出國報告（出國類別：開會）

參加微藻固定二氧化碳及能源應用國際會議

服務機關：台灣電力公司

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派赴國家：加拿大

出國期間：102.6.15~102.6.21

報告日期：102.8.1

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行政院及所屬各機關出國報告提要

出國報告名稱：參加微藻固定二氧化碳及能源應用國際會議

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出國計畫主辦機關/聯絡人/電話：台灣電力公司人事處/陳德隆

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關鍵詞：藻類、生質燃料、生質副產品

內容摘要：(二百至三百字)

能源安全及減少溫室氣體排放量的管理將會成為與公司未來營運發展息息相關的主要課題。今日，發展二氧化碳的捕獲技術(Sequestration technologies)的目的是要滿足產業降低二氧化碳排放的需求並且能達到減小全球暖化對環境的衝擊。藻類養殖固定燃煤電廠排放的二氧化碳，屬於生物法的碳捕捉技術策略之一，原理是利用煙氣中的二氧化碳做為藻類生長所需的營養源，在煙氣的供應下，能加速藻類的分裂及生長，達到減少煙氣中二氧化碳的排放。本公司在微藻固碳技術發展主要以電廠減碳需求為目標，計劃包含進行藻類生產生質能源之生命週期評估及整合性技術經濟分析，以提高未來研發成果實質應用之可行性。為順利推行微藻二氧化碳捕獲與發展生質燃料研發工作，擬派員參加3rd International Conference on Algal Biomass, Biofuels & Bioproducts”與國際專家進行交流，會議內容包含微藻固碳技術與生質燃料等實務與國際上各項計畫之最新進展，可作為本公司火力電廠微藻二氧化碳捕獲與發展生質燃料研發工作的參考。參加此次會議，有助於微藻固定二氧化碳研發工作的推展。因此，本公司乃遴派負責執行微藻固定二氧化碳計畫主持人，化學室陳曉薇化學研究專員前往參加此次國際會議，並於本次會議發表2篇論文，除提高研發成果之能見度並促進國際交流及經驗分享，以利本公司後續相關研究計劃之推展。

本文電子檔已傳至出國報告資訊網

(http://open.nat.gov.tw/reportwork)

目次

壹、目的：

由於全球二氧化碳排放量的過度排放，我們正面臨著越來越嚴重的溫室效應及其他環境問題，爲了合理的限制二氧化碳排放量，將二氧化碳視爲可轉換成有用的化學品或可再生能源，則成爲全球生物質資源化利用的一個焦點。能源安全及減少溫室氣體排放量的管理將會成爲與公司未來營運發展息息相關的主要課題。今日，發展二氧化碳的捕獲技術(Sequestration technologies)的目的是要滿足產業降低二氧化碳排放的需求並且能達到減小全球暖化對環境的衝擊。

藻類養殖固定燃煤電廠排放的二氧化碳，屬於生物法的碳捕捉技術策略之一，原理是利用煙氣中的二氧化碳做爲藻類生長所需的營養源，在煙氣的供應下，能加速藻類的分裂及生長，達到減少煙氣中二氧化碳的排放。本公司在微藻固碳技術發展主要以達成電廠減碳需求爲目標，計劃包含進行藻類生產生質能源之生命週期評估及整合性技術經濟分析，以提高未來研發成果實質應用之可行性。爲順利推行微藻二氧化碳捕獲與發展生質燃料研發工作，擬派員參加 3rd International Conference on Algal Biomass, Biofuels & Bioproducts”與國際專家進行交流，會議內容包含微藻固碳技術與生質燃料等實務與國際上各項計畫之最新進展，可作爲本公司火力電廠微藻二氧化碳捕獲與發展生質燃料研發工作的參考。

參加此次會議，有助於微藻固定二氧化碳研發工作的推展。因此，本公司乃遴派負責執行微藻固定二氧化碳計畫主持人，化學室陳曉薇化學研究專員前往參加此次國際會議，

並於本次會議發表2篇論文，除提高研發成果之能見度並促進國際交流及經驗分享，以利本公司後續相關研究計劃之推展。

貳、過程：

2-1 赴加拿大多倫多參加“3rd International Conference on Algal Biomass, Biofuels & Bioproducts”之行程：

表 2-1 爲職本次赴加拿大參加 3rd International Conference on Algal Biomass, Biofuels & Bioproducts 會議行程概要表。

表2-1、會議行程概要表

日期	工作紀要
102年6月15日	往程(台北－加拿大多倫多)
102年6月16日-19日	參加 3rd International Conference on Algal Biomass, Biofuels & Bioproducts
102年6月20-21日	返程(加拿大多倫多－台北)

2-2 3rd International Conference on Algal Biomass, Biofuels & Bioproducts

2-2-1 會議主題

會議由Elsevire安排，於102.6.16-19在加拿大多倫多The Sheraton Centre Toronto Hotel舉行（如圖一），本次會議的主題涵蓋有關藻類生物學領域所有的新興技術，包含生物質生產(biomass production)，養殖(cultivation)，收成(harvesting)，萃取(extraction)，生物製品(bioproducts)和技術經濟面向(econometrics)等討論。共有425篇摘要投稿(Abstract submissions),入選95篇口頭報告(Oral presentations)及223篇海報發表(Poster presentations)，除此之外，還有5場演講(Plenary speakers)及15場邀請的議題發表(Invited talks)，職將獲選發表之議題及數量整理如圖二及表1並將主要議題分述如下:

(1) 藻類生物學(Algal Biology)：包含微藻生物燃料的代謝調控、微藻生物燃料的分子學、微藻生物燃料的種系發展史，爲本次發表數量排序位居第二，占全體發表數量28%。

(2) 藻類養殖系統(Algal Cultivation)：藻類異營系統或結合廢水處理生產系統、開放式藻類自營養殖系統、光合反應器藻類自營養殖系統，爲本次研討會最熱門之主題占全體發表數量31%。

(3) 藻類回收和萃取系統(Algal Harvesting and extraction)：探討低耗能藻類回收方法及藻類內含物萃取之條件，占全體發表數量15%。

(4) 生物製品(Bioproducts from Algal Biofuels Refining,

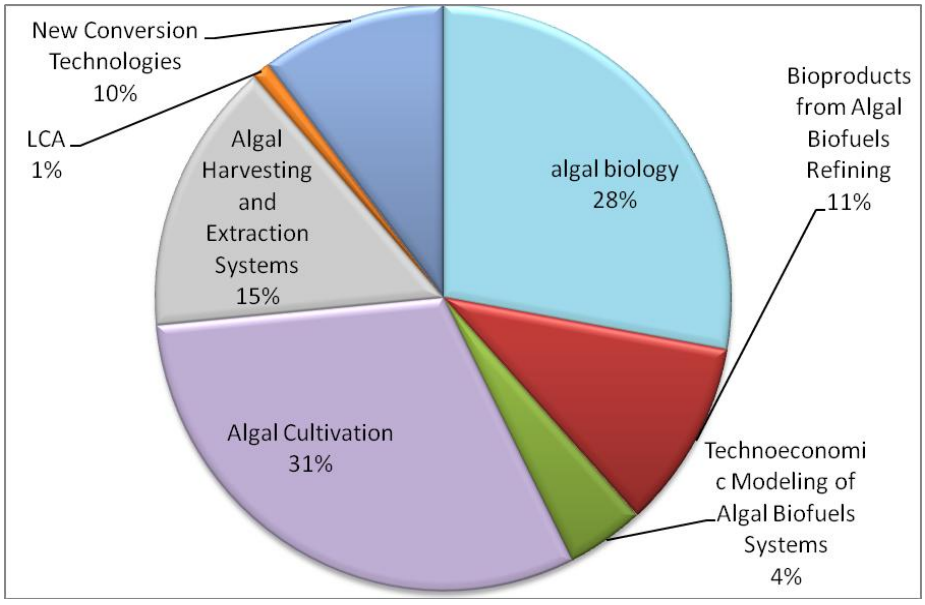
including agricultural, bioplastics, and chemical products)：以藻類爲原料所製成之生物燃料，包括農業，生物塑料和化工產品的探討，占全體發表數量11%。

(5) 生命週期評估(Life cycle analysis)：探討藻類生產流程之能源流及物質流，占全體發表數量1%，爲近年最新討論的領域，發表的文章還不算多，但是其結果對於未來因應區域的變化，並選擇最佳生產流程，使資源有效利用及減少對環境的影響的重要參考依據。

(6) 新的藻類生質燃料轉換技術，包含熱裂解技術及酵素系統(New Conversion Technologies for Algal Biofuels, including catalytic, thermal, and enzymatic systems)：藻類生質燃料轉換技術的發展將可帶動整體能源利用效率，占全體發表數量10%。

(7) 藻類生物燃料系統之技術經濟評估(Technoeconomic modeling of algal biofuel systems)：透過技術經濟分析，可評估不同技術、生產系統的效益及投入產出比、整個系統的能量平衡關係、整體生產經濟成本及對環境的影響情形、從技術發展階段到大規模生產的限制因素等，提供決策者制定政策及指導研發投資方向參考，占全體發表數量4%。

圖一、The Sheraton Centre Toronto Hotel



圖二、獲選發表之議題百分比

2-2-2會議經過

參加出席人數約362人，有40個國家代表與會，會議於6/16下午報到及交流，6/17上午8時正式開始，由演講揭開序幕，演講的內容主要談藻類養殖發展現況及未來商業化藻類燃料可能遇到的瓶頸，並說明地區化差異對於其產業發展的影響性。第一天會議分成A、B兩個Session進行，A session主要發表主題爲藻類生物學(Algal biology)，包含微藻生物燃料之代謝調控(Metabolic Regulation of Microalgae for Biofuels)、藻類基因科學(Algal Genome Sciences)等，B Session發表主題爲藻類生物燃料精煉副產品(Bioproducts from Algal Biofuels Refining)及藻類技術經濟模型系統(Technoeconomic Modeling of Algal Biofuels Systems)，下午5:20~6:45爲poster發表時間，職代表公司發表” Culturing of *spirulina* alga with an improved photobioreactor fed with flue gas and the investigation of an enzymatically hydrolyzed phycocyanin for its anticancer bioactivity”論文(如圖三)，被安排在Poster session 1編號[P1.085]，1.8 Bioproducts from Algal Biofuels Refining, including agricultural, bioplastics, and chemical products區塊。第二天會議，也在8:10~9:20一場演講後，再次安排Poster session 1進行第2次討論至10:15，接著繼續依議題分爲A、B session進行發表與討論，A session主要發表主題爲藻類生物學(Algal biology)包含微藻作爲生物燃料的分子特性(Molecular Traits of Microalgae for Biofuels)、藻類

回收與萃取系統(Algal Harvesting and Extraction Systems)、藻類生物燃料新轉換技術(New Conversion Technologies)等；B session主要發表主題爲藻類養殖系統(Algal Cultivation)包含異營養殖系統(Heterotrophic Systems)及光合反應器自營系統(Phototrophic Systems in Photobioreactors)等，下午5:05~6:45爲poster發表時間，職代表公司發表” Analysis on microlgae based CO2 capture value-chain” 論文(如圖四)，被安排在Poster session 2編號[P2.102]，2.11 Technoeconomic Modeling of Algal Biofuels Systems區塊。

第三天會議，也在8:10~9:00一場演講後，再次安排Poster session 2進行第2次討論至10:15，接著繼續依議題分爲A、B session進行發表與討論，A session主要發表主題爲藻類回收與萃取系統(Algal Harvesting and Extraction Systems)、藻類技術經濟模型系統(Technoeconomic Modeling of Algal Biofuels Systems)、藻類生物燃料新轉換技術(New Conversion Technologies)等；B session主要發表主題爲光合反應器自營系統(Phototrophic Systems in Photobioreactors)、光合反應器自營系統(Open pond Systems in Photobioreactors)等。

Culturing of *Spirulina* Alga with An Improved Photobioreactor Fed with Flue Gas and The Investigation of An Enzymatically Hydrolyzed Phycocyanin for Its Anticancer Bioactivity

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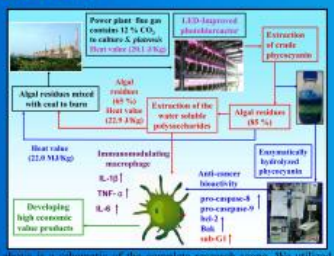
1. Introduction

Along with global human population growth and rapid development of various industries, energy consumption also sees increases. Presently, most of the global electricity is generated by fossil fuel burning power plants. The action provides not only electricity energy but also huge amounts of atmospheric carbon dioxide emission. This contributes significantly to aggravate the greenhouse warming effect. Therefore, how to effectively utilize biological entities to fix carbon and alleviate the impact of greenhouse gas on earth environment is potentially an vital issue. In this study, we describe using the high concentration carbon dioxide from the flue gas of a power plant smokestack to cultivate growth of *Spirulina platnesis* alga for carbon fixation. Then the biomass of *S. platensis* was extracted for its economically important ingredient, phycocyanin C. Then water soluble polysaccharides was extracted from phycocyanin C. The residual algal mass was directly mixed with coal and returned to boiler as fuel. Because the oily algal residue still has heat value of 22-22 MJ/kg, direct incineration obliterated the carbon footprint engendered during the extraction processes. The efficacy of this mode of utilization is more advantageous than extracting the lipophilic fraction of the alga and then making biodiesel from it. Mainly because despite of the high oil ratio, the unsaturated fatty acids account for a high proportion. Using oil with such high economic value for making biodiesel do not appear to produce viable overall economic efficiency, Conversely, if the even more valuable phycocyanin and then the immunomodulating polysaccharides (both are water soluble), while the oily phase is retained. Then because the algal residue has high heat value, mixed burning with coal allow the carbon-neutral biomass carbon to attenuate fossil fuel carbon emission.

2. Graphic abstract



The figure 1 above is a schematic of the complete research scope. We utilized flue gas emitted from smokestack of a local power plant with the NOx and Sox removed by membrane catalyst absorption treatment. The gas had a 12% v/v of carbon dioxide, and was fed to a photobioreactor lit with LED lights to hasten the photosynthetic performance of cultured *Spirulina platensis* alga and attain our objective of carbon fixation through biomass growth.

The algal biomass obtained from the bioreactor was first extracted to obtain crude phycocyanin. The protein was enzymatic hydrolyzed and subjected to column chromatography to provide different fractions. The fraction 2 (F2) was screened and used for anticancer bioactivity assays. F2 protein was found to have strong and significant inhibitory efficacies against human oral epithelial carcinoma (OEC-M1), and human lung adenocarcinoma (A549).

The post-extraction algal biomass was further extracted with hot water to recover polysaccharide fractions. The oil rich residue has a high heat value of 22 MJ/kg, and can be mixed with coal and returned to boiler to be burned for energy regeneration and completion of the cycle. The water soluble polysaccharides have been found to have immunity boosting capacities. The algal polysaccharides have been proven effective in activating immune cells.

Therefore the main objective of this study encompassed effective use of alga to sequestrate CO_2 from flue gas, and also developed ingredients from the algal biomass that have potential high economic values. These compounds may provide important health benefits to mankind in the future. Furthermore, the extracted algal residue was effectively burned to recover the high heat value. Thus the experimental model allows abatement of excessive carbon footprint in many biofuels and in the meantime enables the development of novel biomedical materials with good applicative potential.

3. Methods

CHN elemental analysis was using for total carbon. Extraction of crude phycocyanin from *S. platensis*. Preparation, purification and yield of enzymatic hydrolyzates from C-phycocyanin extracted from *S. platensis*. OEC-M1 and A549 cells were used to investigate the apoptosis by an enzymatically hydrolyzed phycocyanin. Cell apoptosis was measured by flow cytometry analysis, immunofluorescence and TUNEL.

4. Results

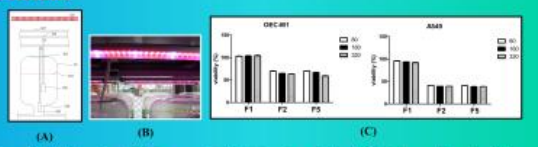


Figure 2A. Schematic of the improved photobioreactor design. 50 is the main body of the photobioreactor; 501 is a three-way connected tube; 502 is an exhaust vent; 503 is a in- and out-flow duct; 504 is the level of sea water culturing medium; 505 is the flue gas injection tube; 506 is the air injection aerator tube; 507 is the recirculation air injection tube. The LED lights are 1 W red light and 3 W blue light; with blue to red at a 1 to 8 ratio. The blue LED emits at 470 nm and the red at 630 nm. Figure 2B. A photo of the actual culturing site.

Figure 2C shows that the fraction 2 (F2) of the C-phycocyanin enzymatic hydrolyzate products has the best growth inhibitory efficacies against oral human epithelial carcinoma M1 cell line (OEC-M1) and human lung adenocarcinoma A549. At F2 dose of 80 μg/mL, for A549, the IC_{50} value was reached (cell survival rate 48%). Thus, F2 appear to be an effective enzymatic hdyrolyzate product of C-phycocyanin candidate for subsequent anti-cancer bioactivity assays.

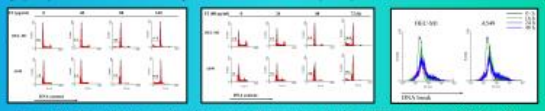


Figure 3A shows that the results of 2 cancer cell lines treated with 4 different doses of F2 (0–160 μg/mL) and cultured for 48 h indicated that along with increasing F2 concentration, the proportions of sub-G1 increased, indicating a more pronounced cell necrosis or apoptosis rates. Also, at different time intervals and 80 μg/mL of F2 dose, the results of cancer cell lines culturing indicated that at 72 h after incubating, the OEC-M1 showed marked increase in necrosis zone to 36.9%; whereas the A549 had a rate of 15.4% (Figure 3B). Figure 3C shows that after 0, 16, 24, and 48 h after treating with enzymatic hydrolyzate product F2 of C-phycocyanin, DNA breakages of the cancer cell lines increased, and the peak shifted clearly to the right (indicating increase in fluorescence, or increase in DNA breakages). The 0 h was the blank group.

5. Conclusion

In recent years, biofuels have become an important research issue. Often, however, the pictures depicted in some of the researches are far-fetched and bottlenecks exist in scaleups. One of the main reasons is the possible ignoring of carbon footprint in the process. Or, simply put, by consuming 3 parts of carbon in the conversion process while obtaining 1 part of usable carbon energy. Such researches are not beneficial to the protection of environment but rather harm it. Our studies thus provide a comprehensive route to an algal application system, from carbon fixation to extraction of bioactive ingredients, and finally to use the residue as fuel. We deem that the comprehensive and highly practical nature of this study should be a potential model to be applied globally to various power plants and realize the positive benefits to global environments and human health. Therefore how to conduct actually useful bioenergy study without the unnecessary trappings is an urgent task for scientists in the future.

圖三、“Culturing of spirulina alga with an improved photobioreactor fed with flue gas and the investigation of an enzymatically hydrolyzed phycocyanin for its anticancer bioactivity”論文

Analysis on microlgae based CO_2 capture value-chain

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1. Introduction

The industrial progress, convenience transportation, improvement of civilization and people's excessive dependent on fossil fuels in the past have resulted in massive amount of CO_2 being released to the atmosphere. Hence, the effective greenhouse gas emissions reduction has become a common globular issue for mankind, as well as a future management challenge for Energy industry.

2. Methodology: Value chain analysis for carbon capture

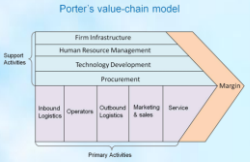

Figure1. Porter's value-chain model

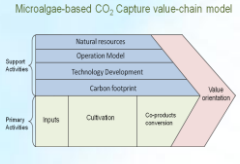

Figure2. Microalgae-based CO_2 capture value-chain model

3. A pilot case study

The bioreactor unit consisted of a stacked three-dimensional microalgae culturing system composed of 2,016 individual 15-L PET transparent containers (for a total volume of 30,240 L), and 2-inch-diameter triple-linked ABS valves. The general culturing conditions entailed an atmospheric temperature of 30~34˚C and a seawater temperature of 28~32˚C. Each batch was cultured for 15 days at a production rate of 7.43 g m-2 d-1.

Figure3. Photobioreactor was located at a coal-fired power plant in southern Taiwan.

Table1. Energy consumption and carbon fixation capacity of a photobioreactor in a year.

Item	
Average flue gas CO_2 concentration (%)	12
Flue-gas pipe (m)	16
Actual volume of culturing (L)	28,728
Footprint of the bioreactor (m^2)	100
Annual capacity (batch)	18
Annual dry algal mass production (kg)	1,220
Annual amount of CO_2 fixation (kg)	2,234
Power consumption per batch (kWh)	130
Energy consumption per batch (kg CO_2)	83
Total annual energy consumption (kg CO_2)	1,494
Actual carbon fixation per year (kg CO_2)	740
Projected annual carbon fixation per hectare (ton CO_2)	74.0

Table2. Microalgae-based CO_2 capture benefits and costs of the photobioreactor in a year.

Item				
Costs		Quantity	Unit price	Total price
Fixed cost (NT$) (retired after 15 years)	flue-gas pipe (NT$/m)	16	10,000	160,000
	Photobioreactor (NT$/yr)	1	425,333	425,333
Variable costs (NT$/kg)		1220	984.21	1,200,745
Item				
Benefits				
Biofuel price (US$/metric ton)		103.25		
Microalgal extracts for skin care products price (NT$/kg)		500,000		
Carbon tax income (NT$/metric ton)		300		

4. Discussion

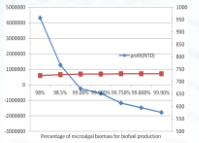

Figure4. Portfolio of microalgal co-products conversion.

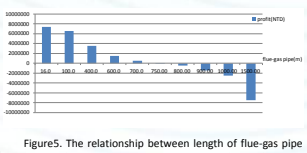

Figure5. The relationship between length of flue-gas pipe and profit at 98.5% microalgal biomass for biofuel and 1.5% microalgal biomass for skin-care product.

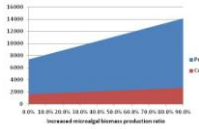

Figure6. Relationship between cultivation cost and profit at total harvested algal mass (dry mass) is increased in 10%~100%.

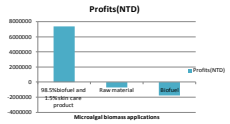

Figure7. Profit chart Microalgal biomass 98.5% for fuel, 1.5% used in the manufacture of skin-care product, 100% for biofuel production and microalgal raw material.

Table3. SWOT analysis on Microalgae-based CO2 capture value-chain in a power plant

	Strength	Weakness
Internal Environment	(S1)Proximity of CO_2 sources at a power plant. (S2)A low cost and minimize process energy intensity. (S3)Co-product extraction and recovery technologies to enhance the feasibility of the value chain.	(W1)Lack of safety trials to meet applicable standards. (W2)Lack of material balance, energy balance, water, and thermal commercial management. (W3)Massive CO_2 emission from power plant.
	Opportunity	**Threat**
External Environment	(O1)No existing standards for various aspects of microalgal biofuels production. (O2)Fist movers can inform further development of applicable laws and standards. (O3)Biofuel production and gains the carbon credit.	(T1)Fuel shortage Lack of government policies to protect biofuel production. (T2)No applicable consumption standards. (T3)Biofuel is in a low price.

5. Conclusion

CO_2 emissions from thermal power generation to cultivate microalgae has not only solved costs, land space and other problems, but also offering a new direction and opportunities in the development of carbon reduction technology. Microalgae are receiving increased global attention as a potential sustainable "energy crop" for biofuel production. Based on Porter's value-chain model, microalgae based CO_2 capture value chain was used to construct a value chain that reflects the opportunity of microalgae based CO_2 capture technology. The value chain primary activities used here were including: (1) inputs; (2) cultivation; (3) Co-products conversion, and support activities used here were including: (1) natural resources; (2) operation model; (3) technology development; (4) carbon footprint. Through a pilot case study, the result shows the location of microalgal culturing system close to the power plant should have been relative to the value added. The improvement of culturing system performance should also have been relative to the value added. There is no niche that microalgal biomass for biofuel and raw material production at present. The adding of other high-valued products will be more cost-effective. Though the SWOT analysis to analyze the microalgae based CO_2 capture value-chain, it shows using strength-opportunity strategy (SO strategy) to develop the core function, and make microalgae based CO_2 capture model more successful. The value chain model will help guide needed investments and the deployment of microalgal based CO_2 capture from a power plant.

圖四、『Analysis on microlgae based CO_2 capture value-chain』論文

2-2-3與本公司相關主要研討內容

(1)藻類燃料:商業化的瓶頸

Professor Yusuf Chisti是紐西蘭Massey University生物化學工程教授，在微藻生產，海洋生物技術，生物燃料和生物煉製領域有傑出的貢獻，他在會中提出，藻類作爲生物

燃料的應用具有十足的潛力，包含生產生質酒精(bioethanol)、生物製氫(biohydrogen)、合成氣(biogas)、生質柴油(biodiesel)和其他液態燃料(other liquid fuels)等，轉換成這些燃料的技術已經存在，但由於原油價格的不確定性，因此無法與化石原料所衍生的燃料競爭。藻類的養殖成本必須大幅降低、尋找便宜及符合低耗能要求的藻類回收及萃取方法、減少大規模養殖時氮營養源輸入的方案(由於氮營養源的生產須利用大量的化石燃料)等，未來也許可以透過藻類生物學的研究、利用coculturing的策略、基因及代謝工程的進步，提高藻類單位時間的產量及減少對外加氮營養源的需求，以利商業化大規模的系統發展並減少對於化石燃料的依賴。

(2)藻類水熱製程(hydrothermal)轉換成液態燃料

Dr. Albrecht任職於美國Pacific Northwest National Laboratory，研究領域主要以熱化學方法將biomass轉換成具附加價值化學品和燃料，他發表了National Alliance for Advanced Biofuels and Bioproducts(NAABB)的研發計畫成果，含油高及含油低的藻類在戶外養殖，經收成、回收、去水後利用

hydrothermal liquiefaction(HTL)方式皆能轉換成crude oil，並能自行與水分層，經進一步處理可製成碳氫燃料(hydrocarbon fuels)，這個結果說明，不一定要執著於找含油率高藻種，只要能容易大量繁殖的藻種結合HTL技術就能符合生產能源的需求。

(3)以技術經濟模式(techno-economic model)評估藻類生質燃料生產生命週期分析(life cycle analysis)

Dr.John R. Benemann是MicroBio Engineering, Inc.的總裁，這家公司主要提供養殖微藻並結合廢水的回收技術，微藻生物燃料的生產，工程設計和經濟分析技術的基礎上，預計將在短期內，於南加州進行佔地400公頃的生產系統。每個養殖池(open, raceway, paddle wheel mixed)佔地4公頃，以連續式沉澱操作（>90%的效率），然後以gravity thickening和太陽能乾燥收穫藻類，後用己烷(hexane)萃取藻油（三甘油酯的TAG）。假設藻類年生產量爲80噸/公頃，TAG可萃取率25%，預估可生產50,000桶油/年（20,000升/公頃年）。經己烷萃取後剩餘的生物質將被送達工廠，用於生產沼氣，應用於發電，另外廢水和煙氣再循環回到池塘。養殖用水、營養源和碳源來自生活污水。資本支出成本估計爲100百萬美元（$250,000/公頃），或2000美元/桶油年。每年10%的資本支出(capital cost)和運營成本(operation cost)600萬美元（售後剩餘電量近100萬美元/年），經估算藻油成本$320/barrel（未經處理的油，無計算污水處理額度）。這個過程經詳細的生命週期評估（Life Cycle Analysis），相較於化石燃料總溫室氣體（GHG）排放減

少 90%以上。生命週期評估和技術經濟的研究可以幫助藻類生物燃料生產技術的開發。

(4)利用超聲波(ultrasound)進行藻類收成及脂質萃取

Dr. Babetta (Babs) L. Marrone是一名細胞生物學家，是洛斯阿拉莫斯國家實驗室(Los Alamos National Laboratory,LANL)生物燃料部門(Biofuels Program)的資深科學家和負責人。她提出藻類生物燃料是一種有潛力的再生能源，經濟上是可行的，對環境也很友善。然而，我們需要創新的技術促使藻類生物燃料商業化生產。藻類回收技術一直是個關鍵因素，過去使用的方式大多以離心爲主，那是屬於能源密集型的處理方式。同樣的，藻類萃取脂質的方法也需要先將耗費大量能源將藻類乾燥，再使用有機溶劑萃取。Dr. Babetta (Babs) L. Marrone提出具有成本效益的超聲波收穫法來回收藻類，說明收穫過程是快速的，也不會留下殘留的有機溶劑，並且不需使用任何機械零件。基於其實驗室規模的研究成果，證實此方法可應用於多種微藻細胞並且具有能耗低的優點。在過去的一年裡，研究團隊擴大這個回收設備，並建立了一個收集系統包含9個模組，使流率可以達到每小時100升左右。未來的工作將集中在控制整體過程及工業化的規模，這樣就可以實現連續、高性能的運轉成果。

(5)藻類生物煉製(Biorefinery of microalgae)

Dr.René H. Wijffels是生物處理工程(Bioprocess engineering)教授，任教於荷蘭Wageningen大學，他的研究方向是生產生物質(biomass)，特殊的生物質成分和酶的轉換以提高生產效率。他指出，微藻被認爲是可持

續生產及最有前途的的商品，是食品、飼料、化學品和生物燃料的原料之一。在生產技術還很不成熟的情況下，生物質可以商業規模生產的成本價格低於0.68歐元/千克乾物質。如果依不同的生物質組成分收集藻類生物量，其商品總價值高於1.65歐元/千克乾物質。最近，他開始執行AlgaePARC（www.AlgaePARC.com）這個計畫，AlgaePARC是一個試驗示範設施，想要藉此結合基礎研究和試驗計畫的差距，並且期待得到發展新反應器的設計概念和製程控制的策略。接續的步驟是將藻類生物質分製成不同的化合物，並且開發溫和的技術僅需少量的能量和成本，有效的提高萃取效率和產品的純度。生物煉製(Biorefinery)是一個工具，包含了生物細胞破碎、萃取、轉換和分離技術，包括從原藻生物質中選擇性分離產品（蛋白質，碳水化合物，脂類）。多種藻類副產品的開發是一項新的挑戰。需要投入的研究和開發資源很多，開發的目標是綜合的、多元的產品，如生物煉製藻類食品、水產飼料和非食品類產品等，研究的關鍵在於溫和的細胞的破壞和對環境友善的萃取、分餾過程和產品功能測試、產品配方的開發。

(6)長期在海洋及高鹽度環境養殖微藻(Long-term cultivation of marine and hypersaline microalgae in open ponds)

Michael A. Borowitzka是默多克大學的藻類研發中心主任，擁有超過35年商業化生產微藻的經驗，他分享了藻類的商業化生產模式，也且特別提到藻類副產品的開發策略，無論是有價值的產品或生物燃料，都需要仰賴可靠和穩定的養殖模式與如何維持年平均生產

力。養殖的管理必須能夠因應氣候變化有好的策略管理方式。其中優化生產率的主要因素包含最佳的細胞密度、稀釋（收穫）頻率、CO_2、pH值管理等。

叁、心得及建議：

微藻固碳技術，是一種非常有潛力應用於減緩全球暖化的綠色科技，爲了要成功發展微藻固碳技術，必須要以整體價值鏈的角度來看從供應端各項要件的輸入、培養、收成、直到最後應用端的整合性利用，才能符合經濟效益及對環境友善的綜效。另外，基於區域經濟之生態經濟觀點，必須進一步從物質流之生命週期價值鏈上來強化了生態經濟的循環性與回饋性，和推展計畫時之微觀面與執行面，繼而從循環經濟觀點來治理生態與經濟複合系統，才能使其永續發展模式又向前邁進。

透過參加”3rd International Conference on Algal Biomass, Biofuels & Bioproducts” 觀摩了最新的技術和科學成果、交流未來研究策略和可能的發展趨勢， 提供了與投入該技術領域的專家和投資者有了最直接的互動機會，對於本公司未來將此項技術大規模商業化應用有很大的助益。