

**DESIGN AND EVALUATION OF A LABORATORY SCALE TORREFACTION
MACHINE FOR RICE STUBBLES**

**ZACK PHILIP D. AQUINO
MELCHIOR M. SONG-AG**

An Undergraduate Thesis Submitted to the Faculty of the Department of Agricultural and
Biosystems Engineering, College of Engineering, Central Luzon State University,
Science City of Muñoz, Nueva Ecija, Philippines in Partial
Fulfillment of the Requirements
for the Degree of

**BACHELOR OF SCIENCE IN AGRICULTURAL
AND BIOSYSTEMS ENGINEERING
(AB Machinery and Power Engineering)**

JULY 2024

ACCEPTANCE SHEET

This undergraduate thesis entitled “**DESIGN AND EVALUATION OF A LABORATORY SCALE TORREFACTION MACHINE FOR RICE STUBBLES,**” prepared and submitted by **ZACK PHILIP D. AQUINO** and **MELCHIOR M. SONG-AG**, in partial fulfillment of the requirements for the degree of **BACHELOR OF SCIENCE IN AGRICULTURAL AND BIOSYSTEMS ENGINEERING**, is hereby accepted:


JOHN VINCENT A. NATE, M.Sc.
Member, Advisory Committee


MELBA D. DENSON, Ph.D.
Member, Advisory Committee

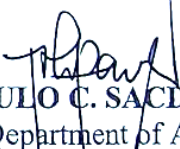
Date Signed

Date Signed


MARLON T. DELOS SANTOS, M.Sc.
Chairperson, Advisory Committee

Date Signed

Accepted as partial fulfillment of the requirements for the degree of **BACHELOR OF SCIENCE IN AGRICULTURAL AND BIOSYSTEMS ENGINEERING (AB MACHINERY AND POWER ENGINEERING)**:


JOHN PAULO C. SACDALAN, Ph.D.
Head, Department of Agricultural
and Biosystems Engineering

Date Signed


ROY SEARCA JOSE P. DELA CRUZ, Ph.D.
Acting Dean, College of Engineering

Date Signed

BIOGRAPHICAL SKETCH

Zack Philip D. Aquino was born on July 7, 2000, in Quezon City, located in Metro Manila, Philippines. From a young age, Zack displayed a remarkable aptitude for academic excellence and a deep passion for learning. His intellectual curiosity and dedication to his studies were evident early on.

Zack began his educational journey at Talang Elementary School in San Carlos City, Pangasinan. It was here that his commitment to academic excellence became apparent, earning him numerous honors and accolades throughout his elementary years. Continuing his educational pursuits, Zack attended Speaker Eugenio Perez National Agricultural School for his high school education. During these formative years, he continued to showcase his exceptional academic abilities and unwavering commitment to learning. His consistent efforts and dedication culminated in him completing Junior High School with honors. For his Senior High School education, Zack remained at Speaker Eugenio Perez National Agricultural School. Embracing the challenges of higher-level education with enthusiasm and determination, he once again excelled academically, graduating with honors. His achievements during this period further solidified his status as an exemplary student. Notably, Zack won first place in a regional research contest during his high school years, highlighting his research skills and academic prowess.

Zack Philip D. Aquino is currently pursuing a Bachelor of Science in Agricultural and Biosystems Engineering at Central Luzon State University in the Science City of Muñoz, Nueva Ecija. His dedication and intellectual capability propel his academic journey, exemplifying his commitment to education and pursuit of excellence.

BIOGRAPHICAL SKETCH

Mr. Melchior Song-ag was born on June 18th in Palayan City, Nueva Ecija, into a supportive family as the sixth child of Mr. Bello Song-ag and Mrs. Melita Song-ag. His academic journey began at Langka Elementary School, followed by graduation from Buklod-Palad National School, where he pursued the standard high school curriculum. In 2019, he completed his senior high school education with distinction, specializing in the Academic Track-GAS Strand at Maligaya Senior High School in Palayan City. Despite the distance from their hometown of General Tinio, his parents provided unwavering encouragement and belief in his abilities to continue his study in college.

Currently, Mr. Song-ag is enrolled at Central Luzon State University, located in the Science City of Muñoz, Nueva Ecija. Here, he is passionately pursuing a Bachelor of Science in Agricultural and Biosystems Engineering. His dedication to academic excellence and passion for agricultural innovation led him to be selected as a beneficiary of the Unified Financial Assistance System (UniFAST) scholarship under R.A. 10687.

Mr. Song-ag's journey embodies perseverance, dedication, and a commitment to contributing to the advancement of agricultural practices. With his family's support and his own determination, he is poised to make significant contributions to his field and community in the future.

ACKNOWLEDGMENT

With profound gratitude and immense appreciation, the authors extend their heartfelt thanks to the following, who made the completion of this study possible:

To their families, whose inspiration and unwavering encouragement have always driven them to achieve their best. Thank you for your continuous support, love, and emotional, spiritual, and financial assistance.

To the Chair and Members of the Advisory Committee, Engr. Marlon T. Delos Santos, Engr. John Vincent A. Nate, and Dr. Melba D. Denson, for their knowledge, encouragement, constructive feedback, and moral support, which were crucial to the completion of this study. Their understanding and patience are deeply appreciated.

To their former thesis adviser, Dr. Elmar M. Villota, whose guidance, support, and expertise were instrumental in the early stages of this study. His contributions to their study have been invaluable.

To their friends, deeply thank Engr. Emmanuel T. Villaruel for his invaluable assistance with statistical analysis. They also appreciate Mr. Jon Krixter L. Mañebo and their friends for their unwavering support and encouragement throughout the project.

And above all, they acknowledge the Almighty God for being a constant source of strength, love, wisdom, guidance, and inspiration throughout the journey, and for bestowing countless blessings along the way.

TABLE OF CONTENTS

	PAGE
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF APPENDICES	xi
LIST OF APPENDIX TABLES	xii
LIST OF APPENDIX FIGURES	xiii
ABSTRACT	xv
INTRODUCTION	1
Background of the Study	1
Statement of the Problem	3
Objectives of the Study	4
Significance of the Study	5
Scope and Limitation of the Study	6
Time and Place of the Study	6
REVIEW OF RELATED LITERATURE	7
Science and Principle of Torrefaction	7
Torrefaction Process Technique	10
Optimizing Biomass Torrefaction: Lab Insights and Reactor Innovations	12
Rotary Drum Reactor	16
Fixed Bed Reactor	17
Science of Induction	18
Rice Stubbles	20
METHODOLOGY	22
Conceptualization of the Study	22
Design Consideration	24
Design Drawing	24
Fabrication of the Torrefaction Machine	27
Rotary Drum Reactor Design Process	27
Torrefaction Machine Testing	29

	PAGE
Preliminary Testing	29
Final Testing and Evaluation	30
Materials and Instruments	31
Torrefaction Parameters	32
Operating Time	32
Torrefaction Time	32
Torrefaction Temperature	32
Heating Rate	33
Particle Size	33
Torrefaction Machine Performance	33
Pre-Treatment of the Rice Stubbles	35
Principle of Operation	36
Experimental Design	37
Data Gathering	39
Moisture Content Determination	39
Mass Yield	39
Hydrophobicity Test	40
Cost Analysis	40
Depreciation (D)	40
Return of Investment (ROI)	41
Fixed Cost (FC)	41
Total Operating Costs (TOC)	42
Operating Cost (OC)	42
Statistical Analysis	42
RESULTS AND DISCUSSION	45
Physical Description of the Torrefaction Machine	45
Performance of the Lab-Scale Torrefaction Machine	46
Heat Profile of the Reactor	46
Physical Characteristics of torrefied Products	49
Mass Yield	49
Physical comparison of torrefied biomass with different treatment	51

	PAGE
Color	51
Hydrophobicity	52
Recommended Torrefaction Operating Parameters	56
Cost Analysis	57
SUMMARY, CONCLUSION, AND RECOMMENDATIONS	61
Summary	61
Conclusion	63
Recommendations	65
LITERATURE CITED	67
APPENDIX I	75
Tables	75
APPENDIX II	82
Detailed Design Drawings	82
APPENDIX III	84
Figures	84

LIST OF TABLES

TABLE		PAGE
1	Yields of typical wood products at various thermal treatment temperature	9
2	Summary of recent studies on torrefaction of rice straw	13
3	Components and materials of the torrefaction machine	26
4	Problems encountered and actions taken during fabrication	29
5	Materials and instruments used during testing	31
6	Component specification of the lab scale torrefaction machine	46
7	Mean for mass yield at different temperature and residence time	49
8	Mean for water absorption at different temperature and residence time	52
9	Investment and operational analysis of a lab-scale torrefaction machine	57

LIST OF FIGURES

FIGURE		PAGE
1	Conceptual framework of the study	23
2	Torrefaction machine parts	26
3	Flowchart process of designing torrefaction machine	28
4	Pretreatment steps	36
5	Operational steps in machine	37
6	Randomization of the treatment	38
7	Design of the fabricated torrefaction machine	44
8	Average temperature profile within the reactor per treatment	47

LIST OF APPENDICES

APPENDIX		PAGE
I	Tables	75
II	Detailed design drawing	82
III	Figures	84

LIST OF APPENDIX TABLES

APPENDIX TABLES	PAGE
1 Estimated bill of materials of proposed design	75
2 Heat profile	76
3 ANNOVA table of mass yield	79
4 Mass of biomass after torrefaction	79
5 ANOVA table of water absorption	80
6 Water absorption of biomass	80
7 Summary of the data	81

LIST OF APPENDIX FIGURES

APPENDIX FIGURES	PAGE
1 Making the frame for the machine	84
2 Cement and reactor	84
3 Welding individual component members	85
4 Welding additional component to frame	85
5 Finished frame for the reactor	86
6 Fixing the threading of the reactor	86
7 Collecting rice stubble for torrefaction machine feedstock	87
8 Sun drying of the collected biomass	87
9 First phase of shredding	88
10 Second phase of shredding	88
11 Sifting grinded rice stubble into 1-2mm pieces	89
12 After sifting (1-2 mm rice stubbles)	89
13 During oven drying of rice stubble	90
14 Installing of two brass ball valves	90
15 Calibration and testing of thermocouple	91
16 Temperature value of thermocouple	91
17 Rice stubbles being put inside the reactor	92
18 Putting the thermocouple sensor inside(center) the reactor	92
19 Purging of nitrogen gas before the start of operation	93
20 Setting up the temperature	93

	PAGE	
21	Behavior of the coil (heating up) during the operation	94
22	First treatment at 200 °C	94
23	Second treatment at 250 °C	95
24	Purging of nitrogen gas every 7 minutes during the operation	95
25	Torrefied biomass (after the operation)	96
26	Weighing the torrefied biomass	96
27	Randomization	96
28	Biomass at different treatment after torrefaction	97
29	Comparison of Treatment 4 and treatment 5	98
30	Deionized water for immersion test	98
31	Physical characteristics and comparison of the torrefied and raw biomass	99
32	Before undergoing immersion test	100
33	Biomass was put in a container with deionized water	100
34	Submerge the biomass for 2 hrs.	101
35	Filtration of biomass	101
36	Submerge the biomass for 2 hrs.	102
37	Measure weight of the biomass after immersion test	102

LITERATURE CITED

- Abdurrahman, M. I., Chaki, S., & Saini, G. (2020). Stubble burning: Effects on health & environment, regulations and management practices. *Environmental Advances*, 2, 100011. <https://doi.org/10.1016/j.envadv.2020.100011>
- Abral, H., & Hartono, J. (2017). Moisture absorption of starch based biocomposites reinforced with water hyacinth fibers. *IOP Conference Series: Materials Science and Engineering*, 213, 012035. <https://doi.org/10.1088/1757-899x/213/1/012035>
- Adeleke, A. A., Odusote, J. K., Ikubanni, P. P., Lasode, O. A., Malathi, M., & Paswan, D. (2020). Essential basics on biomass torrefaction, densification and utilization. *International Journal of Energy Research*, 45(2), 1375–1395. <https://doi.org/10.1002/er.5884>
- Akogun, O. A., & Waheed, M. A. (2019). Property Upgrades of Some Raw Nigerian Biomass through Torrefaction Pre-Treatment- A Review. *Journal of Physics: Conference Series*, 1378(3), 032026. <https://doi.org/10.1088/1742-6596/1378/3/032026>
- Almeida, A., Ribeiro, A., Ramalho, E., & Pilão, R. (2018). Crude glycerol gasification in a fixed bed gasifier. *Energy Procedia*, 153, 149–153. <https://doi.org/10.1016/j.egypro.2018.10.060>
- Balingbing, C., Van Hung, N., Roxas, A. P., Aquino, D., Barbacias, M. G., & Gummert, M. (2020). An Assessment on the Technical and Economic Feasibility of Mechanized Rice Straw Collection in the Philippines. *Sustainability*, 12(17), 7150. <https://doi.org/10.3390/su12177150>
- Bhagwat, S., Ratnaparkhe, S., & Kumar, A. (2015). Biomass Pre-treatment Methods and Their Economic Viability for Efficient Production of Biofuel. *British Biotechnology Journal*, 8(2), 1–17. <https://doi.org/10.9734/bbj/2015/18284>
- Bird, J. O. (1987). Electromagnetic induction and inductance. *Elsevier EBooks*, 73–77. <https://doi.org/10.1016/b978-0-434-90154-8.50015-0>
- Biswas, B., Pandey, N., Bisht, Y., Singh, R., Kumar, J., & Bhaskar, T. (2017). Pyrolysis of agricultural biomass residues: Comparative study of corn cob, wheat straw, rice straw and rice husk. *Bioresource Technology*, 237, 57–63. <https://doi.org/10.1016/j.biortech.2017.02.046>
- Bridgwater, A. V. (1999). Principles and practice of biomass fast pyrolysis processes for liquids. *Journal of Analytical and Applied Pyrolysis*, 51(1-2), 3–22. [https://doi.org/10.1016/s0165-2370\(99\)00005-4](https://doi.org/10.1016/s0165-2370(99)00005-4)

- Bridgwater, A. V., Meier, D., & Radlein, D. (1999). An overview of fast pyrolysis of biomass. *Organic Geochemistry*, 30(12), 1479–1493. [https://doi.org/10.1016/s0146-6380\(99\)00120-5](https://doi.org/10.1016/s0146-6380(99)00120-5)
- Buchireddy, P. R., Peck, D., Zappi, M., & Bricka, R. M. (2021). Catalytic Hot Gas Cleanup of Biomass Gasification Producer Gas via Steam Reforming Using Nickel-Supported Clay Minerals. *Energies*, 14(7), 1875. <https://doi.org/10.3390/en14071875>
- Caldeira, C., Vlysidis, A., Fiore, G., De Laurentiis, V., Vignali, G., & Sala, S. (2020). Sustainability of food waste biorefinery: A review on valorisation pathways, techno-economic constraints, and environmental assessment. *Bioresource Technology*, 312, 123575. <https://doi.org/10.1016/j.biortech.2020.123575>
- Chapter 2 Stoichiometry and extent of decomposition. (1999). *Studies in Physical and Theoretical Chemistry*, 29–73. [https://doi.org/10.1016/s0167-6881\(99\)80003-2](https://doi.org/10.1016/s0167-6881(99)80003-2)
- Ciolkosz, D., & Wallace, R. (2011). A review of torrefaction for bioenergy feedstock production. *Biofuels, Bioproducts and Biorefining*, 5(3), 317–329. <https://doi.org/10.1002/bbb.275>
- Conde-Mejía, C., Jiménez-Gutiérrez, A., & El-Halwagi, M. (2012). A comparison of pretreatment methods for bioethanol production from lignocellulosic materials. *Process Safety and Environmental Protection*, 90(3), 189–202. <https://doi.org/10.1016/j.psep.2011.08.004>
- Demirbas, A., & Arin, G. (2002). An Overview of Biomass Pyrolysis. *Energy Sources*, 24(5), 471–482. <https://doi.org/10.1080/00908310252889979>
- Ding, L., Cheng, J., Qiao, D., Yue, L., Li, Y.-Y., Zhou, J., & Cen, K. (2017). Investigating hydrothermal pretreatment of food waste for two-stage fermentative hydrogen and methane co-production. *Bioresource Technology*, 241, 491–499. <https://doi.org/10.1016/j.biortech.2017.05.114>
- Edwards, E. (2023, December 6). *What is a 3-Phase Motor and How Does it Work?* [www.thomasnet.com. https://www.thomasnet.com/articles/machinery-tools-supplies/what-is-a-3-phase-motor-and-how-does-it-work/](https://www.thomasnet.com/articles/machinery-tools-supplies/what-is-a-3-phase-motor-and-how-does-it-work/)
- Fang, J., Zhan, L., Ok, Y. S., & Gao, B. (2018). Minireview of potential applications of hydrochar derived from hydrothermal carbonization of biomass. *Journal of Industrial and Engineering Chemistry*, 57, 15–21. <https://doi.org/10.1016/j.jiec.2017.08.026>

- G. Cuevas-Rodríguez, & I. Tejero-Monzón. (2003). Sedimentation and prefermentation of domestic wastewater in a fixed bed biofilm reactor. *Water Science & Technology*, 48(3), 47–55. <https://doi.org/10.2166/wst.2003.0158>
- Gan, Y. Y., Ong, H. C., Ling, T. C., Chen, W.-H., & Chong, C. T. (2019). Torrefaction of de-oiled *Jatropha* seed kernel biomass for solid fuel production. *Energy*, 170, 367–374. <https://doi.org/10.1016/j.energy.2018.12.026>
- Gontard, N., Sonesson, U., Birkved, M., Majone, M., Bolzonella, D., Celli, A., Angellier-Coussy, H., Jang, G.-W., Verniquet, A., Broeze, J., Schaer, B., Batista, A. P., & Sebok, A. (2018). A research challenge vision regarding management of agricultural waste in a circular bio-based economy. *Critical Reviews in Environmental Science and Technology*, 48(6), 614–654. <https://doi.org/10.1080/10643389.2018.1471957>
- Hakkou, M., Pétrissans, M., Gérardin, P., & Zoulalian, A. (2006). Investigations of the reasons for fungal durability of heat-treated beech wood. *Polymer Degradation and Stability*, 91(2), 393–397. <https://doi.org/10.1016/j.polymdegradstab.2005.04.042>
- Hsu, T.-C., Chang, C.-C., Yuan, M.-H., Chang, C.-Y., Chen, Y.-H., Lin, C.-F., Ji, D.-R., Shie, J.-L., Manh, D. V., Wu, C.-H., Chiang, S.-W., Lin, F.-C., Lee, D.-J., Huang, M., & Chen, Y.-H. (2018). Upgrading of *Jatropha*-seed residue after mechanical extraction of oil via torrefaction. *Energy*, 142, 773–781. <https://doi.org/10.1016/j.energy.2017.10.046>
- Huang, W.-J., Yu, C.-T., Sheu, W.-J., & Chen, Y.-C. (2021). The effect of non-uniform temperature on the sorption-enhanced steam methane reforming in a tubular fixed-bed reactor. *International Journal of Hydrogen Energy*, 46(31), 16522–16533. <https://doi.org/10.1016/j.ijhydene.2020.07.182>
- Huisman, M. (2023, July 11). *Electrification - Energy System*. IEA. <https://www.iea.org/energy-system/electricity/electrification>
- Jaya Shankar Tumuluru, Wright, C. T., Boardman, R., Hess, R. J., & Shahab Sokhansanj. (2011). *Review on Biomass Torrefaction Process and Product properties and Design of Moving Bed Torrefaction System Model Development*. <https://doi.org/10.13031/2013.37192>
- Jiang, F., & Hsieh, Y.-L. (2017). Rice Straw Nanocelluloses: Process-Linked Structures, Properties, and Self-Assembling into Ultra-Fine Fibers. *Nanocelluloses: Their Preparation, Properties, and Applications*, 133–150. <https://doi.org/10.1021/bk-2017-1251.ch007>

- Joshi, Y., de Vries, H., Woudstra, T., & de Jong, W. (2015). Torrefaction: Unit operation modelling and process simulation. *Applied Thermal Engineering*, 74, 83–88. <https://doi.org/10.1016/j.applthermaleng.2013.12.059>
- K. Sangtongam, & Gupta, A. K. (2008). *Kinetics of Biomass and Waste During Pyrolysis and Steam Gasification*. <https://doi.org/10.1115/detc2008-49376>
- Kader, M. A., Islam, M. R., Parveen, M., Haniu, H., & Takai, K. (2013). Pyrolysis decomposition of tamarind seed for alternative fuel. *Bioresource Technology*, 149, 1–7. <https://doi.org/10.1016/j.biortech.2013.09.032>
- Kandpal, J. B., & Maheshwari, R. C. (1994). THERMOCHEMICAL CONVERSION OF BIOMASS TO CHARCOAL: COLLECTION AND CHARACTERIZATION OF BYPRODUCT. *Petroleum Science and Technology*, 12(1), 75–83. <https://doi.org/10.1080/08843759408916166>
- Kritee, K., Nair, D., Zavala-Araiza, D., Proville, J., Rudek, J., Adhya, T. K., Loecke, T., Esteves, T., Balireddygar, S., Dava, O., Ram, K., S. R., A., Madasamy, M., Dokka, R. V., Anandaraj, D., Athiyaman, D., Reddy, M., Ahuja, R., & Hamburg, S. P. (2018). High nitrous oxide fluxes from rice indicate the need to manage water for both long- and short-term climate impacts. *Proceedings of the National Academy of Sciences*, 115(39), 9720–9725. <https://doi.org/10.1073/pnas.1809276115>
- Kruse, A., & Zevaco, T. (2018). Properties of Hydrochar as Function of Feedstock, Reaction Conditions and Post-Treatment. *Energies*, 11(3), 674. <https://doi.org/10.3390/en11030674>
- Kruse, A., Funke, A., & Titirici, M.-M. (2013). Hydrothermal conversion of biomass to fuels and energetic materials. *Current Opinion in Chemical Biology*, 17(3), 515–521. <https://doi.org/10.1016/j.cbpa.2013.05.004>
- Kung, K. S., Thengane, S. K., & Ghoniem, A. F. (2020). Functional mapping of torrefied product characteristics with index of torrefaction. *Fuel Processing Technology*, 202, 106362. <https://doi.org/10.1016/j.fuproc.2020.106362>
- Liu, Z., & Balasubramanian, R. (2014). Upgrading of waste biomass by hydrothermal carbonization (HTC) and low temperature pyrolysis (LTP): A comparative evaluation. *Applied Energy*, 114, 857–864. <https://doi.org/10.1016/j.apenergy.2013.06.027>
- Matali, S., Rahman, N. A., Idris, S. S., & Yaacob, N. (2017). Combustion properties, water absorption and grindability of raw/torrefied biomass pellets and Silantek coal. *AIP Conference Proceedings*. <https://doi.org/10.1063/1.5010527>



- Righetti, E., Nortilli, S., Fatone, F., Frison, N., & Bolzonella, D. (2020). A Multiproduct Biorefinery Approach for the Production of Hydrogen, Methane and Volatile Fatty Acids from Agricultural Waste. *Waste and Biomass Valorization*. <https://doi.org/10.1007/s12649-020-01023-3>
- Rodsamran, P., & Sothornvit, R. (2020). Carboxymethyl cellulose from rice stubble waste. *Songklanakarin J. Sci. Technol*, 42(2), 454–460. <https://sjst.psu.ac.th/journal/42-2/28.pdf>
- Román, S., Ledesma, B., Andrés Álvarez-Murillo, Sabio, E., González, J. F., Olivares-Marín, M., & Mouzaina Boutieb. (2019). Hydrocarbonization. Does It Worth to Be Called a Pretreatment? *IntechOpen EBooks*. <https://doi.org/10.5772/intechopen.79477>
- Sadaka, S., & Negi, S. (2009). Improvements of biomass physical and thermochemical characteristics via torrefaction process. *Environmental Progress & Sustainable Energy*, 28(3), 427–434. <https://doi.org/10.1002/ep.10392>
- Saleh, S. B., Hansen, B. B., Jensen, P. A., & Dam-Johansen, K. (2013). Efficient Fuel Pretreatment: Simultaneous Torrefaction and Grinding of Biomass. *Energy & Fuels*, 27(12), 7531–7540. <https://doi.org/10.1021/ef401787q>
- Santos, Barbosa, A. G., & M.V. Silva Pinto. (2016). Mechanical Characterization and Water Sorption in Polyester Matrix Composites Reinforced with Sisal Fiber: An Experimental Investigation. *Defect and Diffusion Forum/Diffusion and Defect Data, Solid State Data. Part A, Defect and Diffusion Forum*, 369, 131–134. <https://doi.org/10.4028/www.scientific.net/ddf.369.131>
- Shankar Tumuluru, J., Sokhansanj, S., Hess, J. R., Wright, C. T., & Boardman, R. D. (2011). REVIEW: A review on biomass torrefaction process and product properties for energy applications. *Industrial Biotechnology*, 7(5), 384–401. <https://doi.org/10.1089/ind.2011.7.384>
- Singh, S., Chakraborty, J. P., & Mondal, M. K. (2019). Optimization of process parameters for torrefaction of *Acacia nilotica* using response surface methodology and characteristics of torrefied biomass as upgraded fuel. *Energy*, 186, 115865. <https://doi.org/10.1016/j.energy.2019.115865>
- Soetardji, J. P., Widjaja, C., Djojarahardjo, Y., Soetaredjo, F. E., & Ismadji, S. (2014). Bio-oil from Jackfruit Peel Waste. *Procedia Chemistry*, 9, 158–164. <https://doi.org/10.1016/j.proche.2014.05.019>

- Song, B., Lin, R., Lam, C. H., Wu, H., Tsui, T.-H., & Yu, Y. (2021). Recent advances and challenges of inter-disciplinary biomass valorization by integrating hydrothermal and biological techniques. *Renewable and Sustainable Energy Reviews*, *135*, 110370. <https://doi.org/10.1016/j.rser.2020.110370>
- Sun, J., Peng, H., Chen, J., Wang, X., Wei, M., Li, W., Yang, L., Zhang, Q., Wang, W., & Mellouki, A. (2016). An estimation of CO₂ emission via agricultural crop residue open field burning in China from 1996 to 2013. *Journal of Cleaner Production*, *112*, 2625–2631. <https://doi.org/10.1016/j.jclepro.2015.09.112>
- Tran, V. T., Le, T. M., Vu, P. V., Nguyen, H. M., Yen H.P Duong, & Le, P. K. (2022). Depolymerization of Rice Straw Lignin into Value-Added Chemicals in Sub-Supercritical Ethanol. *the α Scientific World Journal/TheScientificWorldjournal*, *2022*, 1–10. <https://doi.org/10.1155/2022/7872307>
- Tumuluru, J. S., Ghiasi, B., Soelberg, N. R., & Sokhansanj, S. (2021). Biomass Torrefaction Process, Product Properties, Reactor Types, and Moving Bed Reactor Design Concepts. *Frontiers in Energy Research*, *9*. <https://doi.org/10.3389/fenrg.2021.728140>
- Vadiveloo, J. (2000). Nutritional properties of the leaf and stem of rice straw. *Animal Feed Science and Technology*, *83*(1), 57–65. [https://doi.org/10.1016/s0377-8401\(99\)00107-8](https://doi.org/10.1016/s0377-8401(99)00107-8)
- Xu, G., Murakami, T., Suda, T., Kusama, S., & Fujimori, T. (2005). Distinctive Effects of CaO Additive on Atmospheric Gasification of Biomass at Different Temperatures. *Industrial & Engineering Chemistry Research*, *44*(15), 5864–5868. <https://doi.org/10.1021/ie050432o>
- Yang, B., Tao, L., & Wyman, C. E. (2017). Strengths, challenges, and opportunities for hydrothermal pretreatment in lignocellulosic biorefineries. *Biofuels, Bioproducts and Biorefining*, *12*(1), 125–138. <https://doi.org/10.1002/bbb.1825>
- Zhang, L., Liu, Y., & Hao, L. (2016). Contributions of open crop straw burning emissions to PM_{2.5} concentrations in China. *Environmental Research Letters*, *11*(1), 014014. <https://doi.org/10.1088/1748-9326/11/1/014014>
- Zheng, Y., Shi, J., Tu, M., & Cheng, Y.-S. (2017). Principles and Development of Lignocellulosic Biomass Pretreatment for Biofuels. *Advances in Bioenergy*, 1–68. <https://doi.org/10.1016/bs.aibe.2017.03.001>