolution (PDSE), built on the PSO algorithm, to model the catalytic thermal degradation of *Chlorella vulgaris* [88]. From the validation tests, implementing the PDSE algorithm obtained a coefficient of determination (R^2) value above 0.9990, RMSE below 0.0075, and MBE below 0.0026.

4.4.3 Shuffled complex evolution (SCE)

The SCE algorithm introduced by Duan et al. [116] is effective for calibration of hydrological models. The efficacy of this algorithm, a form of differential evolution (DE), comes from its use of geometric operations to find possible optimal solutions to space parameters. The algorithm solves global optimisation problems based on four concepts: (1) probabilistic and deterministic approaches; (2) clustering; (3) systematic evolution of a complex of points spanning the space in the direction of global improvement and (4) competitive evolution. The application of SCE on the woody pyrolysis was studied with six different kinetic models, comprising of single component reactant mechanism, and multicomponent reactant mechanisms (i.e., cellulose, hemicellulose, and lignin) [117]. The optimised kinetic parameters from the results were applied to predict the pyrolysis process with different heating rates, 5 and 80 °C·min^{-1}), where the results were found better fitting of the results of the multicomponent kinetic model, which can reach R^2 values of up to 0.99 [117]. Besides that, SCE has been applied in various pyrolysis kinetic analysis, pyrolysis of beech [118], and pyrolysis of basswood waste [119].

The SCE algorithm starts with generating of a population of random points within the search space, denoted as s. Each of these points contains a vector (i.e., kinetic parameters) and is ranked based on their fitness function value and stored in an array D, and partitioned into p complexes, each containing m points, i.e., $D = \{A^k, k = 1, ..., p\}$. Next, each complex evolved using the competitive complex evolution algorithm, and shuffled. All points are combined to a single population and the procedure of ranking for the function value, partition into complexes, evolution, and shuffling is repeated until convergence value is reached [116,120].

4.5 Predictive models: artificial neural network (ANN)

ANN is an intelligent learning, predictive computational technique, often employed to solve the nonlinear, and complex relationships between the input and output data. An ANN network consists of one or more hidden layers connecting the input (i) and output (o) layers. Each layer has a weight (w) matrix and an output vector [121]. The neuron of each single layer picks up the summation of the activation from the input vectors and their assigned weights and biases, the results then pass through an activation function (i.e., linear, sigmoid, and hyperbolic tangent sigmoid) to generate a new activation value to the neurons in the following layers. The weight matrix is altered to fit the learning algorithms, the learning ends when the weights of each layer achieve convergence as the final output vector (y_o) [122,123]. The ANN parameters influencing the performance are: the number of hidden layers (j), the number of neurons in each hidden layer (n), and the transfer function deployed denoted as f. The general architecture of the ANN is illustrated in Fig. 4.

Generally, the model learning process involves inputting a percentage of sample data to the network, and altering the number of neurons in the hidden layers to optimise the mean square error (MSE) [51]. Besides that, the selection is supervised by a learning algorithm. In literature, this method has been applied in predicting of the kinetic parameters of the pyrolysis process, involving the iso-conversional models, i.e., KAS and FWO shown in Table 7.

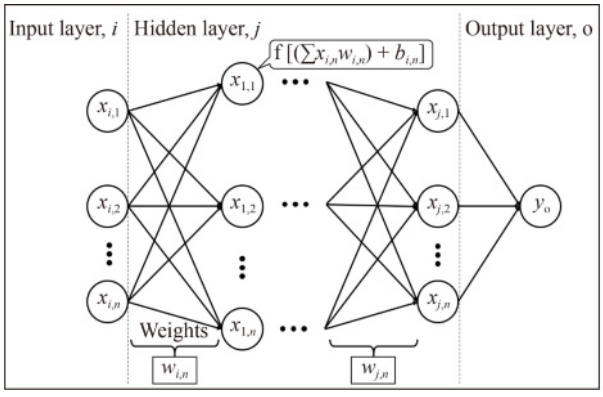

Fig. 4 General ANN architecture.

4.6 Thermodynamics relations

The thermodynamic parameters are important for the scale up and the design of the reactor, i.e., Frequency factor, A (s^{-1}), change in enthalpy, ΔH ($kJ \cdot mol^{-1}$), Gibbs free energy, ΔG ($kJ \cdot mol^{-1}$), and change in entropy, ΔS ($kJ \cdot mol^{-1} \cdot K^{-1}$). The parameters are expressed in the respective equations as Eqs. (17)–(20):

$$A = \frac{\beta \cdot E \cdot \exp\left(\frac{E}{R \cdot T_m}\right)}{R \cdot T_m^2}, \tag{17}$$

$$\Delta H = E_\alpha - R \cdot T, \tag{18}$$

$$\Delta G = E_\alpha + R \cdot T_m \cdot \ln\left(\frac{K_B \cdot T_m}{h \cdot A}\right), \tag{19}$$

$$\Delta S = \frac{\Delta H - \Delta G}{T_m}, \tag{20}$$

where T_m, K_B, h are the maximum temperature where the decomposition occurs (K), Boltzmann constant (1.381×10^{-23} $J \cdot K^{-1}$), and Plank's constant (6.626×10^{-34} $J \cdot s$) [30]. $A < 10^9$ s^{-1} refers to a simpler straightforward reaction, while $A > 10^9$ s^{-1} would mean the reaction follows a complex mechanism [129]. ΔH represents the endothermic or exothermic behaviour of the reaction mechanism; it is the amount of energy transferred during a chemical reaction. According to Gan et al. [130], the smaller the difference of ΔH with the E_α is, the more favourable for the reaction to occur. Hence, the bioenergy from the system is more likely to be attained. Moreover, ΔG is the total potential energy increased in the system, it signifies that the reactants are consumed and activated complexes are formed [21]. The ΔG also represents the suitability of the feedstock for pyrolysis, the higher the ΔG is, the more bioenergy can potentially be attained [30,51]. Furthermore, ΔS is the degree of arrangement of the carbon in the waste and biomass. It is the amount of energy unavailable to work. For higher entropy values, it indicates that the sample has yet to achieve thermodynamic equilibrium, and is highly reactive [131]. Table 8 summarises the kinetic and thermodynamic parameters for different feedstock samples.

5 Future outlooks

Many studies have proven that the combination of feedstock, biomass with waste plastic or biomass with waste tire in co-pyrolysis, with enhancements in the pyrolysis oil through synergistic effects, is an economical way for the production of sustainable fuel as a replacement for fossil fuels. The combination of waste plastics (20 wt %) with biomass generated a higher pyrolytic liquid yield compared to the solely thermal pyrolysis of biomass. This phenomenon shows that the oil produced from co-pyrolysis process can be blended with diesel after minor upgrading or even directly applied in transportation [132]. Nonetheless, not all plastic types can be applied in the process. In this sense, PVC, which consists of about 57% chlorine by weight, is not an ideal feedstock material as it will thermally break down into a very corrosive and toxic hydrochloric acid and influence the diesel quality with the production of chlorinated hydrocarbons. A 0.0145–0.0290 $mg \cdot m^{-3}$ of total chloride level has been recorded in the fuel oil product with just merely adding 1%–3% PVC in the feedstock stream [133,134]. Besides that, Hu et al. [32] stated that more studies are needed for co-pyrolysis especially in establishing a suitable approach in selecting material and the optimum blending ratio of material with biomass [32].

Furthermore, constraints in having straightforward and efficacious characterisation strategies for co-pyrolytic oil also impede the dependence of the industrial community in the technology [135]. Despite the extensive research works on the invention of the co-pyrolysis approach using

Table 7 ANN model compilation from different studies

Biomass/catalyst	Learning algorithm/ topology	Prediction result	ANN parameters	Ref.
Chlorella vulgaris limestone, HZSM-5	PDSE	Thermal degradation	Inputs: heating rate; heat flow; reactor temperature Outputs: remaining mass	[88]
Rice husk, sewage sludge	Levenberg–Marquardt (LM)	Thermal degradation	Inputs: reactor temperature; blend composition Outputs: mass loss	[21]
Chlorella vulgaris, peanut shell, microalgae ash	LM	Thermal degradation	Inputs: heating rate; reactor temperature Outputs: mass loss	[124]
Sewage sludge, peanut shell	LM	Thermal degradation	Inputs: blend compositions; heating rates; reactor temperature Outputs: remaining mass	[122]
Rice husk	Scaled conjugate gradient and LM	Thermal degradation	Inputs: heating rate; reactor temperature Outputs: remaining mass	[125]
Lignocellulosic biomass	Random forest schematic	Biochar yield	Dataset: physicochemical properties of lignocellulosic biomass	[126]
Sewage sludge	LM	HHV of syngas	Dataset: physicochemical properties of biomass	[127]
Mexican sunflower (*Tithonia diversifolia*)	LM	Bio-oil yield	Inputs: heating rate; flow rate; particle size; reactor temperature Output: bio-oil yield	[128]

Table 8 Kinetic and thermodynamic parameters of the pyrolysis process in literature

Feedstock	Catalyst	Kinetic model	E_α/ (kJ·mol^{-1})	A/ min^{-1}	ΔH/ (kJ·mol^{-1})	ΔS/ (J·mol^{-1}·K^{-1})	ΔG/ (kJ·mol^{-1})	Ref.
Pterocarpus indicus	–	Coats-redfern	112.0	–	103.0	–138.0	183.00	[35]
Intsia bijuga	–		99.0	–	89.0	–120.0	160.00	
Corn stover	–		66.0	–	57.0	–173.0	147.00	
HDPE	–		546.0	–	533.0	420.0	226.00	
LDPE	–		487.0	–	475.0	348.0	231.00	
PP	–		423.0	–	411.0	273.0	222.00	
Rice hull	–	DAEM	175.4	2.939×10^{17}	170.2	–	–	[130]
	–	FWO	177.7	7.991×10^{16}	172.6	–	–	
	Limestone	DAEM	123.3	5.803×10^{11}	117.9	–	–	
	Limestone	FWO	132.5	4.148×10^{12}	127.1	–	–	
	Eggshell	DAEM	96.1	2.033×10^{10}	90.8	–	–	
	Eggshell	FWO	100.4	1.948×10^{9}	95.2	–	–	
Sewage sludge (97.5% conversion)	–	KAS	123.6	1.440×10^{6}	119.5	139.4	187.69	[51]
	–	FWO	132.7	1.560×10^{9}	128.6	138.8	196.50	
	–	Friedman	92.4	0.0103	88.3	295.4	232.80	
	–	Popescu	200.9	9.740×10^{10}	196.8	219.3	304..00	
Microalgae:microalgae ash:peanut shell 9:2:9	–	FWO	142.6	2.010×10^{14}	137.0	–	–	[124]
Garlic husk	–	KAS	154.0	–	149.4	–	150.60	[104]
	–	FWO	154.9	–	150.4	–	150.50	
	–	Starink	154.3	–	149.8	–	150.50	
Staghorn sumac	–	FWO	167.9	–	178.9	–	–	[106]
	–	KAS	169.4	–	167.2	–	–	
	–	Starink	169.8	–	167.6	–	–	
Azadirachta indica	–	FWO	–	6.288×10^{15}	188.5	–43.3	215.40	[30]
	–	Friedman	–	8.586×10^{15}	190.9	–39.4	215.40	
	–	Vyazovkin	–	2.965×10^{20}	199.7	–26.0	215.20	
Phyllantus emblica	–	FWO	–	2.075×10^{14}	189.9	–40.9	215.30	[30]
	–	Friedman	–	2.864×10^{13}	181.3	–55.1	215.60	
	–	Vyazovkin	–	3.534×10^{13}	179.4	–58.3	215.60	
Rice husk	–	Friedman	–	–	186	–	–	[92]
	–	KAS	–	–	178	–	–	
	–	FWO	–	–	180	–	–	
	Rice hull ash	Friedman	–		148	–	–	
	Rice hull ash	KAS	–	–	148	–	–	
	Rice hull ash	FWO	–	–	146	–	–	
Chlorella vulgaris	–	KAS	156.2	2.898×10^{20}	151	–	–	[131]
	–	FWO	158.1	2.358×10^{20}	153	–	–	
	HZSM-5	KAS	145.3	2.790×10^{14}	140	–	–	
	HZSM-5	FWO	147.8	4.908×10^{14}	143	–	–	
	Limestone	KAS	138.8	6.360×10^{15}	133	–	–	
	Limestone	FWO	142.1	8.880×10^{15}	137	–	–	

different kinds of agricultural biomass and polymer wastes, the current heat transfer processes for co-pyrolysis, i.e., conduction, convection and radiation still impose several challenges. In conduction, solid attrition is the critical issue once there is a direct contact between fuel particles and heating agent. In convection, small fuel particles and long gas residence times are essential for gas/solid and sufficient heat transfer, respectively. Asymmetrically, the primary challenges of radiation are high concentration of radiation is required for the production of sufficient heat transfer and consideration of wall heating design in pyrolysis reactor [136,137]. Hence, the high installation and operating costs of units with a high efficiency of heat transfer in the short gas residence time and an additional pre-treatment system for various types of biomasses are the main drawbacks of co-pyrolysis. Different studies reported that different conditions are required to blend an appropriate waste with different biomasses before co-processing. More profound fundamental studies on reaction mechanisms and kinetics of biomass with different waste materials are critical in the advancement of the co-pyrolysis process. In this sense, the properties of the co-pyrolytic oil produced with its composition can be determined from the interactivity

of the reaction intermediates. Currently, ANN and Monte Carlo serve as empirical models that are practical in the prediction of intricate input–output interrelations in a co-pyrolysis process. However, these models are only applicable to the process and fuels, which have been well-established [21]. Co-pyrolysis kinetic datasets for predicting of product formation using different reactor systems are still fairly unexplored [135].

Moreover, the commercialisation of co-pyrolysis reactors are still in the early stages since the current reactors still have the challenges of low heat efficiency, high capital and operating costs as well as complexities with biomass handling or storage [32]. Besides that, although there is plenty of extensive research on the single feedstock pyrolysis, the feasibility study of the co-pyrolysis process remains a niche area, whereby research on the techno-economic and life cycle assessment of the process is limited to single feedstock pyrolysis, such as the co-pyrolysis of biomass refineries and the DFM layers in these references [138,139]. To the best of our knowledge, these studies for the case of co-pyrolysis are scarce, existing studies focus on the microwave co-pyrolysis of food waste and LDPE [140], and the co-pyrolysis of lignite coal with single-use plastic waste [141]. Besides that, the existing research on the modelling of the co-pyrolysis of biomass with plastic waste reaction kinetics has been widely studied, but yet to have a consensus on the reaction pathway [32].

6 Conclusions

To conclude, the recent technologies and techniques of co-pyrolysis of biomass and plastic waste to produce bio-oil have been summarised in this review. The growing agriculture industry in ASEAN countries to suit the growing population of the region, has subsequently generated landfills of biomass. To exacerbate the situation, the global pandemic gives rise to the surge of the single-use plastic waste, DMFM wastes. Fortunately, the exploitation of these wastes in co-pyrolysis would positively improve the quantity and quality of the extracted bio-oil of the process, as the result of the synergistic interactions between lignocellulosic properties of biomass and the high hydrogen content of the plastic wastes. Furthermore, the advancement of the kinetic analysis of the pyrolysis process has improved as the catalytic co-pyrolysis process becomes more complex, and unable to be explained via simple iso-conversional models. Advanced conversional models such as Vyazovkin and DAEM methods have been introduced to study the pyrolysis reaction, followed by the heuristic model and predictive models, which prove to produce high-accuracy results. However, the studies of co-pyrolysis of biomass and DMFMs remain limited. Experimental work on the binary feedstock's thermal decompositions and the bio-oil product's quantity and quality result from the co-pyrolysis has yet to be clear. The proposal of this methodology could serve as potential solution to help reduce or eliminate the pollution caused by the DMFM wastes, while producing value-added bio-oil products.

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References

1. Adnan Z A, Saniayan V. Renewable energy outlook for ASEAN: a REmap analysis. Asean Centre for Energy & IRENA Report, 2016
2. Miranda M. Governments across Southeast Asia accelerate renewable energy investment to revive the pandemic-hit economies. Power Technology Report, 2020
3. Erdiwansyah M, Mamat R, Sani M S M, Khoerunnisa F, Kadarohman A. Target and demand for renewable energy across 10 ASEAN countries by 2040. Electricity Journal, 2019, 32(10): 106670
4. Sarraf M, Rismanchi B, Saidur R, Ping H W, Rahim N A. Renewable energy policies for sustainable development in Cambodia. Renewable & Sustainable Energy Reviews, 2013, 22: 223–229
5. Pillai I R, Banerjee R. Renewable energy in India: status and potential. Energy, 2009, 34(8): 970–980
6. Dani S, Wibawa A. Challenges and policy for biomass energy in Indonesia. Journal of International Economic Law, 2018, 15(5): 41–47
7. Mekhilef S, Barimani M, Safari A, Salam Z. Malaysia's renewable energy policies and programs with green aspects. Renewable & Sustainable Energy Reviews, 2014, 40: 497–504
8. Wattana S. Bioenergy development in Thailand: challenges and strategies. Energy Procedia, 2014, 52: 506–515
9. Truong K, Huong C, Dang Xuan T, Trung D, Khanh T. Current status and future plan of development of bioenergy crops as renewable energy sources in Vietnam. Journal of Biology and Nature, 2016, 5: 1–8
10. Myanmar Energy Master Plan. IEA, 2017
11. Energy policy and administration. Open Development Laos Website, 2018
12. Bangkok. East and Southeast Asia renewable energy statistics workshop. IRENA Website, 2016
13. Hirschmann R. Palm oil industry in Indonesia—statistics & facts. Statista Website, 2022
14. Malaysia palm oil production by year. Indexmundi, 2020
15. Loh S K. The potential of the Malaysian oil palm biomass as a renewable energy source. Energy Conversion and Management, 2017, 141: 285–298

16. Kumar N, Chhokar R S, Meena R P, Kharub A S, Gill S C, Tripathi S C, Gupta O P, Mangrauthia S K, Sundaram R M, Sawant C P, Gupta A, Naorem A, Kumar M, Singh G P. Challenges and opportunities in productivity and sustainability of rice cultivation system: a critical review in Indian perspective. Cereal Research Communications, 2022, 50: 573–601
17. Dai L, Wang Y, Liu Y, He C, Ruan R, Yu Z, Jiang L, Zeng Z, Wu Q. A review on selective production of value-added chemicals via catalytic pyrolysis of lignocellulosic biomass. Science of the Total Environment, 2020, 749: 142386
18. Kan T, Strezov V, Evans T, He J, Kumar R, Lu Q. Catalytic pyrolysis of lignocellulosic biomass: a review of variations in process factors and system structure. Renewable & Sustainable Energy Reviews, 2020, 134: 110305
19. Sivagurunathan P, Raj T, Mohanta C S, Semwal S, Satlewal A, Gupta R P, Puri S K, Ramakumar S S V, Kumar R. 2G waste lignin to fuel and high value-added chemicals: approaches, challenges and future outlook for sustainable development. Chemosphere, 2021, 268: 129326
20. Yang H, Yan R, Chen H, Lee D H, Liang D T, Zheng C. Pyrolysis of palm oil wastes for enhanced production of hydrogen rich gases. Fuel Processing Technology, 2006, 87(10): 935–942
21. Naqvi S R, Hameed Z, Tariq R, Taqvi S A, Ali I, Niazi M B K, Noor T, Hussain A, Iqbal N, Shahbaz M. Synergistic effect on co-pyrolysis of rice husk and sewage sludge by thermal behavior, kinetics, thermodynamic parameters and artificial neural network. Waste Management, 2019, 85: 131–140
22. Suriapparao D V, Vinu R, Shukla A, Haldar S. Effective deoxygenation for the production of liquid biofuels via microwave assisted co-pyrolysis of agro residues and waste plastics combined with catalytic upgradation. Bioresource Technology, 2020, 302: 122775
23. Geyer R, Jambeck J R, Law K L. Production, use, and fate of all plastics ever made. Science Advances, 2017, 3(7): e1700782
24. Jambeck J R, Geyer R, Wilcox C, Siegler T R, Perryman M, Andrady A, Narayan R, Law K L. Plastic waste inputs from land into the ocean. Science, 2015, 347(6223): 768–771
25. Abnisa F, Alaba P A. Recovery of liquid fuel from fossil-based solid wastes via pyrolysis technique: a review. Journal of Environmental Chemical Engineering, 2021, 9(6): 106593
26. Liang Y, Song Q, Wu N, Li J, Zhong Y, Zeng W. Repercussions of COVID-19 pandemic on solid waste generation and management strategies. Frontiers of Environmental Science & Engineering, 2021, 15(6): 115
27. Chaib F. Shortage of personal protective equipment endangering health workers worldwide. World Health Organization Website, 2020
28. Patrício Silva A L, Prata J C, Duarte A C, Barcelò D, Rocha-Santos T. An urgent call to think globally and act locally on landfill disposable plastics under and after Covid-19 pandemic: pollution prevention and technological (Bio) remediation solutions. Chemical Engineering Journal, 2021, 426: 131201
29. Patrício Silva A L, Prata J C, Mouneyrac C, Barcelò D, Duarte A C, Rocha-Santos T. Risks of Covid-19 face masks to wildlife: present and future research needs. Science of the Total Environment, 2021, 792: 148505
30. Mishra R K, Mohanty K. Kinetic analysis and pyrolysis behaviour of waste biomass towards its bioenergy potential. Bioresource Technology, 2020, 311: 123480
31. Akhtar J, Saidina Amin N. A review on operating parameters for optimum liquid oil yield in biomass pyrolysis. Renewable & Sustainable Energy Reviews, 2012, 16(7): 5101–5109
32. Hu X, Gholizadeh M. Biomass pyrolysis: a review of the process development and challenges from initial researches up to the commercialisation stage. Journal of Energy Chemistry, 2019, 39: 109–143
33. Miandad R, Barakat M A, Rehan M, Aburiazaiza A S, Ismail I M I, Nizami A S. Plastic waste to liquid oil through catalytic pyrolysis using natural and synthetic zeolite catalysts. Waste Management, 2017, 69: 66–78
34. Navarro M V, López J M, Veses A, Callén M S, García T. Kinetic study for the co-pyrolysis of lignocellulosic biomass and plastics using the distributed activation energy model. Energy, 2018, 165: 731–742
35. Salvilla J N V, Ofrasio B I G, Rollon A P, Manegdeg F G, Abarca R R M, de Luna M D G. Synergistic co-pyrolysıs of polyolefin plastics with wood and agricultural wastes for biofuel production. Applied Energy, 2020, 279: 115668
36. Wang L, Chai M, Liu R, Cai J. Synergetic effects during co-pyrolysis of biomass and waste tire: a study on product distribution and reaction kinetics. Bioresource Technology, 2018, 268: 363–370
37. Ansari K B, Hassan S Z, Bhoi R, Ahmad E. Co-pyrolysis of biomass and plastic wastes: a review on reactants synergy, catalyst impact, process parameter, hydrocarbon fuel potential, COVID-19. Journal of Environmental Chemical Engineering, 2021, 9(6): 106436
38. Roy P, Dias G. Prospects for pyrolysis technologies in the bioenergy sector: a review. Renewable & Sustainable Energy Reviews, 2017, 77: 59–69
39. Bridgwater A V. Review of fast pyrolysis of biomass and product upgrading. Biomass and Bioenergy, 2012, 38: 68–94
40. Fahmy T Y A, Fahmy Y, Mobarak F, El-Sakhawy M, Abou-Zeid R E. Biomass pyrolysis: past, present, and future. Environment, Development and Sustainability, 2020, 22(1): 17–32
41. Papari S, Hawboldt K. A review on the pyrolysis of woody biomass to bio-oil: focus on kinetic models. Renewable & Sustainable Energy Reviews, 2015, 52: 1580–1595
42. Perkins G, Bhaskar T, Konarova M. Process development status of fast pyrolysis technologies for the manufacture of renewable transport fuels from biomass. Renewable & Sustainable Energy Reviews, 2018, 90: 292–315
43. Foong S Y, Liew R K, Yang Y, Cheng Y W, Yek P N Y, Wan Mahari W A, Lee X Y, Han C S, Vo D V N, Van Le Q, Aghbashlo M, Tabatabaei M, Sonne C, Peng W, Lam S S. Valorization of biomass waste to engineered activated biochar by microwave pyrolysis: progress, challenges, and future directions. Chemical Engineering Journal, 2020, 389: 124401
44. Tsai F M, Bui T D, Tseng M L, Lim M K, Hu J. Municipal solid waste management in a circular economy: a data-driven

bibliometric analysis. Journal of Cleaner Production, 2020, 275: 124132

45. Andreo-Martínez P, Ortiz-Martínez V M, García-Martínez N, de los Ríos A P, Hernández-Fernández F J, Quesada-Medina J. Production of biodiesel under supercritical conditions: state of the art and bibliometric analysis. Applied Energy, 2020, 264: 114753
46. Losse M, Geissdoerfer M. Mapping socially responsible investing: a bibliometric and citation network analysis. Journal of Cleaner Production, 2021, 296: 126376
47. Murillo J, Villegas L M, Ulloa-Murillo L M, Rodríguez A R. Recent trends on omics and bioinformatics approaches to study SARS-CoV-2: a bibliometric analysis and mini-review. Computers in Biology and Medicine, 2021, 128: 104162
48. Bensidhom G, Ben Hassen Trabelsi A, mahmood M A, Ceylan S. mahmood M A, Ceylan S. Insights into pyrolytic feedstock potential of date palm industry wastes: kinetic study and product characterization. Fuel, 2021, 285: 119096
49. Domínguez A, Menéndez J A, Inguanzo M, Pis J J. Investigations into the characteristics of oils produced from microwave pyrolysis of sewage sludge. Fuel Processing Technology, 2005, 86(9): 1007–1020
50. Ghodke P, Mandapati R N. Investigation of particle level kinetic modeling for babul wood pyrolysis. Fuel, 2019, 236: 1008–1017
51. Naqvi S R, Tariq R, Hameed Z, Ali I, Taqvi S A, Naqvi M, Niazi M B K, Noor T, Farooq W. Pyrolysis of high-ash sewage sludge: thermo-kinetic study using TGA and artificial neural networks. Fuel, 2018, 233: 529–538
52. Polin J P, Carr H D, Whitmer L E, Smith R G, Brown R C. Conventional and autothermal pyrolysis of corn stover: overcoming the processing challenges of high-ash agricultural residues. Journal of Analytical and Applied Pyrolysis, 2019, 143: 104679
53. Singh R K, Pandey D, Patil T, Sawarkar A N. Pyrolysis of banana leaves biomass: physico-chemical characterization, thermal decomposition behavior, kinetic and thermodynamic analyses. Bioresource Technology, 2020, 310: 123464
54. Tabal A, Barakat A, Aboulkas A, El harfi K. Pyrolysis of ficus nitida wood: determination of kinetic and thermodynamic parameters. Fuel, 2021, 283: 119253
55. Ding Z, Chen H, Liu J, Cai H, Evrendilek F, Buyukada M. Pyrolysis dynamics of two medical plastic wastes: drivers, behaviors, evolved gases, reaction mechanisms, and pathways. Journal of Hazardous Materials, 2021, 402: 123472
56. Honus S, Kumagai S, Fedorko G, Molnár V, Yoshioka T. Pyrolysis gases produced from individual and mixed PE, PP, PS, PVC, and PET—Part I: Production and physical properties. Fuel, 2018, 221: 346–360
57. Jeon W, Kim Y D, Lee K H. A comparative study on pyrolysis of bundle and fluffy shapes of waste packaging plastics. Fuel, 2021, 283: 119260
58. Jung S, Lee S, Dou X, Kwon E E. Valorization of disposable COVID-19 mask through the thermo-chemical process. Chemical Engineering Journal, 2021, 405: 126658
59. Parku G K, Collard F X, Görgens J F. Pyrolysis of waste polypropylene plastics for energy recovery: influence of heating rate and vacuum conditions on composition of fuel product. Fuel Processing Technology, 2020, 209: 106522
60. Xu F, Wang B, Yang D, Hao J, Qiao Y, Tian Y. Thermal degradation of typical plastics under high heating rate conditions by TG-FTIR: pyrolysis behaviors and kinetic analysis. Energy Conversion and Management, 2018, 171: 1106–1115
61. Park Y K, Ha J M, Oh S, Lee J. Bio-oil upgrading through hydrogen transfer reactions in supercritical solvents. Chemical Engineering Journal, 2021, 404: 126527
62. Kwon D, Jung S, Lin K Y A, Tsang Y F, Park Y K, Kwon E E. Synergistic effects of CO_2 on complete thermal degradation of plastic waste mixture through a catalytic pyrolysis platform: a case study of disposable diaper. Journal of Hazardous Materials, 2021, 419: 126537
63. Wan Mahari W A, Awang S, Zahariman N A Z, Peng W, Man M, Park Y K, Lee J, Sonne C, Lam S S. Microwave co-pyrolysis for simultaneous disposal of environmentally hazardous hospital plastic waste, lignocellulosic, and triglyceride biowaste. Journal of Hazardous Materials, 2022, 423: 127096
64. Park Y K, Lee B, Lee H W, Watanabe A, Jae J, Tsang Y F, Kim Y M. Co-feeding effect of waste plastic films on the catalytic pyrolysis of *Quercus variabilis* over microporous HZSM-5 and HY catalysts. Chemical Engineering Journal, 2019, 378: 122151
65. Hu Y, Yu W, Wibowo H, Xia Y, Lu Y, Yan M. Effect of catalysts on distribution of polycyclic-aromatic hydrocarbon (PAHs) in bio-oils from the pyrolysis of dewatered sewage sludge at high and low temperatures. Science of the Total Environment, 2019, 667: 263–270
66. Zhang X, Lei H, Zhu L, Zhu X, Qian M, Yadavalli G, Wu J, Chen S. Thermal behavior and kinetic study for catalytic co-pyrolysis of biomass with plastics. Bioresource Technology, 2016, 220: 233–238
67. Lin X, Zhang Z, Wang Q, Sun J. Interactions between biomass-derived components and polypropylene during wood-plastic composite pyrolysis. Biomass Conversion and Biorefinery, 2020, 12(8): 3345–3357
68. Önal E, Uzun B B, Pütün A E. Bio-oil production via co-pyrolysis of almond shell as biomass and high density polyethylene. Energy Conversion and Management, 2014, 78: 704–710
69. Sun J, Luo J, Lin J, Ma R, Sun S, Fang L, Li H. Study of co-pyrolysis endpoint and product conversion of plastic and biomass using microwave thermogravimetric technology. Energy, 2022, 247: 123547
70. Yang J, Rizkiana J, Widayatno W B, Karnjanakom S, Kaewpanha M, Hao X, Abudula A, Guan G. Fast co-pyrolysis of low density polyethylene and biomass residue for oil production. Energy Conversion and Management, 2016, 120: 422–429
71. Ojha D, Shukla S, Raghunath S, Sachin R S, Vinu R. Understanding the interactions between cellulose and polypropylene during fast co-pyrolysis via experiments and DFT calculations. Chemical Engineering Transactions, 2016, 50: 67–72
72. Uzoejinwa B B, He X, Wang S, El-Fatah Abomohra A, Hu Y, Wang Q. Co-pyrolysis of biomass and waste plastics as a thermochemical conversion technology for high-grade biofuel

production: recent progress and future directions elsewhere worldwide. Energy Conversion and Management, 2018, 163: 468–492

73. Lin X, Kong L, Ren X, Zhang D, Cai H, Lei H. Catalytic co-pyrolysis of torrefied poplar wood and high-density polyethylene over hierarchical HZSM-5 for mono-aromatics production. Renewable Energy, 2021, 164: 87–95
74. Pogaku R, Hardinge B S, Vuthaluru H, Amir H A. Production of bio-oil from oil palm empty fruit bunch by catalytic fast pyrolysis: a review. Biofuels, 2016, 7(6): 647–660
75. Dai L, Zhou N, Li H, Deng W, Cheng Y, Wang Y, Liu Y, Cobb K, Lei H, Chen P, Ruan R. Recent advances in improving lignocellulosic biomass-based bio-oil production. Journal of Analytical and Applied Pyrolysis, 2020, 149: 104845
76. Yang H, Yan R, Chin T, Liang D T, Chen H, Zheng C. Thermogravimetric analysis-fourier transform infrared analysis of palm oil waste pyrolysis. Energy & Fuels, 2004, 18(6): 1814–1821
77. Ly H V, Park J W, Kim S S, Hwang H T, Kim J, Woo H C. Catalytic pyrolysis of bamboo in a bubbling fluidized-bed reactor with two different catalysts: HZSM-5 and red mud for upgrading bio-oil. Renewable Energy, 2020, 149: 1434–1445
78. Ahmed M H M, Batalha N, Mahmudul H M D, Perkins G, Konarova M. A review on advanced catalytic co-pyrolysis of biomass and hydrogen-rich feedstock: insights into synergistic effect, catalyst development and reaction mechanism. Bioresource Technology, 2020, 310: 123457
79. Jin X, Lee J H, Choi J W. Catalytic co-pyrolysis of woody biomass with waste plastics: effects of HZSM-5 and pyrolysis temperature on producing high-value pyrolytic products and reducing wax formation. Energy, 2022, 239: 121739
80. Ratnasari D K, Nahil M A, Williams P T. Catalytic pyrolysis of waste plastics using staged catalysis for production of gasoline range hydrocarbon oils. Journal of Analytical and Applied Pyrolysis, 2017, 124: 631–637
81. Li Z, Zhong Z, Zhang B, Wang W, Seufitelli G V S, Resende F L P. Catalytic fast co-pyrolysis of waste greenhouse plastic films and rice husk using hierarchical micro-mesoporous composite molecular sieve. Waste Management, 2020, 102: 561–568
82. Zhao Y, Wang Y, Duan D, Ruan R, Fan L, Zhou Y, Dai L, Lv J, Liu Y. Fast microwave-assisted ex-catalytic co-pyrolysis of bamboo and polypropylene for bio-oil production. Bioresource Technology, 2018, 249: 69–75
83. Cao Z, Niu J, Gu Y, Zhang R, Liu Y, Luo L. Catalytic pyrolysis of rice straw: screening of various metal salts, metal basic oxide, acidic metal oxide and zeolite catalyst on products yield and characterization. Journal of Cleaner Production, 2020, 269: 122079
84. Chen X, Chen Y, Yang H, Chen W, Wang X, Chen H. Fast pyrolysis of cotton stalk biomass using calcium oxide. Bioresource Technology, 2017, 233: 15–20
85. Chong Y Y, Thangalazhy-Gopakumar S, Ng H K, Lee L Y, Gan S. Effect of oxide catalysts on the properties of bio-oil from in-situ catalytic pyrolysis of palm empty fruit bunch fiber. Journal of Environmental Management, 2019, 247: 38–45
86. Kim S, Park C, Lee J. Reduction of polycyclic compounds and biphenyls generated by pyrolysis of industrial plastic waste by using supported metal catalysts: a case study of polyethylene terephthalate treatment. Journal of Hazardous Materials, 2020, 392: 122464
87. Lin X, Zhang Z, Zhang Z, Sun J, Wang Q, Pittman C U. Catalytic fast pyrolysis of a wood-plastic composite with metal oxides as catalysts. Waste Management, 2018, 79: 38–47
88. Teng S Y, Loy A C M, Leong W D, How B S, Chin B L F, Máša V. Catalytic thermal degradation of *Chlorella vulgaris*: evolving deep neural networks for optimization. Bioresource Technology, 2019, 292: 121971
89. Thangalazhy-Gopakumar S, Wei Lee C, Gan S, Kiat Ng H, Yee Lee L. Comparison of bio-oil properties from non-catalytic and in-situ catalytic fast pyrolysis of palm empty fruit bunch. Materials Today: Proceedings, 2018, 5(11): 23456–23465
90. Chow L W, Tio S A, Teoh J Y, Lim C G, Chong Y Y, Thangalazhy-Gopakumar S. Sludge as a relinquishing catalyst in co-pyrolysis with palm empty fruit bunch fiber. Journal of Analytical and Applied Pyrolysis, 2018, 132: 56–64
91. Jeong J Y, Lee U D, Chang W S, Jeong S H. Production of bio-oil rich in acetic acid and phenol from fast pyrolysis of palm residues using a fluidized bed reactor: influence of activated carbons. Bioresource Technology, 2016, 219: 357–364
92. Loy A C M, Gan D K W, Yusup S, Chin B L F, Lam M K, Shahbaz M, Unrean P, Acda M N, Rianawati E. Thermogravimetric kinetic modelling of *in-situ* catalytic pyrolytic conversion of rice husk to bioenergy using rice hull ash catalyst. Bioresource Technology, 2018, 261: 213–222
93. Loy A C M, Yusup S, Lam M K, Chin B L F, Shahbaz M, Yamamoto A, Acda M N. The effect of industrial waste coal bottom ash as catalyst in catalytic pyrolysis of rice husk for syngas production. Energy Conversion and Management, 2018, 165: 541–554
94. Santosa D M, Zhu C, Agblevor F A, Maddi B, Roberts B Q, Kutnyakov I V, Lee S J, Wang H. *In situ* catalytic fast pyrolysis using red mud catalyst: impact of catalytic fast pyrolysis temperature and biomass feedstocks. ACS Sustainable Chemistry & Engineering, 2020, 8(13): 5156–5164
95. Dong Q, Li H, Niu M, Luo C, Zhang J, Qi B, Li X, Zhong W. Microwave pyrolysis of moso bamboo for syngas production and bio-oil upgrading over bamboo-based biochar catalyst. Bioresource Technology, 2018, 266: 284–290
96. Chen W, Fang Y, Li K, Chen Z, Xia M, Gong M, Chen Y, Yang H, Tu X, Chen H. Bamboo wastes catalytic pyrolysis with N-doped biochar catalyst for phenols products. Applied Energy, 2020, 260: 114242
97. An Y, Tahmasebi A, Zhao X, Matamba T, Yu J. Catalytic reforming of palm kernel shell microwave pyrolysis vapors over iron-loaded activated carbon: enhanced production of phenol and hydrogen. Bioresource Technology, 2020, 306: 123111
98. Gaurh P, Pramanik H. Production of benzene/toluene/ethyl benzene/xylene (BTEX) via multiphase catalytic pyrolysis of hazardous waste polyethylene using low cost fly ash synthesized natural catalyst. Waste Management, 2018, 77: 114–130
99. Luo W, Fan Z, Wan J, Hu Q, Dong H, Zhang X, Zhou Z. Study on the reusability of kaolin as catalysts for catalytic pyrolysis of

low-density polyethylene. Fuel, 2021, 302: 121164
100. Nalluri P, Prem Kumar P, Ch Sastry M R. Experimental study on catalytic pyrolysis of plastic waste using low cost catalyst. Materials Today: Proceedings, 2021, 45: 7216–7221
101. Xu D, Xiong Y, Zhang S, Su Y. The synergistic mechanism between coke depositions and gas for H_2 production from co-pyrolysis of biomass and plastic wastes via char supported catalyst. Waste Management, 2021, 121: 23–32
102. Zhang D, Lin X, Zhang Q, Ren X, Yu W, Cai H. Catalytic pyrolysis of wood-plastic composite waste over activated carbon catalyst for aromatics production: effect of preparation process of activated carbon. Energy, 2020, 212: 118983
103. Chang G, Shi P, Guo Y, Wang L, Wang C, Guo Q. Enhanced pyrolysis of palm kernel shell wastes to bio-based chemicals and syngas using red mud as an additive. Journal of Cleaner Production, 2020, 272: 122847
104. Singh R K, Patil T, Sawarkar A N. Pyrolysis of garlic husk biomass: physico-chemical characterization, thermodynamic and kinetic analyses. Bioresource Technology Reports, 2020, 12: 100558
105. Sbirrazzuoli N. Determination of pre-exponential factors and of the mathematical functions $f(\alpha)$ or $G(\alpha)$ that describe the reaction mechanism in a model-free way. Thermochimica Acta, 2013, 564: 59–69
106. Sajjad Ahmad M, Liu H, Alhumade H, Hussain Tahir M, Çakman G, Yıldız A, Ceylan S, Elkamel A, Shen B. A modified DAEM: to study the bioenergy potential of invasive *Staghorn sumac* through pyrolysis, ANN, TGA, kinetic modeling, FTIR and GC-MS analysis. Energy Conversion and Management, 2020, 221: 113173
107. Hameed S, Sharma A, Pareek V, Wu H, Yu Y. A review on biomass pyrolysis models: kinetic, network and mechanistic models. Biomass and Bioenergy, 2019, 123: 104–122
108. Cano-Pleite E, Rubio-Rubio M, García-Hernando N, Soria-Verdugo A. Microalgae pyrolysis under isothermal and non-isothermal conditions. Algal Research, 2020, 51: 102031
109. Ding Y, Zhang W, Yu L, Lu K. The accuracy and efficiency of GA and PSO optimization schemes on estimating reaction kinetic parameters of biomass pyrolysis. Energy, 2019, 176: 582–588
110. Aghbashlo M, Almasi F, Jafari A, Nadian M H, Soltanian S, Lam S S, Tabatabaei M. Describing biomass pyrolysis kinetics using a generic hybrid intelligent model: a critical stage in sustainable waste-oriented biorefineries. Renewable Energy, 2021, 170: 81–91
111. Ferreiro A I, Rabaçal M, Costa M. A combined genetic algorithm and least squares fitting procedure for the estimation of the kinetic parameters of the pyrolysis of agricultural residues. Energy Conversion and Management, 2016, 125: 290–300
112. Ding Y, Zhang Y, Zhang J, Zhou R, Ren Z, Guo H. Kinetic parameters estimation of pinus sylvestris pyrolysis by Kissinger–Kai method coupled with particle swarm optimization and global sensitivity analysis. Bioresource Technology, 2019, 293: 122079
113. Buyukada M. Co-combustion of peanut hull and coal blends: artificial neural networks modeling, particle swarm optimization and Monte Carlo simulation. Bioresource Technology, 2016, 216: 280–286
114. Xu L, Jiang Y, Wang L. Thermal decomposition of rape straw: pyrolysis modeling and kinetic study via particle swarm optimization. Energy Conversion and Management, 2017, 146: 124–133
115. Majid M, Chin B L F, Jawad Z A, Chai Y H, Lam M K, Yusup S, Cheah K W. Particle swarm optimization and global sensitivity analysis for catalytic co-pyrolysis of *Chlorella vulgaris* and plastic waste mixtures. Bioresource Technology, 2021, 329: 124874
116. Duan Q Y, Gupta V K, Sorooshian S. Shuffled complex evolution approach for effective and efficient global minimization. Journal of Optimization Theory and Applications, 1993, 76(3): 501–521
117. Ding Y, Zhang J, He Q, Huang B, Mao S. The application and validity of various reaction kinetic models on woody biomass pyrolysis. Energy, 2019, 179: 784–791
118. Ding Y, Wang C, Chaos M, Chen R, Lu S. Estimation of beech pyrolysis kinetic parameters by Shuffled Complex Evolution. Bioresource Technology, 2016, 200: 658–665
119. Liu H, Chen B, Wang C. Pyrolysis kinetics study of biomass waste using Shuffled Complex Evolution algorithm. Fuel Processing Technology, 2020, 208: 106509
120. Hasalová L, Ira J, Jahoda M. Practical observations on the use of Shuffled Complex Evolution (SCE) algorithm for kinetic parameters estimation in pyrolysis modeling. Fire Safety Journal, 2016, 80: 71–82
121. Al-Yaari M, Ibrahim D. Application of artificial neural networks to predict the catalytic pyrolysis of HDPE using non-isothermal TGA data. Polymers, 2020, 12(8): 1813
122. Bi H, Wang C, Jiang X, Jiang C, Bao L, Lin Q. Thermodynamics, kinetics, gas emissions and artificial neural network modeling of co-pyrolysis of sewage sludge and peanut shell. Fuel, 2021, 284: 118988
123. Balsora H K, S K, Dua V, Joshi J B, Kataria G, Sharma A, Chakinala A G. Machine learning approach for the prediction of biomass pyrolysis kinetics from preliminary analysis. Journal of Environmental Chemical Engineering, 2022, 10(3): 108025
124. Bong J T, Loy A C M, Chin B L F, Lam M K, Tang D K H, Lim H Y, Chai Y H, Yusup S. Artificial neural network approach for co-pyrolysis of *Chlorella vulgaris* and peanut shell binary mixtures using microalgae ash catalyst. Energy, 2020, 207: 118289
125. Alaba P A, Popoola S I, Abnisal F, Lee C S, Ohunakin O S, Adetiba E, Akanle M B, Abdul Patah M F, Atayero A A A, Wan Daud W M A. Thermal decomposition of rice husk: a comprehensive artificial intelligence predictive model. Journal of Thermal Analysis and Calorimetry, 2020, 140(4): 1811–1823
126. Zhu X, Li Y, Wang X. Machine learning prediction of biochar yield and carbon contents in biochar based on biomass characteristics and pyrolysis conditions. Bioresource Technology, 2019, 288: 121527
127. Li H, Xu Q, Xiao K, Yang J, Liang S, Hu J, Hou H, Liu B. Predicting the higher heating value of syngas pyrolyzed from

sewage sludge using an artificial neural network. Environmental Science and Pollution Research International, 2020, 27(1): 785–797

128. Whiteman J K, Gueguim Kana E B. Comparative assessment of the artificial neural network and response surface modelling efficiencies for biohydrogen production on sugar cane molasses. BioEnergy Research, 2014, 7(1): 295–305
129. Zhang Y, Ahmad M S, Shen B, Yuan P, Shah I A, Zhu Q, Ibrahim M, Bokhari A, Klemeš J J, Elkamel A. Co-pyrolysis of lychee and plastic waste as a source of bioenergy through kinetic study and thermodynamic analysis. Energy, 2022, 256: 124678
130. Gan D K W, Loy A C M, Chin B L F, Yusup S, Unrean P, Rianawati E, Acda M N. Kinetics and thermodynamic analysis in one-pot pyrolysis of rice hull using renewable calcium oxide based catalysts. Bioresource Technology, 2018, 265: 180–190
131. Fong M J B, Loy A C M, Chin B L F, Lam M K, Yusup S, Jawad Z A. Catalytic pyrolysis of Chlorella vulgaris: kinetic and thermodynamic analysis. Bioresource Technology, 2019, 289: 121689
132. Kumar Mishra R, Mohanty K. Co-pyrolysis of waste biomass and waste plastics (polystyrene and waste nitrile gloves) into renewable fuel and value-added chemicals. Carbon Resources Conversion, 2020, 3: 145–155
133. Abnisa F, Wan Daud W M A. A review on co-pyrolysis of biomass: an optional technique to obtain a high-grade pyrolysis oil. Energy Conversion and Management, 2014, 87: 71–85
134. Scheirs J. Feedstock recycling and pyrolysis of waste plastics. Manhattan: John Wiley & Sons Inc., 2006: 381–433
135. Gouws S M, Carrier M, Bunt J R, Neomagus H W J P. Co-pyrolysis of coal and raw/torrefied biomass: a review on chemistry, kinetics and implementation. Renewable & Sustainable Energy Reviews, 2021, 135: 110189
136. Lede J. Biomass fast pyrolysis reactors: a review of a few scientific challenges and of related recommended research topics. Oil & Gas Science and Technology, 2013, 68(5): 801–814
137. Venderbosch R, Prins W. Fast pyrolysis technology development. Biofuels, Bioproducts & Biorefining, 2010, 4(2): 178–208
138. Yousef S, Eimontas J, Stasiulaitiene I, Zakarauskas K, Striūgas N. Pyrolysis of all layers of surgical mask waste as a mixture and its life-cycle assessment. Sustainable Production and Consumption, 2022, 32: 519–531
139. Brassard P, Godbout S, Hamelin L. Framework for consequential life cycle assessment of pyrolysis biorefineries: a case study for the conversion of primary forestry residues. Renewable & Sustainable Energy Reviews, 2021, 138: 110549
140. Neha S, Prasanna Kumar Ramesh K, Remya N. Techno-economic analysis and life cycle assessment of microwave co-pyrolysis of food waste and low-density polyethylene. Sustainable Energy Technologies and Assessments, 2022, 52: 102356
141. Joshi V V, Swaminathan G, Prabhakaran S P S. Life cycle assessment of the co-combustion system of single-use plastic waste and lignite coal to promote circular economy. Journal of Cleaner Production, 2021, 329: 129579

MANIPAL UNIVERSITY JAIPUR

School of Civil and Chemical Engineering

Department of Civil Engineering
Course Hand-out

Solid & Liquid Waste Management | CV 3251| 3 Credits | 3 0 0 3

Session: Aug.24- Dec 24 | Faculty: Mr Sagar Gupta| Class: Solid & Liquid Waste Management

A. Introduction: This course is offered by Dept. of Civil Engineering as a Departmental Course, targeting students who wish to work in the field of Solid & Liquid Waste Management.

B. Course Outcomes: At the end of the course, students will be able to:

CV3251.1	recall and describe the fundamental principles and concepts governing liquid and solid waste management.
CV3251.2	interpret and explain the processes involved in waste generation, collection, transportation, and treatment to enhance employability.
CV3251.3	apply theoretical knowledge to develop practical solutions for effective waste management in diverse contexts to promote entrepreneurship.
CV3251.4	evaluate different waste treatment technologies and policy frameworks to identify strengths, weaknesses, and opportunities for improvement to infuse skill development

C. PROGRAM OUTCOMES AND PROGRAM SPECIFIC OUTCOMES

[PO.1]. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems

[PO.2]. Problem analysis: Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences

[PO.3]. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations

[PO.4]. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions

[PO.5]. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations

[PO.6]. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to the professional engineering practice

[PO.7]. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development

[PO.8]. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practices

[PO.9]. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings

[PO.10]. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design

documentation, make effective presentations, and give and receive clear instructions

[PO.11]. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments

[PO.12]. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change

[PSO.1] Design economic, environment friendly, sustainable Civil engineering structures keeping in view national and social requirements.

[PSO.2] Conduct investigation, analysis and interpretation of the results using modern scientific tools and technical skills for solving complex Civil engineering problem.

[PSO.3] Manage/ execute Civil engineering projects effectively and ethically as a member or/and leader in diverse teams.

[PSO.4] Communicate effectively with multidisciplinary members with discharge of social responsibilities as a civil engineer and engage in independent and lifelong learning for global betterment

D. Assessment Plan:

Criteria	Description	Maximum Marks
Internal Assessment (Summative)	Sessional Exam	30
	Quizzes and Assignments , Activity feedbacks (Accumulated and Averaged)	30
End Term Exam (Summative)	End Term Exam (On line)	40
	Total	100
Attendance (Formative)	A minimum of 75% Attendance is required to be maintained by a student to be qualified for taking up the End Semester examination.	
Make up Assignments (Formative)	Students who misses a class will have to report to the teacher about the absence. A makeup assignment on the topic taught on the day of absence will be given which has to be submitted within a week from the date of absence. No extensions will be given on this. The attendance for that particular day of absence will be marked blank, so that the student is not accounted for absence. These assignments are limited to a maximum of 5 throughout the entire semester.	

E. Syllabus

CV3251 **SOLID & LIQUID WASTE MANAGEMENT** **[3 0 0 3]**

Policies for Liquid & Solid Waste Management, quality and quantities of waste – properties of solid and liquid waste, sources of waste generation- method for estimation of waste at household and city level, segregation of solid and liquid waste, Analysis using excreta flow diagram, collection and transport of solid and liquid waste, Waste treatment Technologies - Physical, chemical, biological and thermal treatment of waste, Application of IEC in Waste Management – Introduction to Behaviour change campaigns and intervention and case studies, Financial, Social and Institutional aspects- Costs of collection, separation, management; equipment costs; social costs, stakeholders, scavengers, public health issues, policy and legislation, business opportunities and models in waste management.

References:

Rekha, D. K. (2019). Waste Management Principle and Practice. New Delhi: Ministry of Human Resource Development.
Rekha, K. N. (2019). Waste Management Entrepreneurship and procedures. New Delhi: Ministry of Human Resource Development.
Rekha, K. N. (2019). Waste Management Treatment Technologies and Methods. New Delhi: Ministry of Human Resource Development.
Strande, L. (2014). Faecal Sludge Management Systems Approach for Implementation and Operation. IWA publishing.

Lecture Plan:

Lecture No.	Topic to be Covered	Hours

1	Introduction to Liquid & Solid Waste Management	1
2	Quality and Quantities of Waste: Properties of Solid and Liquid Waste	2
3	Sources of Waste Generation: Understanding the drivers behind waste production	2
4	Method for Estimation of Waste at Household and City Level	2
5	Segregation of Solid and Liquid Waste: Importance and Techniques	2
6	Analysis Using Excreta Flow Diagram: Understanding waste flow patterns	2
7	Collection and Transport of Solid and Liquid Waste: Strategies and Challenges	2
8	Waste Treatment Technologies: Physical Treatment Methods	2
9	Waste Treatment Technologies: Chemical Treatment Methods	2
10	Waste Treatment Technologies: Biological Treatment Methods	2
11	Waste Treatment Technologies: Thermal Treatment Methods	2
12	Introduction to Information, Education, and Communication (IEC) in Waste Management	1
13	Behaviour Change Campaigns and Interventions: Strategies for Effective Communication	2
14	Case Studies on Successful Behaviour Change Campaigns	2
15	Financial Aspects of Waste Management: Costs of Collection, Separation, and Management	2
16	Social Aspects of Waste Management: Understanding the societal impact of waste management	2
17	Institutional Aspects of Waste Management: Stakeholders and their roles in waste management	2
18	Scavengers in Waste Management: Issues and Challenges	2
19	Public Health Issues Related to Poor Waste Management	2
20	Policy and Legislation in Waste Management: Overview and Importance	2
21	Business Opportunities in Waste Management: Exploring entrepreneurial ventures	2
22	Models in Waste Management: Analyzing different approaches to waste management	2
23	Review and Discussion: Recap of key concepts covered so far	1
24	Guest Lecture: Industry Perspective on Waste Management	2
25	Student Presentations: Research findings on specific waste management topics	2
26	Q&A Session: Addressing student queries and clarifications on course content	1
27	Midterm Examination: Assessing understanding of course material	2
28	Innovative Waste Management Practices: Exploring cutting-edge solutions	2
29	Case Studies on Integrated Waste Management Systems	2
30	Waste-to-Energy Technologies: Harnessing energy from waste	2
31	Environmental Impacts of Waste Management: Addressing concerns and mitigating measures	2
32	International Perspectives on Waste Management: Learning from global best practices	2
33	Emerging Trends in Waste Management: Exploring advancements and future directions	2
34	Final Project Presentation Preparation: Guidance on structuring and presenting project findings	2
35	Final Project Presentations: Showcasing student projects	2
36	Course Conclusion and Evaluation: Reflection on learning outcomes, feedback, and assessment	1

1. **Course Articulation Matrix: (Mapping of COs with POs)**

CO	STATEMENT	CORRELATION WITH PROGRAM OUTCOMES												CORRELATION WITH PROGRAM SPECIFIC OUTCOMES				
		PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12	PSO 1	PSO 2	PSO 3	PSO 4	PSO 5
CV3251.1	recall and describe the fundamental principles and concepts governing liquid and solid waste management.	3	2		2								2		2			
CV3251.2	interpret and explain the processes involved in waste generation, collection, transportation, and treatment to enhance employability.	2		3	3	2	1						3		3	1		
CV3251.3	apply theoretical knowledge to develop practical solutions for effective waste management in diverse contexts to promote entrepreneurship.	2			2	2	3	3		1					3			
CV3251.4	evaluate different waste treatment technologies and policy frameworks to identify strengths, weaknesses, and opportunities for improvement to infuse skill development				2	3	1			3	2	3			2	2	2	

1- Low Correlation; 2- Moderate Correlation; 3- Substantial Correlation

Head
Civil Engg. Dept.
MBM. Deemed to, Jaipur

Head
Department of Civil Engineering

Manipal University Jaipur

Manipal University Jaipur
Registrar Office
Recd on 31/8/23 Sr.No 2464
Signature

Note Sheet

Date: 31.07.2023

It is informed you that the consultancy proposal was discussed and finalised during the time of Australia. Therefore, the agreed amount is in USD. However, UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION is also operating from India, and they have agreed for the transfer of the money in INR in the MUJ Account. The total amount of the consultancy is INR 1591619 including GST.

The based on the attached agreement the following will be the payment plan under this consultancy:

- 20% up receipt of the duly countersigned contract - INR 318324
- 20% upon completion of Deliverable - 1 and acceptance of the corresponding report by UNIDO- INR 318324
- 50% upon submission of Deliverable -2 and acceptance of the corresponding report by UNIDO - INR 795809
- 10% upon acceptance of the Final report by UNIDO - INR 159162

This consultancy belongs to the Department of Chemical and Biotechnology with association of Department of Mechanical Engineering.

The detail of the proposal is attached in the separate format "Request for proposal".

The proposal is submitted for the approval and booking of the consultancy amount as per the MUJ rules.

Abhishek Sharma | Anand G. Chakinala | Rahul Goyal | Dharmesh Yadav

Name and Sign of PI and Co-PIs

HoD :

Director : 31/07/23

DOR

2/8/23

Recommended and forwarded to Director (Research)

2.8.23

Registrar

04/08/2023

MANIPAL UNIVERSITY
JAIPUR

Directorate of Research

Proposal for Consultancy

Date: 31.07.2023

To
The Registrar
Manipal University Jaipur
Subject: Approval of Proposal for Consultancy Project
The Following details are submitted for your kind pursual and approval of the same.

1.	Title of the Consultancy Proposal	BENCH-SCALE EXPERIMENTATION RELATED TO THERMOCHEMICAL CONVERSION (THROUGH PYROLYSIS) OF PLASTIC WASTES GENERATED FROM RECYCLED-FIBRE BASED PAPER MILLS
2.	Consultancy Type (Research Based/Non-Research based)	Research based
2.	Name of the Principal Investigator (Department/School/Phone/E-mail)	Dr. Abhishek Sharma Professor, Department of Biotechnology and Chemical Engineering
3.	Name of the Co-Principal Investigator (Department/School/Phone/E-mail)	Dr. Anand Chakinala (Biotechnology and Chemical Engineering) Dr. Rahul Goyal (Mechanical Engineering) Mr. Dharmesh Yadav (Mechanical Engineering)
4.	Name of the Institution with Full Address	Manipal University Jaipur
5.	Proposed duration of Consultancy Project	6 months
6.	Name of Consultant Partner	United Nations Industrial Development Organization
7.	Address and Contact Details of Consultation Partner	Wagramer Strasse 5, A-1220 Vienna, Austria
8.	Consultancy Amount requested as per Estimated Budget (in Rs.)	INR 1591619 (including GST)
9.	Bank Account Details for Fund Transfer (Kindly Endorse by MUJ Finance)	**Name: MANIPAL UNIVERSITY JAIPUR** **Account No. 41058604477** **Account Type: Savings** **Branch Name and Code: SBI Bhankrota, Jaipur (11396)** **IFSC Code: SBIN0011396**

MANIPAL UNIVERSITY
JAIPUR

Technical Details of the Consultancy Proposal

1.	Title of the Consultancy Proposal	BENCH-SCALE EXPERIMENTATION RELATED TO THERMOCHEMICAL CONVERSION (THROUGH PYROLYSIS) OF PLASTIC WASTES GENERATED FROM RECYCLED-FIBRE BASED PAPER MILLS
2.	Summary of the proposed consultancy project .	The novel thermo-chemical conversion of waste plastic and paper mixture has a great potential for the recovery of value-added products such as diesel grade fuel, adsorbents, catalysts, fillers, and raw materials for graphene and activated carbon fabrication. Further research is required in this direction for establishing overall sustainability in circular economy framework.
3.	Objectives	For improving the overall process design and conducting application-based studies, specific activities are proposed in this project. The applications focused under this project are extensive diesel engine performance testing and rubber compounding, with process optimization and high-level techno-economic analysis.
4.	Approach	1. Feed characterization will be carried out with thermo-chemical upgradation in a semi-continuous unit at varying operating conditions (temperature between 500 to 700°C and residence time between 60 to 120 mins). Product yield and quality will also be studied. This will be completed in first and second month. 2. Diesel engine studies will be conducted for improving the overall performance with emission characteristics analysis at four different blending ratios (5-20) and six engine loading (2-12 kg) at fixed compression ratio and engine speed. The optimal blend fuel will be selected based on considerable enhancement in brake thermal efficiency and maximum reduction in emissions. This will be completed in second and third month. 3. Investigate long-term effect of plastic oil in diesel engines to identify operational problems related to wear and maintenance such as engine deposits, piston ring sticking, injector choking, gum formation, and lubricating oil thickening. Experimental study will be conducted on diesel engine for 512 h with optimum blend fuel. This test will complete in 32 days (32 cycles). This will be completed in third and fourth month. 4. Rubber compounding studies using char will be performed at site of Indian Rubber Manufacturer Research Association (IRMRA) in Mumbai. Details of this activity with budget will be shared by IRMRA team. This will be completed in second and third month. 5. High level techno-economics for process scale up and project reporting with stakeholder engagement. This will

		be completed in fifth and sixth month.	
5.	Available Institutional facilities	Semi pilot pyrolysis unit Research engine test rig Distillation setup Analytical Facilities	
6.	Consultancy Amount	Consultancy Charges	1348829
		GST (18% of Consultancy Charges)	242789
		Total Amount	1591619

Please enclose the sanction letter of the consultancy partner.

Abhishek Sharma Anand G. Chakinala Rahul Goyal Dharmesh Yadav

Name and sign of the PI Name and Sign of the Co-PI

HOD 31/07/2023

Director (School) Forwarded

Directorate of Research

CONTRACT NO. 3000116873

between the

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

(UNIDO)

and

MANIPAL UNIVERSITY JAIPUR

(MUJ)

FOR THE PROVISION OF SERVICES RELATED TO BENCH-SCALE EXPERIMENTATION RELATED TO THERMOCHEMICAL CONVERSION (THROUGH PYROLYSIS) OF PLASTIC WASTES GENERATED FROM RECYCLED-FIBRE BASED PAPER MILLS

UNIDO Project No.: 180200

This Contract comprises this cover page, a table of contents and 6 pages of text and 9 pages of Annexes (Annex A through B).

UNIDO
COR/PRO

TABLE OF CONTENTS

CONTRACT

between the

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

(UNIDO)

and

MANIPAL UNIVERSITY JAIPUR

(MUJ)

FOR THE PROVISION OF

SERVICES RELATED TO BENCH-SCALE EXPERIMENTATION RELATED TO THERMOCHEMICAL CONVERSION (THROUGH PYROLYSIS) OF PLASTIC WASTES GENERATED FROM RECYCLED-FIBRE BASED PAPER MILLS

THIS CONTRACT is entered into between the UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION, a Specialized Agency of the United Nations, having its headquarters located at Wagramer Strasse 5, A-1220 Vienna, Austria (hereinafter referred to as "UNIDO"), and **MANIPAL UNIVERSITY JAIPUR**, having its principal office located at Dehmi Kalan, Off Jaipur-Ajmer Expressway, Jaipur - 303007, Rajasthan, India, (hereinafter referred to as the "Contractor"). UNIDO and the Contractor are collectively referred to herein as the "Parties" and each individually as a "Party".

WHEREAS, UNIDO, in response to a request from the Government of India (hereinafter referred to as the "Government"), has agreed to provide assistance to the Government in carrying out the project entitled "Firm-level demonstration of technologies and productivity enhancement for the pulp and paper industry (hereinafter referred to as the "Project") in India (hereinafter referred to as the "Project Area");

WHEREAS, in this connection, UNIDO, acting in agreement with the Government, desires to engage a contractor to provide the services and perform the work hereinafter set forth;

WHEREAS, UNIDO intends to procure services required to implement manufacturing excellence /lean manufacturing tools in selected pulp and paper mills in the Project Area; and

WHEREAS, the Contractor represents that it possesses the requisite knowledge, skill, personnel, resources and experience and that it is fully qualified, ready, willing, and able to provide such services (as defined below) and perform such work in accordance with the terms and conditions set forth in this Contract;

NOW, **THEREFORE**, the Parties hereto mutually agree as follows:

ARTICLE 1

SCOPE OF THE CONTRACT

In accordance with the terms and conditions stated herein and in the Annexes hereto, the Contractor shall provide all the services (hereinafter referred to as the "Services") as described in detail in the terms of reference dated 02 June, 2023, as subsequently clarified and/or amended in writing by UNIDO, (hereinafter collectively referred to as the "Terms of Reference") and the Contractor's proposal dated 09 June, 2023, which the Contractor submitted to UNIDO in response to UNIDO's Request for Proposal No. 7000006278 dated 02 June, 2023 and clarified by e-mails dated 29 June, 2023 and 05 & 06 July, 2023 (hereinafter collectively referred to as the "Proposal"). The Contractor's said Proposal although not attached hereto, is made a part hereof by way of reference.

ARTICLE 2

CONTRACT DOCUMENTS

This document, together with the Annexes attached hereto and referred to below, all of which are incorporated herein and made part hereof, constitute the entire contract between UNIDO and the Contractor for the provision of the Services (hereinafter referred to as the "Contract"). The Contract supersedes all prior representations, agreements, contracts and proposals, whether written or oral, by and between the Parties with regard to the subject matter. The documents comprising the Contract are complementary to one another, but in case of ambiguities, discrepancies or inconsistencies between or among them, the following order of priority for purposes of application and interpretations shall apply:

i. This document;

ii. General Conditions of Contract (hereinafter referred to as "GCC") (Annex A);

iii. Terms of Reference (Annex B);

iv. Proposal.

ARTICLE 3

ENTRY INTO FORCE AND DURATION

The Contract shall enter into force upon the date of the last signature by the duly authorized representatives of the Parties, and shall remain in force until satisfactory fulfillment of all contractual terms and conditions unless terminated earlier pursuant to the terms of the Contract.

ARTICLE 4

DELIVERABLES

The Contractor shall submit to UNIDO in English in one electronic copy of editable format the following deliverables:

Deliverable 1: Conduct of experiments for feed characterization and pre-treatment of plastic waste and corresponding report as specified in section "scope of the proposed contracted services" at Section 3 at Sl # 3 a and c) of this Terms of Reference **within 2 months from the date of issuance of contract.**

Deliverable 2: Experiments for thermochemical conversion of plastic waste through pyrolysis (for conversion into oil, char and syn gas), process optimization and corresponding report on "technical process and findings of experiments conducted for thermochemical conversion of plastic waste through pyrolysis (for conversion into oil, char and syn gas) and process optimization"; as specified in section "scope of the proposed contracted services" at Section 3 at Sl # 3 b and c) of this Terms of Reference **within 5 months from the date of issuance of contract.**

Deliverable 3: Final Report on "experiments and studies conducted covering background of the thermochemical conversion process, assessment of this pyrolytic conversion vis-à-vis comparable treatment/technology options; strategy adopted and rationale for choice of optimal process parameters; results of experiments conducted; and estimated technoeconomic parameters for scaling up adoption of pyrolytic conversion of plastic wastes from RCF-based paper mills"; as specified in section "scope of the proposed contracted services" at Section 3 at Sl # 3 c) of this Terms of Reference **within 6 months from the date of issuance of contrac**t.

ARTICLE 5

PERSONNEL

For the performance of its obligations under the Contract, the Contractor shall make available in line with the Contractor's Proposal.

The Key Personnel to be provided by the Contractor, their project function and the duration of their assignments shall be as follows:

Name	Project Function
Dr. Abhishek Sharma	Project Leader
Dr. Rahul Goyal	Project Team member
Dr. Anand Gupta Chakinala	Project Team member
Dr. Dharmesh Yadav	Project Team member

The Contractor's Team Leader shall be: Dr. Abhishek Sharma

ARTICLE 6

CONTRACT PRICE

UNIDO shall pay the Contractor for the full and proper performance of its obligations under the Contract the sum of USD 19,347 (including GST *); hereinafter referred to as the "Contract Price".

Progress payments on account of the Contract Price shall be made in the currency and in the pro-rated amounts, against receipt and acceptance of the Contractor's invoices, as follows:

[USD]

i. 20% upon UNIDO's receipt of the duly countersigned contract - USD 3,869.40
ii. 20% upon completion of Deliverable - 1 and acceptance of the corresponding report by UNIDO- USD 3,869.40
iii. 50% upon submission of Deliverable -2 and acceptance of the corresponding report by UNIDO - USD 9,673.50
iv. 10% upon acceptance of the Final report by UNIDO - USD 1,934.70

Grand Total: USD 19, 347 (inclusive of GST)

No payment shall be released until receipt by UNIDO, along with the countersigned Contract, of the Bank Information Form, which shall be completed, signed and stamped by the Contractor.

* GST to be claimed separately

ARTICLE 7

COMMUNICATIONS

Official communications in relation to the Contract shall be in English and shall be made to the following contact persons:

UNIDO:

For contractual matters:

Mr. Farrukh Alimdjanov
Project Manager
Industrial Development Officer, TCS/DAS
UNIDO
Wagramer Strasse 5
A-1220 Vienna
Austria
Tel.: +43 1 26026 Ext. [5090]
Email: F.ALIMDJANOV@UNIDO.ORG

Contractor:

Dr. Abhishek Sharma
Professor of Chemical Engineering, Faculty of Engineering
MANIPAL UNIVERSITY JAIPUR (MUJ)
Dehmi Kalan, Off Jaipur-Ajmer Expressway
Jaipur – 303007
State-Rajasthan-India
Tel.: +91- 7073024573
Email: abhishek.sharma@jaipur.manipal.edu

IN WITNESS WHEREOF, the Parties hereto have executed this Contract.

For and on behalf of **UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION** By.....…… Mr. Farrukh Alimdjanov Project Manager Industrial Development Officer, TCS/DAS UNIDO Wagramer Strasse 5, A-1220 Vienna Austria Date.....……	For and on behalf of **Manipal University Jaipur** By.....…… Dr. Abhishek Sharma Professor of Chemical Engineering Faculty of Engineering MANIPAL UNIVERSITY JAIPUR Dehmi Kalan, Off Jaipur-Ajmer Expressway Jaipur – 303007, Rajasthan India Date.....……

****

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

TERMS OF REFERENCE

For services related to "bench-scale experimentation related to thermochemical conversion (through pyrolysis) of plastic wastes generated from recycled-fibre based paper mills."
Project ID 180200

1. GENERAL BACKGROUND INFORMATION

The United Nations Industrial Development Organization (UNIDO) is the specialized agency of the United Nations that promotes industrial development for poverty reduction, inclusive globalization and environmental sustainability. UNIDO supports countries to industrialize in ways that foster digital and green transitions and accelerate progress with the Sustainable Development Goals. UNIDO provides support to its 171 Member States through four mandated functions: technical cooperation; action-oriented research and policy-advisory services; normative standards-related activities; and fostering partnerships for knowledge and technology transfer. The Directorate of Technical Cooperation and Sustainable Industrial Development (TCS), headed by a Managing Director, oversees the Organization's development of capacities for industrial development as well as industrial policy advice, statistics and research activities and the Organization's normative contribution to Member States and global development community in achieving the SDGs. The Directorate also ensures the application of strategies and interventions for sustainable industrial development related to Environment, Energy, SMEs, Competitiveness and Job creation, as well as Digitalization and Artificial Intelligence.

One of the projects implemented by UNIDO is a project in India ''Firm-level demonstration of technologies and productivity enhancement for the pulp and paper industry" funded by the Department for Promotion of Industry and Internal Trade (DPIIT), Ministry of Commerce and Industry, Government of India. The objective of the project is to enhance the productivity and competitiveness of the Indian pulp and paper industry. This project aims to demonstrate process improvement interventions as well as the applicability of two innovative technologies in Indian paper mills.

2. AIM OF THE PROJECT

The objective of the current project is to contribute to enhancing the productivity and competitiveness of the Indian pulp and paper industry. The project aims to achieve this objective through two types of interventions at the firm level: (i) demonstration of process optimization and productivity enhancement measures and (ii) demonstration of innovative technologies (Membrane filtration technology, black liquor heat treatment technology and application of Chlorine dioxide).

Under this project, it is aimed to explore and demonstrate a potential option for the utilization of plastic wastes generated in recycled fibre (RCF)-based paper mills. India produces approximately 22 million tonnes of paper per annum (including paper, paperboard, and newsprint). About ~73% of this production comes from mills using recycled fibre (or wastepaper) as the primary fibre source for the production of paper, paperboard, and newsprint. RCF-based mills generate over 0.5 million tonnes of plastic wastes per

annum, disposal of which is a major challenge for the paper industry, from an environmental point of view. Disposal also represents a productivity loss and waste of resources with potential alternative, albeit unexplored, applications.

It is envisaged to facilitate bench-scale experimentation to explore the feasibility of (i) thermochemical conversion of plastic waste generated in paper mills into pyrolysis oil, char and syn gases through pyrolysis; (ii) utilization of the resultant oil as a boiler fuel or for blending applications along with diesel fuel in paper mills; and (iii) utilization of resultant syn gaseous fractions for heating of pyrolysis reactor for sustaining the energy requirement of the process.

In this context, UNIDO is looking to identify a suitable technical institution to conduct bench-scale experiments at their facilities, as per the details provided in the following sections.

3. THE SCOPE OF THE PROPOSED CONTRACTED SERVICES

The scope of the Terms of Reference (ToR) includes activities related to conducting bench-scale experimentation related to thermochemical conversion (through pyrolysis) of paper wastes generated from recycled-fibre based paper mills. In context of the aforementioned, UNIDO would like to receive a technical offer (inclusive of tentative implementation schedule) and a respective cost estimate in the form of a proforma invoice for the activities defined and listed below:

a) Experiments for feed characterization and pre-treatment:
   - Conduct bench-scale experiments and trials for characterization and pre-treatment for feed plastic waste, prior to experiments for thermochemical conversion through pyrolysis.

b) Experiments for thermochemical conversion of plastic waste through pyrolysis (for conversion into oil, char and syn gas) and process optimization:
   - Conduct bench-scale experiments using a pyrolysis reactor[1] to determine optimal process conditions of the pyrolytic process that would convert plastic wastes (emerging from RCF-based paper mills) into oil, char and syn/fuel gases. Process optimization and related adjustments would be done with a view to understand the conversion behavior and product generation via thermochemical treatment process, and would aim to maximize oil yields and enhance quality of oil generated (which would involving upgrading or separation of oil fractions including yield estimation of liquid, solid and gaseous products in different operating conditions).
   - Conduct studies on oil generated through pyrolysis of the plastic waste to explore the feasibility of its use as a boiler fuel or feasibility of blending this oil with diesel fuel in paper mills.
   - Conduct studies to assess the generated syngas in terms of composition and calorific value to determine its usage for heating the pyrolysis reactor and other thermal requirements of the thermochemical conversion process.

c) Preparation of three reports on:
   - Findings of feed characterization and pre-treatment experiments/studies;
   - Technical process and findings of experiments conducted for thermochemical conversion of plastic waste through pyrolysis (for conversion into oil, char and syn gas) and process optimization;

[1] It is expected that potential bidders would already be in possession of a pyrolysis reactor for the intended experiments. Purchase of additional equipment is not within the scope of this contract.

- Final report on experiments and studies conducted covering background of the thermochemical conversion process, assessment of this pyrolytic conversion vis-à-vis comparable treatment/technology options; strategy adopted and rationale for choice of optimal process parameters; results of experiments conducted; and estimated technoeconomic parameters for scaling up adoption of pyrolytic conversion of plastic wastes from RCF-based paper mills.

4. LOCATION

The services as defined in the scope of this ToR are required to be carried out in the Republic of India.

5. GENERAL TIME SCHEDULE

The scope of services, as defined in section 3 are to be completed in no more than **six months from the date of issuance of contract.** Interim deadlines for different activities are indicated below:

S.No.	Milestones	Month
1	Experiments for feed characterization and pre-treatment of plastic waste and report	Within 2 months from issuance of contract
2	Experiments for thermochemical conversion of plastic waste through pyrolysis (for conversion into oil, char and syn gas) and process optimization and report	Within 5 months from issuance of contract
5	Final report	Within 6 months from issuance of contract

6. PERSONNEL REQUIREMENTS

Technical and Functional Experience

a) The bidding institution should demonstrate at least 10 years' experience in providing research and testing-related services related to chemical engineering or related areas.
b) The experts undertaking the assignment from the bidding institutions should have a minimum of a post-graduate degree in chemical engineering or related areas.
c) The experts undertaking the assignment from the bidding institutions should have a minimum of 8 years' work experience in providing research or testing-related services.
d) CVs of the expert(s) should be submitted in order to demonstrate respective backgrounds (1 electronic copy each, to be included in the offer).
e) Fluency in written and spoken English is required.

7. LANGUAGE REQUIREMENTS

All written material submitted to UNIDO should be in English and of such quality that no additional technical editing is required.

8. DELIVERABLES

Conclusion of contract implies delivery of:

a) Conduct of experiments for feed characterization and pre-treatment of plastic waste;
b) Report on experiments for feed characterization and pre-treatment of plastic waste;

c) Conduct of experiments for thermochemical conversion of plastic waste through pyrolysis (for conversion into oil, char and syn gas) and process optimization;

d) Report on experiments for thermochemical conversion of plastic waste through pyrolysis (for conversion into oil, char and syn gas) and process optimization;

e) Final report.

9. QUALIFICATION REQUIREMENTS

Following are qualification requirements for bidders' offer to be considered:

a) Corporate registration: The bidder should provide a certified copy of their Certificate of Incorporation or other documents setting forth the legal basis of the company/organization and therefore proving a legal capacity to enter into a contract.

b) **Authorization:** The bidder should provide a copy of relevant licenses and/or authorizations enabling the company to perform the services required under the RFP.

c) Internationally recognized quality standards: The bidder should provide evidence of relevant accreditation and/or relevant international quality standards.

d) **Years in business:** The bidder should be able to evidence existence of operations for at least ten (10) years.

e) **Required financial information:** The bidder shall provide a certified copy of its Financial Statements for the last 3 years of business (if the bidder has not been in business for 3 years Certified Financial Statements for the period that they have been in business should be provided).

f) Failure by the bidder to meet mandatory qualification requirements will exclude the bidder from further consideration in the procurement process.

10. EVALUATION CRITERIA

COMMERCIAL

a) Total price/cost: The total cost of the services to be delivered as per the details provided in the Terms of Reference. Financial proposal to be included as per format attached in Annex I.

b) Payment Schedule: The bidders comply with the following payment schedule:

Deliverable	**Instalment against deliverable**
Signing of contract	20%
Experiments for feed characterization and pre-treatment of plastic waste and report	20%
Experiments for thermochemical conversion of plastic waste through pyrolysis (for conversion into oil, char and syn gas) and process optimization and report	50%
Final report	10%

CONTRACTUAL

a) **Agreement to the UNIDO contractual terms and conditions:** The bidder should confirm the acceptance of UNIDO contractual terms and conditions.

b) **Scope**: The bidder should confirm agreement to deliver scope of services as outlined in section 3 of the Terms of Reference.

TECHNICAL

a) Compliance with requirements of the Terms of Reference:

- The bidder should submit a technical proposal in compliance with the Terms of Reference, as well as detailed descriptions of sub-activities.
- The proposer should submit a narrative description of implementation plan to be used for the delivery of requested services, including an explanation of understanding of the work to be performed and the services to be provided and the overall operational plan for the execution of the work.
- Workplan for delivery of requested services should include proposed timeline/delivery schedule with clear milestones.

b) Management:

- The bidder should indicate facilities (in terms of testing laboratory, equipment and other resources) available in line with scope of services specified in the Terms of Reference.
- The bidder should indicate experience of fulfilling contracts of a similar nature to the scope of services specified in this Terms of Reference.

c) Personnel qualifications:

Technical qualifications and experience of the proposed principal personnel must meet the requirements specified in this Terms of Reference.

11. SUBMISSION OF OFFERS

a) The terms set forth in this ToR and in UNIDO General Conditions of Contract, will form a part of any contract should UNIDO accept bidder´s offer.

b) The bidder´s offer must be signed by an official legally authorized to enter into contracts on behalf of the bidder.

c) Together with an offer, following statements must be submitted by the bidder:

i) A statement that bidder has carefully reviewed the Contract/Purchase Order Form and UNIDO General Conditions and is in agreement with its terms and conditions.

ii) A statement that bidder's quotation is valid for a minimum period of 60 days from the date of the quotation. Once the offer is accepted during this period, the price quoted must remain unchanged for the entire period of the resulting contract.

iii) The bidder should also commit in writing, on company paper signed by the official signatory of the company, to following:

- company pursues a zero tolerance towards fraud and corruption;
- company confirms that not of its managers/administrators /owners has been convicted of any crime
- company confirms absence of conflict of interest of its employees, managers / administrators or owners in relation to this tender;
- company confirms that it is not and has not been suspended /barred from doing business with any UN or other public organization.

12. AWARD CONDITION

UNIDO reserves the right to split an award between any suppliers in any combination, as it may deem appropriate. If the quotation is submitted on an "all or none" basis, it should be clearly stated as such in your response to this RFP.

ANNEX I: FINANCIAL PROPOSAL FORMAT

Financial proposal format

- **A.** This form is a standardized document, which the bidder must submit to UNIDO in connection with this contract for delivery of technical/expert services.
- **B.** Where a particular cost element is not appropriate for the proposed contract, please indicate "Not applicable" or "NA" on the form.
- **C.** In addition to the cost breakdown on this form, the bidder, in good faith, should submit with this form any additional data, supporting schedules and substantiation, which are reasonably necessary for the conduct of an appropriate review of the proposed contract costs. Failure to furnish the information requested on this form may render his proposal non-responsive.
- **D.** If a cost is included in a particular item, do not duplicate the cost or any portion thereof in another item on the form.
- **E.** Unless otherwise advised, all costs on the form should be stated in Indian Rupees (INR) equivalent United States dollars.

Grand Total and Sub-totals

UNIDO RFP reference No.
Specification of Supply

UNIDO REQUIREMENTS		**TO BE COMPLETED BY THE INVITEE**				
Item	**Name and required parameters**	**Qty**	**Unit price Currency**	**Total price Currency**	**Compliance Yes/no *)**	**Remarks**
	I. Technical Services, incl.					
1						
2						
…						
	Sub-total:					
	II. Equipment, parts, supplies					
1						
2						
…						
	Sub-total:					
	III. Installation, commissioning					
	IV. Cost of transportation & insurance					
	V. Taxes, as applicable					
	Total price:					

*****

Annex A

UNIDO GENERAL TERMS AND CONDITIONS

1.Confidential Nature of Documents

All maps, drawings, photographs, mosaics, plans, reports, recommendations, estimates, documents and all other data compiled by or received by the Contractor under this Contract shall be the property of UNIDO, shall be treated as confidential and shall be delivered only to UNIDO's authorized officials on completion of the work under this Contract; their contents shall not be made known by the Contractor, without the written consent of UNIDO, to any person other than the personnel of the Contractor performing services under this Contract. The obligations of this paragraph do not lapse upon satisfactory completion of the work under this Contract or termination of this Contract, including termination by UNIDO.

2.Independent Contractor.

The Contractor shall have the legal status of an independent contractor. Any person assigned by the Contractor to perform services under this Contract shall remain in the employment of the Contractor. The Contractor's personnel and sub-contractors shall not be considered in any respect as being the employees or agents of UNIDO or the United Nations. Without restricting the generality of the foregoing, UNIDO shall not be liable for any claims and demands, loss, costs, damages, actions, suit or other proceedings, brought or prosecuted, in any manner based upon, occasioned by or attributable to the employment relationship between any person assigned by the Contractor to perform services under this Contract and the Contractor. Unless otherwise provided for in this Contract, UNIDO shall not be liable for claims of any kind in connexion with the performance of such services. The Contractor and his employees shall conform to all applicable laws, regulations and ordinances promulgated by legally constituted authorities of the Government.

3.The Contractor's Responsibility for Employees

The Contractor shall supervise and be fully responsible for the work performed by and the professional and technical competence of his employees and shall select, for work under this Contract, reliable individuals who will perform effectively in the implementation of the Contract, comply with the laws of the Government, respect the local customs and conform to a high standard of moral and ethical conduct.

4.Assignment of Personnel

The Contractor shall not assign any personnel other than those referred to in this Contract for the performance of work in the field without the prior written approval of UNIDO. Prior to assigning any other personnel for the performance of work in the field, the Contractor shall submit to UNIDO for its consideration, the curriculum vitae of any person the Contractor proposes to assign for such service.

5.Removal of Personnel

Upon written request by UNIDO, the Contractor shall withdraw from the field any personnel provided under this Contract and shall replace such personnel by other acceptable to UNIDO, if UNIDO so requests. All costs and additional expenses resulting from the replacement, for whatever reason, of any of the Contractor's personnel shall be for the account of the Contractor. Such withdrawal shall not be considered as termination in part or in total of this Contract under the provisions of paragraph 12 "Termination" hereafter.

6.Assignment

The Contractor shall not assign, transfer, pledge or make other disposition of this Contract or any part thereof or of any of the Contractor's rights, claims or obligations under this Contract except with the prior written consent of UNIDO.

7.Sub-Contracting

In the event the Contractor requires the services of sub-contractors, the Contractor shall obtain the prior written approval and clearance of UNIDO for all sub-contractors. UNIDO's approval of a sub-contractor shall not relieve the Contractor of any of his obligations under this Contract, and the terms of any sub-contract shall be subject to and in conformity with the provisions of this Contract.

8.UNIDO Privileges and Immunities

Nothing in or relating to this Contract shall be deemed a waiver of any of the privileges and immunities of UNIDO**.**

9.Non-employment of UNIDO Staff Members

The Contractor shall not, while this Contract is in effect, employ or consider the employment of UNIDO staff members without the prior written approval of UNIDO.

10.Language, Weights and Measures

Unless otherwise specified in the Contract, the English language shall be used by the Contractor in all written communications to UNIDO with respect to the services to be rendered and all documents procures or prepared by the Contractor pertaining to the work. The Contractor shall use the metric system of weights and measures and estimates of quantities involved shall be made and recorded in metric units, except when otherwise specified in the Contract.

11.Force Majeure

Force Majeure as used herein shall mean acts of God, laws or regulations, industrial disturbances, acts of the public enemy, civil disturbances, explosions and any other similar event of equivalent force not caused by nor within the control of either party and which neither party is able to overcome. As soon as possible after the occurrence of any event constituting Force Majeure, and if the Contractor is thereby rendered unable, wholly or in part, to perform its obligations and meet its responsibilities under this Contract, the Contractor shall give notice and full particulars thereof in writing to UNIDO. In this event, the following provisions shall apply:

(a) The obligations and responsibilities of the Contractor under this Contract shall be suspended to the extent of its inability to perform them and for as long as such inability continues. During such suspension and in respect of work suspended, the Contractor shall be entitled only to reimbursement by UNIDO, against appropriate vouchers, of the essential costs of maintenance of any of the Contractor's equipment and of per diem of the Contractor's personnel rendered idle by such suspension.

(b) The Contractor shall, within fifteen (15) days of the occurrence of the Force Majeure, submit a statement to UNIDO of estimated expenditures for the duration of the period of suspension.

(c) The term of this Contract shall be extended for a period equal to the period of suspension taking, however, into account any special conditions which may cause the time for completion of the work to be different from the period of suspension.

(d) If the Contractor is rendered permanently unable, wholly or in part, by reason of Force Majeure, to perform its obligations and meet its responsibilities under this Contract, UNIDO shall have the right to terminate this Contract on the same terms and conditions as are provided for in paragraph 12, "Termination" except that the period of notice may be seven (7) days instead of thirty (30) days.

(e) For the purpose of the preceding sub-paragraph (d), UNIDO may consider the Contractor permanently unable to perform in case of any period of suspension in excess of ninety (90) days. Any such period of ninety (90) days or less shall be deemed temporary inability to perform.

…/…

12.Termination

UNIDO may terminate this Contract in whole or in part and at any time, upon thirty (30) days' notice of termination to the Contractor. The initiation of arbitral proceedings in accordance with paragraph 16, "Arbitration", below shall not be deemed a termination of this Contract. In the event such termination is not caused by the Contractor's negligence or fault, UNIDO shall be liable to the Contractor for payment in respect of work already accomplished, for the cost of repatriation of the Contractor's personnel, for necessary terminal expenses of the Contractor, and for the cost of such urgent work as is essential and as the Contractor is asked by UNIDO to complete. The Contractor shall keep expenses at a minimum and shall not undertake any forward commitment from the date of receipt of UNIDO's notice of termination.

13.Bankruptcy

Should the Contractor be adjudged bankrupt or be liquidated or become insolvent, or should the Contractor make a general assignment for the benefit of its creditors, or should a receiver be appointed on account of the Contractor's insolvency, UNIDO may, without prejudice to any other right or remedy it may have under the terms of this Contract, terminate this Contract forthwith by giving the Contractor written notice of such termination. The Contractor shall immediately inform UNIDO of the occurrence of any of the above events.

14.Insurance and Liabilities to Third Parties

(a) The Contractor shall provide and thereafter maintain insurance against all risks in respect of its property and any equipment used for the execution of this Contract.

(b) The Contractor shall provide and thereafter maintain all appropriate workmen's compensation insurance, or its equivalent, with respect to its employees to cover claims for personal injury or death in connection with this Contract.

(c) The Contractor shall also provide and thereafter maintain liability insurance in an adequate amount to cover third party claims for death or bodily injury, or loss of or damage to property, arising from or in connection with the provision of services under this Contract or the operation of any vehicles, boats, airplanes or other equipment owned or leased by the Contractor or its agents, servants, employees or sub-contractors performing work or services in connection with this Contract.

(d) Except for the workmen's compensation insurance, the insurance policies under this Article shall:

(i) Name UNIDO as additional insured;

(ii) Include a waiver of subrogation of the Contractor's rights to the insurance carrier against UNIDO;

(iii) Provide that UNIDO shall receive thirty (30) days written notice from the insurers prior to any cancellation or change of coverage.

(e) The Contractor shall, upon request, provide UNIDO with satisfactory evidence of the insurance required under this Article.

(f) Any amounts not insured or not recovered from the insurers shall be borne by the Contractor.

If the Contractor fails to effect and keep in force any of the insurances required under the Contract, then and in any such case UNIDO may, at its option, hold the Contractor in default in accordance with the Contract, or effect and keep in force any such insurances and pay any premium as may be necessary for that purpose and from time to time deduct the amount so paid from any monies due to the Contractor, or recover the same as a debt due from the Contractor.

15.Indemnification

The Contractor shall indemnify, hold and save harmless and defend at its own expense UNIDO, its officers, agents, servants and employees from and against all suits, claims, demands and liability of any nature or kind, including costs and expenses, arising out of acts, omissions, negligence or misconduct of the Contractor or its officers, agents, servants, representatives, employees, or sub-contractors in the performance of this Contract. This requirement shall extend to claims or liabilities in the nature of workmen's compensation and to claims or liabilities arising out of the use of patented inventions or devices. The obligations under this paragraph do not lapse upon termination of this Contract.

16.Settlement of Disputes

(a) Amicable Settlement:

The Parties shall use their best efforts to settle amicably any dispute, controversy or claim arising out of, or relating to this Contract or the breach, termination or invalidity thereof. Where the parties wish to seek such an amicable settlement through conciliation, the conciliation shall take place in accordance with the UNCITRAL Conciliation Rules then obtaining, or according to such other procedure as may be agreed between the parties.

(b) Arbitration

Unless, any such dispute, controversy or claim between the Parties arising out of or relating to this Contract or the breach, termination or invalidity thereof is settled amicably under the preceding paragraph of this Article within sixty (60) days after receipt by one Party of the other Party's request for such amicable settlement, such dispute, controversy or claim shall be referred by either Party to arbitration in accordance with the UNCITRAL Arbitration Rules then obtaining, including its provisions on applicable law. The arbitral tribunal shall have no authority to award punitive damages. The parties shall be bound by any arbitration award rendered as a result of such arbitration as the final adjudication of any such dispute. It is understood, however, that the provisions of this paragraph shall not constitute nor imply the waiver by UNIDO of its privileges and immunities.

17.Conflict of Interest

No employee of the Contractor assigned to perform work under this Contract shall engage, directly or indirectly, either in his own name or through the agency of another person, in any business, profession or occupation in the country of the Government; nor shall he make loans to or investments in any business, profession, or occupation in the said country.

18.Obligations

In connexion with the performance of its services under this Contract, the Contractor shall neither seek nor accept instructions from any authority external to UNIDO. The Contractor shall refrain from any action which may adversely affect UNIDO and shall fulfill its commitments with full regard for the interests of UNIDO. Unless authorized in writing by UNIDO, the Contractor shall not advertise or otherwise make public the fact that it is performing or has performed services for UNIDO. Also, the Contractor shall not, in any manner whatsoever, use the name, emblem or official seal of the United Nations or of UNIDO or any abbreviation of the name of the United Nations in connexion with its business or otherwise. The Contractor is required to exercise utmost discretion in all matters relating to this Contract. Unless required in connexion with the performance of its work under this Contract or where specifically authorized by UNIDO, the Contractor shall not communicate at any time to any person, government or authority external to UNIDO any information which has not been made public and which is known to it by reason of its association with UNIDO. The Contractor shall not, at any time, use such information to private advantage. These obligations do not lapse upon satisfactory completion of the work under this Contract or termination of this Contract, including termination by UNIDO.

…/…

19.Title Rights

(a)The United Nations or UNIDO, as the case may be, shall be entitled to all property rights including but not limited to patents, copyrights and trademarks, with regard to material which bears a direct relation to, or results from the services provided to the United Nations or UNIDO by the Contractor under this Contract. At the request of UNIDO, the Contractor shall take all necessary steps, prepare and process all necessary documents and assist in securing such property rights and transferring them to the United Nations and UNIDO in compliance with the requirements of the applicable law.

(b)Title to any equipment and supplies which may be furnished by UNIDO shall rest with the United Nations or UNIDO as the case may be and any such equipment and supplies shall be returned to UNIDO at the conclusion of this Contract or when no longer needed by the Contractor. Such equipment and supplies, when returned to UNIDO, shall be in the same condition as when delivered by UNIDO to the Contractor, subject to normal wear and tear.

20.Facilities, Privileges and Immunities of Contractor and Contractor's Personnel

UNIDO agrees to use its best efforts to obtain for the Contractor and his personnel (except Government nationals employed locally), to the extent granted by the Government to UNIDO staff members, such facilities, privileges and immunities as the Government has agreed to grant to contractors and to their personnel performing services for the United Nations Development Programme within the country. Such facilities, privileges and immunities shall include exemption from or reimbursement of the cost of any taxes, duties, fees or levies which may be imposed in the country on salaries or wages earned by the Contractor's foreign personnel in connexion with the execution of the work under this Contract and on any equipment, materials and supplies which the Contractor may bring into the country in connection with the work under this Contract or which, after having been brought into the country, may be subsequently withdrawn there from. A copy of the relevant provisions concerning facilities, privileges and immunities that UNIDO shall seek to obtain, is attached to and made a part of this Contract (Annex B).

21.Waiver of Facilities, Privileges and Immunities

Any provision, whether in an Agreement, Plan of Operation or any other instrument, to which the recipient Government is a party and by which the recipient Government confers benefits upon the Contractor and his personnel in the form of facilities, privileges, immunities, or exemptions by reason of his performance of services for UNIDO under this Contract may be waived by the UNIDO where, in its opinion, the facility, privilege or immunity would impede the course of justice and can be waived without prejudice to the successful completion of the work under this Contract or to the interest of the United Nations Development Programme or UNIDO.

22.Encumbrances/liens

The Contractor shall not cause or permit any lien, attachment or other encumbrance by any person to be placed on file or to remain on file in any public office or on file with UNIDO against any monies due or to become due for any work done or materials furnished under this Contract, or by reason of any other claim or demand against the Contractor.

23.Tax Exemption

(a) In accordance with Section 7 of the Convention on the Privileges and Immunities of the United Nations and Section 9 of the Convention on the Privileges and Immunities of Specialized Agencies which are applicable to UNIDO by virtue of Article 21 of its Constitution, UNIDO is exempt from all direct taxes, except charges for public utility services, and is exempt from customs duties and charges of a similar nature in respect of articles imported or exported for its official use. In the event any governmental authority refuses.to recognize UNIDO's exemption from such taxes, duties or charges, the Contractor shall immediately consult with UNIDO to determine a mutually acceptable procedure.

(b) Accordingly, the Contractor authorizes UNIDO to deduct from the Contractor's invoice any amount representing such taxes, duties or charges, unless the Contractor has consulted with UNIDO before the payment thereof and UNIDO has, in each instance, specifically authorized the Contractor to pay such taxes, duties or charges under protest. In that event, the Contractor shall provide UNIDO with written evidence that payment of such taxes, duties or charges has been made and appropriately authorized.

24.Child labor

(a) The Contractor represents and warrants that neither him, nor any of his suppliers is engaged in any practice inconsistent with the rights set forth in the Convention on the Rights of the Child, including Article 32 thereof, which, inter alia, requires that a child shall be protected from performing any work that is likely to be hazardous or to interfere with the child's education, or to be harmful to the child's health or physical mental, spiritual, moral or social development.

(b) Any breach of this representation and warranty shall entitle UNIDO to terminate this Contract immediately upon notice to the Contractor, without any liability for termination charges or any other liability of any kind of UNIDO.

25.Mines

(a) The Contractor represents and warrants that neither him, nor any of his suppliers is actively and directly engaged in patent activities, development, assembly, production, trade or manufacture of mines or in such activities in respect of components primarily utilized in the manufacture of Mines. The term "Mines" means those devices defined in Article 2, Paragraphs 1, 4 and 5 of Protocol II annexed to the Convention on Prohibitions and Restrictions on the Use of Certain Conventional Weapons Which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects of 1980.

(b) Any breach of this representation and warranty shall entitle UNIDO to terminate this Contract immediately upon notice to the Contractor, without any liability for termination charges or any other liability of any kind of UNIDO.

Waste Generation and Disposal Report

MANIPAL UNIVERSITY
JAIPUR
(University under Section 2(f) of the UGC Act)

SOLID WASTE MANAGEMENT- Segregation & Collection at Source

Solid waste Generation Data

MANIPAL UNIVERSITY
JAIPUR
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MEDICAL WASTE SEGREGATION MANAGEMENT

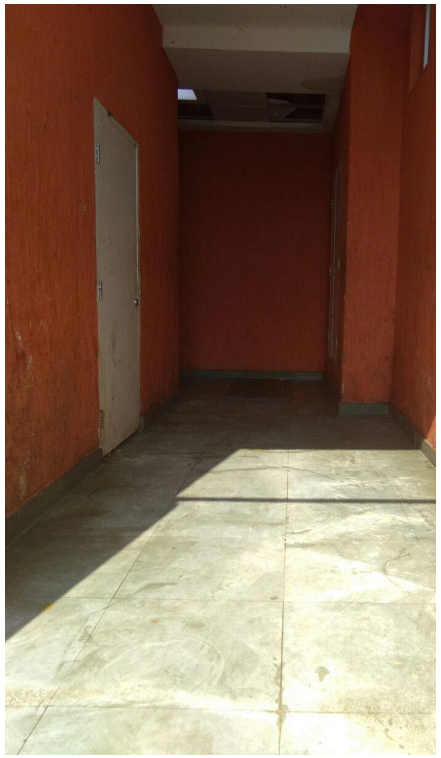
MANIPAL UNIVERSITY
JAIPUR
(University under Section 2(f) of the UGC Act)

SOLID KITCHEN WASTE MANAGEMENT

Sr.No.	Department/ Area of source of waste (Everypoint of waste generation within the campus should be identified and listed - cross	Types of waste generated in each of the point source (for each type of waste, use separate row)						Dry (in kgs/ day
		Food wastage	Paper/Card board	Plastic	Wood	Glass	Metal	
Mar-19	MUJ Academic Blocks		6790	65	60		120	7035
Mar-19	MUJ HOSTEL Blocks	4279						
Apr-19	MUJ Academic Blocks		92	33	44	0	20	189
Apr-19	MUJ HOSTEL Blocks	3689					940	940
May-19	MUJ Academic Blocks		73	28	31	2	17	151
May-19	MUJ HOSTEL Blocks	2452		591			860	1451
Jun-19	MUJ Academic Blocks		68	25	31	1	17	142
Jun-19	MUJ HOSTEL Blocks	1160					700	700
Jul-19	MUJ Academic Blocks		85	36	45	0	26	192
Jul-19	MUJ HOSTEL Blocks	4638					240	240
Aug-19	MUJ Academic Blocks		101	40	47	0	29	217
Aug-19	MUJ HOSTEL Blocks	4596		260			380	640
Sep-19	MUJ Academic Blocks		97	30	62	1	37	227
Sep-19	MUJ HOSTEL Blocks	2839						
Oct-19	MUJ Academic Blocks		170	95	92	0	82	357
Oct-19	MUJ HOSTEL Blocks	4799						
Nov-19	MUJ Academic Blocks		66	55	71	0	75	192
Nov-19	MUJ HOSTEL Blocks	4155						
Dec-19	MUJ Academic Blocks		81	58	48	0	45	187
Dec-19	MUJ HOSTEL Blocks	2033						
Jan-20	MUJ Academic Blocks		112	62	51	0	76	225
Jan-20	MUJ HOSTEL Blocks	6195						
Feb-20	MUJ Academic Blocks		73	70	51	8	82	202
Feb-20	MUJ HOSTEL Blocks	6178						
Mar-20	MUJ Academic Blocks		55	50	46	8	49	159
Mar-20	MUJ HOSTEL Blocks	5159						
Apr-20	MUJ Academic Blocks		23	17	26	2	17	68
Apr-20	MUJ HOSTEL Blocks	NIL						
May-20	MUJ Academic Blocks		40	46	35	5	41	126
Jun-20	MUJ Academic Blocks		38	35	24	3	42	100
Jul-20	MUJ Academic Blocks		43	33	33	6	59	115
Aug-20	MUJ Academic Blocks		20	21	31	3	26	75
Sep-20	MUJ Academic Blocks		27	16	22	6	41	71

Collection frequency & clearance: Twice a day

Time: 9:00 AM & 4:00 PM



MANIPAL UNIVERSITY
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HUMAN RESOURCE FOR WASTE MANAGEMENT

HOUSEKEEPING and SUPPORT STAFF AT MUJ

MANIPAL UNIVERSITY
JAIPUR
(University under Section 2(f) of the UGC Act)

DISPOSAL OF SOLID WASTE - INHOUSE

Solid Waste Management

1. Organic waste from kitchen and horticulture used in **Biogas Plant** which supplies fuel to Food Court.
2. Recyclable solid waste **collected separately**
3. Pilot project with BEIL (Bharuch Enviro Infrastructure Ltd) for converting MSW to Fuel / Energy.
4. Bio Medical waste is collected separately and Disposed
5. Papers printed on one side are not discarded but reused.

➢ **Agreement for external agency for partial waste management (click here)**

Bio-Gas generation system
30kg of Gas per day with 500 kg of Kitchen waste

MANIPAL UNIVERSITY
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LIQUID WASTE MANAGEMENT-INHOUSE- SEWAGE TREATMENT PLANT

MUJ is equipped with **4 STP** Plants with different capacity 1000 KLD, 350 KLD(two) and 150 KLD **IN TOTAL 1850 KLD**. Sewage treatment removes contaminants from wastewater, which includes physical, chemical, and biological processes to remove these contaminants and produce environmentally safer treated water (it has been used for flushing and gardening). In normalcy are producing 1850KL treated water per day.

➢ **Production of recycle waste-water report (click here)**

MANIPAL UNIVERSITY
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LIQUID WASTE MANAGEMENT-INHOUSE- SEWAGE TREATMENT PLANT

MANIPAL UNIVERSITY
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Waste Usage /COMPOSE PIT

1. Waste is collected from different corners of campus
2. After segregation, waste is put into compose pit
3. After a few weeks, earthworms and microorganisms in the soil convert the organic matter into useable compost.