RGC Ref. No.:
UGC/FDS25/E09/17
(please insert ref. above)

RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR
THE LOCAL SELF-FINANCING DEGREE SECTOR

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report
(for completed projects only)

Submission Deadlines: *1. Auditor's report with unspent balance, if any: within **six** months of the approved project completion date.*
*2. Completion report: within **12** months of the approved project completion date.*

Part A: The Project and Investigator(s)

1. Project Title

Treatment and Catalytic Upgrading of Mixed Oil Wastes and Wood/Paper Wastes to Transportation Fuels in Hong Kong

2. Investigator(s) and Academic Department(s) / Unit(s) Involved

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Dr/TSANG Chi Wing	Faculty of Science and Technology/ Technological and Higher Education Institute of Hong Kong
Co-Investigator(s)	Prof/Zuowei XIE	Department of Chemistry, Chinese University of Hong Kong
Co-Investigator(s)	Prof/LEE Kin Man Amazon	Faculty of Science and Technology/ Technological and Higher Education Institute of Hong Kong
Co-Investigator(s)	Dr/YAN Yuk Shing Dickson	Faculty of Science and Technology/ Technological and Higher Education Institute of Hong Kong
Co-Investigator(s)	Prof/LIANG Changhai	Laboratory of Advanced Materials & Catalytic Engineering/ Dalian University of Technology
Co-Investigator(s)	Dr/FENG Maoqi	Division of Chemistry and Chemical Engineering/

		Southwest Research Institute

3. Project Duration

	Original	**Revised**	**Date of RGC / Institution Approval** *(must be quoted)*
Project Start Date	01/01/2018	N/A	N/A
Project Completion Date	31/12/2019	30/6/2020	26/9/2019
Project Completion Date	30/6/2020	31/12/2020	28/4/2020
Duration *(in month)*	24	30	26/9/2019
Duration *(in month)*	30	36	28/4/2020
Deadline for Submission of Completion Report	31/12/2020	31/12/2021	28/4/2020

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. For industrial application: to develop a sustainable solution to tackle both the

landfills overburden problem and the non-recyclable wastes problem in the recycling industry. In addition, to provide an alternative route to the production of bio-renewable transportation fuels.

2. For academic interest: to develop a bimetallic catalyst supported on stable solid acidic supports which is capable of simultaneously converting cooking oil wastes and wood wastes components under hydrolysis conditions into valuable transportation fuels.

3. For public interest: to raise the level of public interest on the value of wastes, especially wood wastes and non-recyclable wastes, which would otherwise goes to the landfills.

4. For educational purpose: to reform teaching through development of lecture materials and Final Year Projects with the research experiences.

5.2 Revised objectives

Date of approval from the RGC: N/A

Reasons for the change: N/A

5.3 Realisation of the objectives
(Maximum 1 page; please state how and to what extent the project objectives have been achieved; give reasons for under-achievements and outline attempts to overcome problems, if any

Objectives 1 - For industrial application: to develop a sustainable solution to tackle both the landfills overburden problem and the non-recyclable wastes problem in the recycling industry. In addition, to provide analternative route to the production of bio-renewable transportation fuels.

Waste treatment company could potentially consider converting wood waste to liquid fuels or biomass fractionation products chemically as an option to the common physical treatment of wood waste to wood pellet, as liquid fuels could provide more applications such as automotive fuel system. From the economic evaluation study, it was found that selling the biomass fractionation products alone does have a greater profit than valorization of lignin toproduce bio-gasoline, with net present value of RMB 22,653,000 and RMB 177,000, respectively at the same return on investment if the plant is set up in Hong Kong (*BMC Chemical Engineering* **2019**, *1*(24), submitted to the RGC with the second progress report).

Objectives 2 - For academic interest: to develop a bimetallic catalyst supported on stable solid acidic supports which is capable of simultaneously converting cooking oil wastes and wood wastes components under hydrolysis conditions into valuable transportation fuels

In this part, we have three sub-tasks to perform: First is the catalytic degradation of lignin from wood wastes, second is the degradation of oil wastes, third is the co-degradation (or simultaneously) of mixed oil wastes and wood wastes components (including real lignin and lignin-derived components). In this regard, we have completed 100% on all the tasks.

Objectives 3 - For public interest: to raise the level of public interest on the value of wastes,

especially woodwastes and non-recyclable wastes, which would otherwise goes to the landfills.

As a result of the economic analysis from **Objective 1**, we have partnered with a local construction company to bid for the wood waste treatment project at ECO park in 2019. Although it was eventually unsuccessful, our idea have received generous comments from the EPD. On the other hand, to increase the publicity of our research, we have published a video publication: Journal of Visualized Experiments in 2019 to disseminate our research results to the public and it was very well-received (a soft copy had been submitted to the RGC with the second progress report). The research video is shown in:
https://www.jove.com/video/59870/tuning-acidity-pt-cnts-catalysts-for-hydrodeoxygenation-diphenyl

Objectives 4 - For educational purpose: to reform teaching through development of lecture materials and FinalYear Projects with the research experiences.

With combined effort from my students, the experimental and process design for the "Conceptual Process Design and Techno-Economic Evaluation of Hydrodeoxygenation of Lignin to Blendstocks for Gasoline Production" was successfully completed in 2020. Also, I have given talks at the research seminar held at THEi to let the students keep abreast of the current technology in waste treatment and management. I am also invited to give lectures to master degree students at City University of Hong Kong on up-to-date wood waste treatment topics. I have also incorporated the economic analysis of the waste treatment process into my modules at THEi: SEV5351 – Integrated Solid Waste Management.

5.4 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
1. For industrial application: to develop a sustainable solution to tackle both the landfills overburden problem and the non-recyclable wastes problem in the recycling industry. In addition, to provide an alternative route to the production of bio-renewable transportation fuels.	Yes	100%
2. For academic interest: to develop a bimetallic catalyst supported on stable solid acidic supports which is capable of simultaneously converting cooking oil wastes and wood wastes components under hydrolysis conditions into valuable transportation fuels.	Yes	100%
3. For public interest: to raise the level of public interest on the value of wastes, especially wood wastes and non-recyclable wastes, which would otherwise goes to the landfills.	Yes	100%
4. For educational purpose: to reform teaching through development of	Yes	100%

lecture materials and Final Year Projects with the research experiences.		

6. Research Outcome

6.1 Major findings and research outcome
(Maximum 1 page; please make reference to Part C where necessary)

In this experimental research, we have focus on three areas to tackle the wood waste/oil waste (from food waste) and their mixtures. First is the catalytic degradation of wood wastes, second is degradation of cooking oil wastes; finally, the co-degradation (or simultaneously) of mixed cooking oil wastes and wood wastes components. We have devised various catalysts for specific targeted products, such as cyclohexanes and aromatics. Efficient upgrading of lignin bio-oils into oxygen-free liquid alkane fuels is a challenging task owing to the incompatibility of the phenolic feedstock with conventional fuels and the availability of effective hydrotreating catalysts based on the current refinery infrastructure. In this work, a series of solid acid nanosheets ($HNbWO_6$, $HNbMoO_6$, $HTaWO_6$) modified Pt/CNTs bifunctional catalysts were evaluated in hydrodeoxygenation (HDO) of lignin-derived compounds. The effects of types of nanosheets and the synergistic effect between metal sites and acid sites were investigated via HDO of diphenyl ether. $Pt/HNbWO_6$/CNTs catalyst exhibited the most efficient performance for the HDO of diphenyl ether to cyclohexane (conversion: 99.7%, selectivity: 96.4%) at 200 °C and at 3MPa. It was found that the $Pt/HNbWO_6$/CNTs catalyst exhibited favorable stability (*Molecular Catalysis* **2019**, *467*, 61-69). Another catalytic system was found to specifically turns wood-waste derived molecules to aromatics. In this work, the effects of metals and process parameters were investigated via the catalytic hydrogenolysis of β-O-4 lignin model compound, 2-phenethyl phenyl ether. The best results were obtained over Rh/Nb_2O_5 with an overall conversion of 99.3% and exceptional selectivity of 98.9% to aromatic products when the hydrogenolysis was carried out at 260 °C and 0.1 MPa H_2 for 4 h. The high efficiency is mainly attributed to the cooperation between Rh and NbO_x at the perimeter sites, in which Rh particles are responsible for the dissociation of H_2 and NbO_x for activating C-O bonds. With respect to depolymerize of ash wood lignin, the liquid products were mostly aromatics over Rh/Nb_2O_5 under 0.1 MPa H_2. The results achieved in this work provide a promising prospect towards valorization of lignin into production of valuable aromatic compounds under low hydrogen pressure. (*Fuel Processing Technology* **2020**, *203*, 106392. Submitted to the RGC with the second progress report) Due to high cost associated with using precious metal catalysts, we have devised a synergistic catalyst using Co metal and MoO_3 metal supports and used dibenzofuran (DBF) as the wood-waste derived substrates. Hydrogenolysis of dibenzofuran (DBF) was investigated at 360 °C and atmospheric hydrogen pressure with Co/MoO_3 catalysts. All catalysts selectively cleaved the C−O bond and thus effectively transformed DBF to biphenyl (BP) at relatively moderate conditions. A strong promotional effect in the catalytic activity was observed over the Co/MoO_3 catalyst with the optimal Co content of 3 wt %, as evidenced by the decreasing activation barrier which was resulted from Co-facilitated increase of active Mo species and acidic sites. The best catalytic activity was realized with almost 100% yield of BP over Co/MoO_3. Characterization studies demonstrated that the formation of $MoO_xC_yH_z$ played an important role in stabilizing Mo species by preventing over-reduction to inactive Mo^{4+} species. (*Industrial & Engineering Chemistry Research* **2020**, DOI: 10.1021/acs.iecr.9b06442. Submitted to the RGC with the second progress report) For the degradation of cooking oil wastes task, we have reviewed all the literatures (*Molecular Catalysis* **2020**, *494*, 111128. Attached to this report) and decided to use the Rh/Nb_2O_5 system to treat wood waste and oil waste mixtures. This catalyst is very active in converting fatty acid (hexadecenoic acid) to alkane as well (6 hr, 100% conversion, 51% selectivity to pentadecane and 49% selectivity to hexadecane). When the mixed fatty acid and lignin were reacted together, after 2 hr of reaction at 200ºC, the pentadecane selectivity was 51.8% while the conversion of diphenyl ether remains 100% with 100% selectivity to cyclohexane. When the reaction was prolonged to 6 hr, the pentadecane selectivity was increased to 60.82%. These results validated that it is desirable to utilize Rh/Nb_2O_5 catalyst in the HDO of

actual lignin macromolecules and oil waste from food waste into hydrocarbon fuels, and the expected products are cyclohexane, cyclohexanol, pentadecane and hexadecane.

6.2 Potential for further development of the research and the proposed course of action *(Maximum half a page)*

1. It could be interesting to use Density Functional Theory (DFT) to study the respective adsorption and desorption energy of the various substrate and product on the Rh/Nb_2O_5 catalyst. After knowing the different product selectivity at different reaction conditions, specific products can be preferentially obtained from wood waste/oil waste mixtures at specific ratio.

2. Waste treatment company could potentially consider converting wood waste to liquid fuels or biomass fractionation products chemically as an option to the common physical treatment of wood waste to wood pellet, as liquid fuels could provide more applications such as automotive fuel system. From the economic evaluation study, it was found that selling the biomass fractionation products alone does have a greater profit than valorization of lignin to produce bio-gasoline, with net present value of RMB 22,653,000 and RMB 177,000, respectively at the same return on investment if the plant is set up in Hong Kong (*BMC Chemical Engineering* **2019**, *1*(24), submitted to the RGC with the second progress report).

7. Layman's Summary

(Describe <u>in layman's language</u> the nature, significance and value of the research project, in no more than 200 words)

Non-recyclable solid wastes such as contaminated paper, wood and cardboard, polystyrene packaging is a problem to the recycling industry since they must either be directed to landfills or incineration plants. One of the major contaminants should be the food waste and the related edible oil waste, as food wastes constitute a major part of the municipal solid wastes (~40%). Food wastes are therefore always mixed with various types of other waste materials such as paper, wood and plastic wastes from packaging materials, thus complicating the waste separation and recycling processes. In this study, we aim at finding a sustainable solution to treat mixed solid waste. We used the wood waste/oil waste (from food waste) mixtures as the pioneer system for this investigation. We have devised a series of catalytic system to degrade the lignin (from wood waste) and palmitic acid (hexadecenoic acid, commonly found in oil waste) and eventually co-degrade the mixtures successfully. We have also demonstrated to the recycling industry that wood waste recycling to fuels could be an economic and viable option provided that the catalyst could be economically produced. Finally, with this conclusion, we have further optimized the catalytic system using cobalt instead of using rhodium metal.

Part C: Research Output

8. Peer-Reviewed Journal Publication(s) Arising Directly From This Research Project

(Please attach a copy of the publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				**Author(s)** *(denote the correspond-ing author with an asterisk*)*	**Title and Journal / Book** *(with the volume, pages and other necessary publishing details specified)*	**Submitted to RGC** *(indicate the year ending of the relevant progress report)*	**Attached to this Report** *(Yes or No)*	**Acknowledged the Support of RGC** *(Yes or No)*	**Accessible from the Institutional Repository** *(Yes or No)*
Year of Publication	**Year of Acceptance** *(For paper accepted but not yet published)*	**Under Review**	**Under Preparation** *(optional)*						
2019	N/A	N/A	N/A	Weixiang Guan, Xiao Chen, Chuang Li,Jie Zhang, Chi-Wing Tsang*, Haoquan Hu, ShaojieLi, Changhai Liang*	Nb(Ta)-based solid acid modified Pt/CNTs catalysts for hydrodeoxygenation of lignin-derived compounds/ *Molecular Catalysis* **2019**, *467*, 61-69.	2020	No	Yes	Yes
2019	N/A	N/A	N/A	Weixiang Guan, Chuang Li,Xiao Chen, Xiao-Ying Lu, Chi-Wing Tsang*, Haoquan Hu, HongxuQi, Changhai Liang	Tuning the Acidity of Pt/ CNTs Catalysts for Hydrodeoxygenation of Diphenyl Ether/ *Journal of Visualized Experiments* **2019**, (150), e59870, doi:10.3791/59870.	2020	No	Yes	Yes
2019	N/A	N/A	N/A	Weixiang Guan, Sim-Ying Chua, Chi-Wing Tsang*, Xiao Chen, Carol Sze Ki Lin, Raymond Sze Wai Fu, HaoquanHu1 and Changhai Liang	Economic feasibility of gasoline production from lignocellulosic wastes in Hong Kong/ *BMC Chemical Engineering* **2019**, *1*(24).	2020	No	Yes	Yes

2019	N/A	N/A	N/A	Weixiang Guan, Xiao Chen, Haoquan Hu, Chi-Wing Tsang, Jie Zhang, Carol SzeKi Lin, Changhai Liang*	Catalytic hydrogenolysis of lignin β-O-4 aryl ether compound and lignin to aromatics over Rh/Nb_2O_5 under low H_2 pressure/ *Fuel Processing Technology* **2020**, *203*, 106392.	2020	No	Yes	Yes
2019	N/A	N/A	N/A	Chong Lia, Chao Chen, Xiaofen Wu, Chi-Wing Tsang, Jinhua Mou,Jianbin Yan,Yun Liu, Carol Sze Ki Lin*	Recent advancement in lignin biorefinery: With special focus on enzymatic degradation and valorization/ *Bioresource Technology* **2019**, *291*, 121898.	2020	No	Yes	Yes
2020	N/A	N/A	N/A	Jie Zhang, Chuang Li, Weixiang Guan, Xiaozhen Chen, Xiao Chen, Chi-Wing Tsang,* and Changhai Liang*	Deactivation and Regeneration Study of a Co-Promoted MoO_3 Catalyst in Hydrogenolysis of Dibenzofuran/ *Industrial & Engineering Chemistry Research* **2020**, *59(10)*, 4313-4321	2020	No	Yes	Yes
2020	N/A	N/A	N/A	Xiao Chen, Weixiang Guan, Chi-Wing Tsang*, Haoquan Hu and Changhai Liang*	Lignin Valorizations with Ni Catalysts for Renewable Chemicals and Fuels Productions/ *Catalysts* **2019**, 9(6), 488. DOI: 10.3390/cat	2020	No	Yes	Yes

					al9060488.				
2020	N/A	N/A	N/A	Weixiang Guan, Chi-Wing Tsang, Carol SzeKi Lin, Christophe Len, Haoquan Hu, Changhai Liang*	A review on high catalytic efficiency of solid acid catalysts for lignin valorization/ *Bioresource Technology* **2020**, *298*, 122432.	2020	No	Yes	Yes
2020	N/A	N/A	N/A	Weixiang Guan, Xiao Chen, Haoquan Hu, Chi-Wing Tsang, Jie Zhang, Carol Sze Ki Lin, Changhai Liang	Catalytic hydrogenolysis of lignin β-O-4 aryl ether compound and lignin to aromatics over Rh/Nb_2O_5 under low H_2 pressure / *Fuel Processing Technology* **2020**, *203*, 106392	N/A	Yes	Yes	Yes
2020	N/A	N/A	N/A	Mohamad R. Khodadadi, Irene Malpartida, Chi-Wing Tsang, Carol Sze Ki Lin, Christophe Len	Recent Advances on the Catalytic Conversion of Waste Cooking Oil" *Molecular Catalysis*/ **2020**, *494*, 111128	N/A	Yes	Yes	Yes
2021	N/A	N/A	N/A	Weixiang Guan, Xiao Chen, Chi Wing Tsang, Haoquan Hu, and Changhai Liang	Highly Dispersed Rh/NbO_x Invoking High Catalytic Performances for the Valorization of Lignin Monophenols and Lignin Oil into Aromatics/ *ACS Sustainable Chemistry & Engineering* **2021**, *9*, *9*, 3529-3541	N/A	Yes	Yes	Yes

(a) Weixiang Guan, Xiaozhen Chen, Chuang Li, Jie Zhang, Shaojie Li, Haoquan Hu are research assistants of Prof Changhai Liang, responsible for catalyst and product characterizations.
(b) Xiao Chen and Chuang Li are associate professor at Dalian University of Technology and are my research partners.
(c) Sim-Ying Chua is my trained students at THEi, responsible for catalytic degradation of lignin.
(d) Hongxu Qi is my research assistant, responsible for catalytic degradation of lignin.
(e) Xiao-ying Lu and Raymond Sze Wai Fu are my colleagues at THEi, responsible for product characterizations and process economic analysis.
(f) Carol Sze Ki Lin, Prof. Christophe Len and Yun Liu are my research partners in lignin chemistry.
(g) Chong Lia, Chao Chen, Xiaofen Wu, Jinhua Mou, Jianbin Yan are students of Yun Liu.
(h) Mohamad R. Khodadadi and Irene Malpartida are research assistants of Prof. Christophe Len

9. Recognized International Conference(s) In Which Paper(s) Related To This Research Project Was / Were Delivered
(Please attach a copy of each conference abstract)

Month / Year / Place	**Title**	**Conference Name**	**Submitted to RGC** *(indicate the year ending of the relevant progress report)*	**Attached to this Report** *(Yes or No)*	**Acknowledged the Support of RGC** *(Yes or No)*	**Accessible from the Institutional Repository** *(Yes or No)*
23-24 May 2019/Singapore	"Catalytic Hydrodeoxygenation of Lignin for Fuels and Chemicals Productions"	*Southeast Asia Catalysis Conference 2019*, Singapore Catalysis Society, Singapore	No	*No,* submitted with the 2nd progress report	Yes	Yes
07/2018/ Shenyang, China	Ni-Based Catalyst for theConversion of Lignin-Derived Model Compound into Fuel Components	The 11th National Conference for the Environmental Catalysis and Environmental Materials	2018	No, submitted with the 1st progress report	Yes	Yes

10. Whether Research Experience and New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning
(Please elaborate)

1. Shared new findings to master degree students at City University of Hong Kong on woodwaste treatment and utilizations.
2. Given talks at the research seminar held at THEi.
3. Incorporated new found knowledge on wood waste and food waste utilization into teaching materials (SEV5351-Integrated Solid Waste Management)
4. Explored new direction from research data and obtained new research funding on wood waste utilization (ECF 2020-54)

11. Student(s) Trained
(Please attach a copy of the title page of the thesis)

Name	**Degree Registered for**	**Date of Registration**	**Date of Thesis Submission /**

			Graduation
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

* These students' thesis title pages had already been submitted with the second progress report.

In this project, I have trained 3 undergraduate students:

[redacted]

12. Other Impact

(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, teaching enhancement, etc.)

1. Collaborated with Dr. Carol Sze Ki Lin from City University of Hong Kong on lignin degradation, and process techno-economic analysis and related process studies.
2. THEi Researcher Award 2018
3. Invited as keynote speaker by Southeast Asia Catalysis Conference 2019, Singapore Catalysis Society, Singapore
4. Invited lectures to master degree students at City University of Hong Kong on wood waste treatment topics.
5. Given talks at the research seminar held at THEi.
6. Collaborated with Prof Christophe Len at Université de Technologie de Compiègne on waste cooking oil study.

13. Statistics on Research Outputs

	Peer-reviewed Journal Publications	**Conference Papers**	**Scholarly Books, Monographs and Chapters**	**Patents Awarded**	**Other Research Outputs (please specify)**	
					Type	No.
No. of outputs arising directly from this research project	11	2	N/A	N/A	N/A	N/A

14. Public Access Of Completion Report

(Please specify the information, if any, that cannot be provided for public access and give the reasons.)

Information that Cannot Be Provided for Public Access	Reasons
N/A	N/A