Biofuels Production and Microalgal Production in Taiwan

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Abstract:

This paper reports on how Taiwan tries to meet its energy supply challenge and CO_2 mitigation targets by developing renewable biofuels, the technological progresses and the bottlenecks. Dependent to imported fossil fuels Taiwan ranked among largest greenhouse gas emitters. By documenting the policy development and efforts for biofuels production from indigenous terrestrial crops or recycled cooked oils, this paper points out the potentials of microalgal crops if turned to lipids production. Current methods for culturing microalgae and capabilities: fast multiplication, recyclable water resources, reduced land occupancy, not competing with food/feed cultures submitted to Climate change risks. Combined with potential bio-remediation functions, microalgae can treat effluents with highest carbon capture fixation through photosynthesis process, catch up international abatement while producing oxygen, hydrogen and valuable by-products for multiple applications .

Benefiting from a rich, subtropical environment, Eastern Pacific ocean coast and Strait temperate streams, Taiwan became larger health food producers in open ponds. Research and technological developments are made on strains characteristics selection and cell biosynthesis control aiming to improve biomass content through genomics engineering, combined to optimization in bioreactor design, harvesting, and trans-esterification extractions processes.

Technological, environmental and economical challenges need to be thought over, before mass production can take place. At this stage evaluations of impacts of this potential biodiesel resource are missing, and related life cycle assessment yet to be published and become worrying as monocultures yield and productivity targets set at very large scale photobioreactors or ponds size, with efficiency high lifted to meet escalating transport fuels demand and replace depleting polluting fuels.

Keywords: Taiwan Biofuels policy; Second generation biofuels; Microalgal productions; Carbon capture

Introduction

During the past decades our reliance on fossil fuels energy has resulted in large amount of Greenhouse Gas (GHG) released into our atmosphere, to an extent that it becomes a threat to the global climate (COP15). The situation is aggravated by the escalating transportation energy demand, the depletion and volatility of crude oil, and the expected future energy resources needed. With the fast developing economies, such as BRICs and other 8 fastest growing countries it can only accelerate the depletion term and supply for less than one to two generations' time. The quest for renewable energies has begun in most of the World. Brazil represents the largest carbon neutral ethanol production model caring for sugar cane plant extraction. USA, UK, France and Sweden have become major biofuels producers supporting biotechnologies with farm bills and energy policies, getting prepared to meet the demands of this new century. It is more recently that Taiwan started researches on indigenous varieties dedicated to Bioenergies and supporting innovative second generation biodiesel production. The year 2008 has seen the launching of E3, a complement fuel for hybrid motor cars targeting expansive growth for the short- and mid-terms, with renewable energy independently from crude oil, gas, coal and nuclear energy. Hence, debate on biofuels and have been raised, as food competing large-scale genetically modified organism production, and their possible impacts on water resource, arable land and soil changes have emphasized the importance of finiteness of the resources for human sustainable development. This subject has been largely treated by many countries, authors and organization, proposing solutions against fossil oil depletion in the quest for renewable energy and its supply at a competitive price, not only for the short run but also for the long run to meet escalating energy demand, among which the transportation sector. Biofuels in their liquid form are presenting compatibilities to our modern means of conveyance, storage or transportation. Solar energy is captured with much higher efficiency in the photosynthesis process than through our present photovoltaic or other solar systems. The transformation of carbohydrates accumulated in the biomass into advanced biofuels may replace in totality petroleum, in theory this CO_2 emissions could contribute positively to the reduction of GHG emissions and help to achieve the mitigation recommendations of the Intergovernmental Panel for Climate Change (IPCC) and become an important factor of climate policy. The International Energy Agency (IEA) (2009) has declared that in order to control World GHG concentration in the atmosphere at lower than 450ppm level by 2100, the development of new renewable energies is necessary. Bioenergies are playing a key role to meet the international mitigation recommendations.

At the moment, second-generation Bioenergies are not commercially viable, but the European Union (EU), United States and Canada, along with China, Brazil, India and Thailand, have begun to invest in the research and pilot production projects. In particular, the European Commission research program on bio-refineries, focuses on Second-generation Bioenergies, is reflecting the shift under way in the EU toward second-generation biofuels and integrated systems that combine electricity, fuels and commodities. Worldwide, jobs in renewable energy industries exceeded 3 million in 2009. A 2008 report by the United Nations Environment Program (UNEP) on jobs from renewable energy observes that, while developed economies have shown the most outstanding technological leadership in developing viable renewable energy, developing countries are playing an increasingly important role. This is reflected in employment; China and Brazil account for largest share of global total employment, having strong roles in solar hot water and bioenergy industries. Many of these jobs will constitute a new sector of activity in charge of installation, operation and maintenance, as well as bioenergy feedstock scattered in each area all over the country. Jobs are expected to be created rapidly in the emerging industries and by market growth.

We will present in this paper the situation in Taiwan, where energy supply relies almost fully on imported fossil fuels and is vulnerable to their depletion, market price sensitivity, air and sea worrying pollutions. Besides, fossil fuels account for 80% of the GHG emissions while the other main energy source, the nuclear energy is highly disputed (nuclear power plants and low cost energy, have been part of Taiwan's economic development, and remain to be replaced due to the high risks involved). Sustainable energy development has become a priority policy for Taiwan, where measures on national energy security are instated. In order to promote renewable energy in Taiwan, the Legislative Yuan passed the 'Renewable Energy Development Act' (REDA) in 2009. Provided by this Act, the government was authorized to use Feed-in Tariffs, a buy-back price scheme, to induce nationwide installations for renewable energy capacity and to expect a result of 650~1,000MW of green power generated by 2030. The government also supported the research and production of renewable energies, including biofuels, which gave birth to many research projects on the experiments with different local vegetal sources. Nevertheless, research on both bioethanol and biodiesel proved that their production costs are very high in Taiwan and do not allow competitiveness without subsidies or other forms of support. The cost-effectiveness remains as the most challenging part for biofuels to become a sustainable substitute for fossil fuels. Research has now been diverted to second generation from cellulosic origin, as well as to new directions such as algae unicellular oil production, by experimenting genetically modified microorganisms to raise yields and find the lowest cost of oil production as oppose to the present fossil fuels price between US$100 and 150 per barrel.

Taiwan is ranked both among the most dynamic industrialized economies and the largest gas polluting nations in the world with its high GHG (CO_2 in particular) emissions. Although Taiwan was not invited to sign the Kyoto Protocol, the government has approved since 1999 a GHG Voluntary Reduction Project and Program, following the Liberalization of Industrial Energy Supply Policy in 1996. The voluntary program involved many industrial plants to reduce their CO_2 emission and improve their energy efficiency, resulting in 2.6% less emissions from 1999 to 2006. Efforts alike were evident to the government and industry's willingness to engage in efficient and environmentally conscious measures and to develop sustainable renewable energies alternatives, such as microalgal biofuels, which present a superiority among other forms of biomass energy for their high oil contents and valuable by-products, as well as a combined CO_2 capture capacity under both day and lighting time.

1.1 Economic situation and energy consumption in Taiwan

Taiwan is an industrialized country listed among the top thirtieth wealthiest economies in the world. According to International Monetary Fund and Taiwan Customs statistics, the GDP in Taiwan (2011) was US$466.9 billion (NT$13,757 billion) and per capita GDP as US$20,139 or US$37,932 PPP. The energy situation in Taiwan, however, is severe and challenging, because there is a high energy demand with very little resource in the island, that over 99% of the energy has to be imported. The need to power its industrial, transportation, services, residential and energy sectors is met by an overly dependence on imported energies. Among these major sectors, the industries were the largest user consuming over half (53.42%) of the total energy supplies, the transportation sector was the second largest user (13.26%), while the residential (11.21%) and services (11.33%) sectors were the third and fourth largest (Table 1). Bureau of Energy statistics (2011) showed that imported coal (34.1%), petroleum (45.3%), LNG (11.3%) and nuclear (8.7%) energies accounted for 99.3% of the country's total energy supply of 140,943,000 KLOE, while indigenous supply accounted only 0.7% only, consisting of natural gas (0.2%), conventional hydraulic electricity (0.3%) and renewables (0.2%). In fact, the high import dependence has remained as the reality throughout the last decade: in 2002 the dependency was 99% and it stayed at between 99.3% - 99.4% since 2005; and the annual consumption of transportation gasoline remains as approximately 10.57 million kiloliters and diesel as 5 million kiloliters in the recent years.

Table 1. Energy consumption by sector, 1990-2011 (Unit: 1000 KLOE)

YEAR	TOTAL	ENERGY	INDUSTRI-AL	TRANSPO-RTATION	AGRICUL-TURAL	RESIDEN-TIAL	SERVIC-ES	NON-ENE-RGY USE
1990	50986.7	4841.5	23145.8	8010.7	1457.8	5944.5	4972.2	2614.2
2000	91737.4	8251.2	41619.6	14435.6	1436.7	11443.7	10596.4	3954.2
2005	111168.3	9315.4	54463.9	16192.3	1571.1	13016.2	13024.9	3584.6
2009	113047.5	8159.5	59397.6	14876	1010.7	13064.1	13032.5	3507.1
2010	119391.5	8381.7	64735.8	15546.3	982	12885.1	13173.3	3687.3
2011	118671.2	8430.6	63398.3	15739.6	1017.2	13300.4	13247.9	3537.2

Source: Energy Statistics, Bureau of Energy, Ministry of Economic Affairs

An import dependence as alarmingly high as such means that Taiwan's economic development, industrial competitiveness, trade potentials and consumer prices are all riskily subject to fluctuations in the global energy supply. Hence, the earlier versions of Taiwan's energy policy – 'Energy Policy of the Taiwan Area' promulgated in 1973 and underwent four revisions to date - mainly aimed at safeguarding the security and maintaining the stability of the country's energy supply. Sustainable development and carbon reduction was added more recently as the second policy objectives in response to scientific arguments and mounting evidences of climate change in Taiwan and internationally, for instance fatal typhoons and hurricanes. Nevertheless, since Taiwan's energy prices have for a long time been under government intervention and do not reflect the actual internal and external costs, the market lacks a strong incentive for developing alternative energies; in fact, the energy prices in Taiwan are relatively cheap in relation to the GDP and the electricity price, for instance, is among the lowest in the world (Chang, 2010).

In the recent years, however, there have been subtle but important changes in Taiwan's energy supply and the demand pattern, as results of research progresses made targeting at improving energy efficiency and developing renewable energies, as well as nationwide campaigns on energy saving and carbon reduction initiatives both at a corporate level and an individual's level. The latest Bureau of Energy statistics (renewable energy installations as of February 2012) showed that the renewable energy installed capacities for wind power, hydropower, biomass (urban waste, agricultural and industrial waste, and biogas) and solar PV have altogether generated 351.5 MW of electricity, which was 8.68% of total electricity supply in Taiwan. Although the import dependence for energies remained high and seemed to be unchanged since 2005, analysis of the relationship between the national energy consumption and GDP growth actually suggested a slowdown trend in the growth of energy consumption during 2008-2010. In other words, GDP and energy consumption was being decoupled and energy intensity lowering; studies on CO_2 emission intensity also suggested a same pattern.

1.2 Energy policy, incentives and options for alternative energy supply

In Taiwan, the competent authority for energy policies and regulating the energy market is the Bureau of Energy (BOE) of the Ministry of Economic Affairs (MOEA) under the Executive Yuan. Energy security and carbon reduction are the two most important rationales for Taiwan to develop its own alternative and renewable energies. Although not being a member of the United Nations and hence not included as a signatory to the Kyoto Protocol to the UN Framework Convention on Climate Change, Taiwan sees itself as an integral and responsible part of the global community and voluntarily follows international norms on among others environmental conservation and greenhouse gas emission cuts. Whereas existing major energy policies in Taiwan are resulted from an important elites consultation mechanism, the National Energy Conferences (NEC), hosted by MOEA and convened in May 1998, June 2005 and April 2009, respectively, the agenda of the second (2005) NEC was developed largely around the Kyoto Protocol, which came into effect on 16 February 2005 and demands its signatories to cut their emissions of six major GHGs, including CO_2, and how Taiwan would respond to it. In the first NEC in 1998 the importance of developing renewable energies was recognized but no substantial policy was made about it and certainly not on biomass biofuels. The second NEC in 2005, however, as responding to the Kyoto Protocol, has paved the way for a more systemic promotion of renewable energies in Taiwan. Under the agenda point of 'developing green energies and improving energy efficiency,' it was concluded that renewables should account for 3%-5% of the power generation market by 2010, or 10% of power installations with capacity equivalent to 500 MW. Targets for each type of renewables (biomass energy, wind power, solar energy, hydrogen cell and fuel cell, solar water heating, marine power and thermal heat) were proposed as well. The detailed targets for biomass energies and their implementation will be discussed in the subsequent part of this paper.

In June 2008 the Executive Yuan approved the new ‘Framework for Sustainable Energy’ which emphasized the balance between energy, environmental and economic developments, and identified three policy objectives to pursue: improving energy efficiency, developing clean energy, and securing stable energy supply. Targets were set forth in the Framework, for instance the energy intensity to be decreased by 20% by 2015 compared to 2005 level, and nationwide CO_2 emission to return to its 2008 level between 2016-2020. The development of carbon-free renewable energy toward a market share of 8% renewables in the electricity system by 2025, reconsideration of nuclear power as an non-carbon energy option to diversify energy supply, and allocation of emission quotas, for example, were some of the policy items listed in the Framework. To help reach these targets, the Framework also emphasized the need for certain regulatory policy instruments to be in place, the most important of which being the Greenhouse Gas Reduction Act (not yet passed due to ongoing vigorous debates) and the Renewable Energy Development Act (passed in July, 2009), and the drafting of Energy Tax Reductions to reflect the external cost of energy consumption.

Further, in the third NEC (April 2009) the government announced the ambition to cut GHG emissions in 7-10 years to 2008 level and by 2025 to 2000 level. A few months after the NEC, the Renewable Energy Development Act (REDA) was passed, which provided guidelines and financial incentives for the development of clean energy in Taiwan. The REDA introduced a buy-back price mechanism called the ‘Feed-in Tariff (FIT)’ and the idea was to fix a guaranteed price for a guaranteed period of time and at a reasonable return rate. By doing so the FIT would encourage investments in clean energy developments. The FIT rates would be decided by a committee composed of MOEA and other related government agencies, experts and industry players and are subject to yearly revision. At present the FIT covers only limited forms of renewable energies and the buy-back prices for solar PV energy are much higher than biomass energies (Table 2). There were also criticisms that the FIT calculation, especially on biofuels cost, was wrongly based and much lower than the actual production cost. It was recommended that the buyback rates for biofuels be calculated independently from the operational cost and land capital (Lee, 2010). Further, investors on biofuels should seek incentives from other mechanisms such as the agricultural development fund provided by the Council of Agriculture. Various other MOEA-BOE support programs and capacity building initiatives have been in place and implemented by research groups such as Industrial Technology and Research Institute (ITRI). For instance ITRI’s Green Energy and Environment Research Laboratories (GEL) was commissioned to set up a ‘Green Energy Industry Information Net’ to collect and disseminate market intelligence and sectoral information around seven chosen subsectors: photovoltaic, LED lighting, wind energy, biomass fuels, energy ICT, hydrogen and fuel cell and electric cars. One of the objectives was to foster synergy and innovation on the basis of clear information and knowledge exchange.

Table 2. Current Feed-In Tariffs for renewable energy and biomass energy

Type of renewable energies	FIT (NT$ per

	unit)
Solar energy (PV): 1-10 kwp	11.1883
Solar energy (PV): 10-500 kwp	12.9722
Solar energy (PV): > 500 kwp	11.1190
Onshore wind energy: 1-10 kw	7.2714
Onshore wind energy: > 10 kw	2.3834
Offshore wind energy	4.1982
Conventional hydraulic power	2.0615
Thermal heat power	5.1838
Biomass power	2.0615
Waste power	2.0615
Others	2.0615

Source : Bureau of Energy (2010)

Despite all the policies and efforts which have been in place and even though the recent energy consumption in relation to GDP has started to show a negative growth, continual endeavors and more consistent policies are requisite if Taiwan is to achieve its energy policy targets and emission ambitions. Total CO_2 emission of Taiwan remains high and ranked among the highest, per capita, in the world. In 2011, the total world CO_2 emission was 28999 M.T., of which 0.09% (250.11 M.T.) was contributed by Taiwan. According to 2011 Key World Energy Statistics by IEA, on average, a Taiwanese was responsible for 10.89 tons of yearly CO_2 emission, which was 2.54 times more than the world average of 4.29 per capita and made Taiwan the sixteenth largest emitter in the world. On the other hand, the global warming rate in Taiwan was also 2 times faster than the global average. From 1901 to 2000, the temperature raised 1.1℃ in Taiwan. Global Climate Risk Index (2012) showed that Taiwan has been among the largest CO_2 emitters and largest energy consuming country, and also among those countries which did not do enough to prevent dangerous climate change. In 2012 Taiwan's Climate Change Permance Index (CCPI) further dropped from ranking 49th to 50th, out of 61 countries. To indeed meet the voluntary climate reduction plans by referencing to the IPCC recommendation for GHG mitigation, the current picture of Taiwan's CO_2 emission, warming rates and energy consumption needed to be changed more drastically and the development of renewable energy technology is pressing. The promotion of biofuels in Taiwan started in 2006 following the decisions by the Executive Yuan as well as in the second National Energy Conference. Both bioethanol and biodiesel production were encouraged as alternatives to transportation fuels, the demand for which have been escalating, along with other measures encouraging the improvement of energy efficiency in household utilities and the use of hybrid or electric vehicles (motorcycles and cars). A raise in electricity price is also being decided for by the government, applying to the industrial sectors and will be implemented in the third quarter of 2012. Compared to other countries, Taiwan electricity price has been relatively cheaper and do not reflect the real cost. According to the MOEA, energy bills account for approximately 3% only of industrial expenses, a slight increase in the energy cost is therefore not expected to damage the industry's competitiveness.

II. Biofuels Policy Development in Taiwan

2.1 Policy Development

The bioenergy targets announced at the second NEC in 2005 was the first substantial policy made by the MOEA for Taiwan on biomass energies. It included both ethanol and biodiesel to substitute for transportation gasoline and diesel, and biogas derived from waste biomass to replace conventional coal and natural gas based electricity supply. The targets set for bioethanol were to generate 1-3 million KLOE by 2010, doubling to 2-6 million KLOE by 2015 and tripling to 3-9 million KLOE by 2020. For biodiesel the targets were to create a supply of 0.1 million KLOE by 2010 and 1.5 million KLOE by 2020. For biogas converted from waste biomass, the targets were to supply 0.74 MW by 2010, 85 MW by 2015 and 103 MW by 2020 electricity, which would be about 1.4% of total electricity installation capacity in Taiwan (Table 3). Biodiesel was an emphasis by the time of the 2005 NEC and was also then less of a research focus than ethanol.

Table 3. Biofuels target proposed by the 2005 NEC

Target year	Bioethanol (million KLOE)	Biodiesel (million KLOE)	Biomass energy from waste (MW)
2010	1.0 ~ 3.0	0.1	0.74
2015	2.0 ~ 6.0	---	0.85
2020	3.0 ~ 9.0	0.15	1.03

Source: Bureau of Energy (2005)

Paired with Taiwan's natural landscape and current technological capacities, solar PV and biomass energy were identified to be possessing better potentials in Taiwan than other major renewables, namely wind power, hydropower, thermal heat and hydrogen cell and fuel cell, according to the 'Sustainable Energy Policy' that was introduced in 2007 by MOEA. Solar energy has high potential thanks to Taiwan's abundance in sunlight and the country's established industrial foundation in the opto-electronics and semiconductors sectors, facilitating the supply of electricity and heating to household and industrial needs. On the other hand, bioethanol and biodiesel have the compatibility, when at a low blend percentage, with most of the current vehicle engines, making these two types of biofuels ready substitution for gasoline and diesel. The application of biofuels in the transportation sector could reduce the reliance on imported fossil fuels but also decrease the GHG emission produced by the sector.

To help reach the biofuels targets, BOE launched a 5-years demonstration plan for bioethanol from October 2006 (Table 4) and another demonstration plan for biodiesel from June 2007 (Table 5). In the first phase (Sep 2007-2008) all office cars used by the government agencies would have blended in E3. This would mean a volume of 770 KLOE of bioethanol, which would preferably be mainly made from local feedstock and for about 15% coming from imported sources. Taiwan Agricultural Research

Institute of the Council of Agriculture was charged with the research and trial plantation of local feedstock, namely sugar crops such as sugar cane, sweet potato and sorghum, and oil crops such as soybean, peanut and *Jatropha*, of up to 130 ha. In the second phase (2009) there would be E3 supplied at the gas stations in Taipei and Kaohsiung, the two largest cities in Taiwan. This would mean a bioethanol volume of 12000 KLOE and preferably supplied exclusively from local feedstock. Market players such as CPC, Taiwan and Taiwan Sugar Corporation (TSC) would have planted up to 3000 ha. of ethanol crops aiming at supplying E3 in Taipei and Kaohsiung. In the third phase (2011), E3 would become available in all cities in Taiwan. Such policy goal would create a market demand for 100,000 KLOE of bioethanol and it could be reached by planting 20,000 ha. of sugar crops. The market would be allowed to choose between using local feedstock and importing materials, for instance molasses. As for the promotion of biodiesel, the first phase (2005) was to introduce 'green buses' with biodiesel contents. In the second phase (2007) was to promote 'green counties' by establishing a production-sales supply chain system in selected counties in Taiwan, and to have trial sales of B1 (diesels with 1% blending of biodiesel). In the third phase (2008), all diesel put in the market must contain 1% biodiesel. The market players may decide for the ways by which such goals can be reached; they could get B1 from local feedstock as well as from overseas. In the fourth phase (2010) all diesel in the market should contain B2 (i.e. with 2% biodiesel content). (Yuan and Lee, 2011)

Table 4. Five-Year Demonstration Plan for the Promotion of Bioethanol

	Sep 2007 -2008	2009	2011
Goal	All (government) office cars	E3 application in Taipei and Kaohsiung cities	E3 application in all cities in Taiwan
Ethanol promotional volume	770 KLOE	12000 KLOE	100000 KLOE
Feedstock	Preferably locally produced	Preferably locally produced	Free market
Planned cultivation area for fuel crops	130 ha	3000 ha	20000 ha
Imported ethanol feedstock	120 KLOE		
Implementing agency	Government (Taiwan Agricultural Research Institute of Council of Agriculture)	Market players	Market players

Source: adapted from Yuan and Lee, 2011.

Table 5. Five-Year Demonstration Plan for the Promotion of Biodiesel

	2005	June 2007	July 2008	2010
Goal	'Green bus' campaign: promoting the use of biodiesel in public buses.	'Green County' campaign: establishing biodiesel production-sales supply system in selected counties. Trial sales of B1 biodiesel.	All diesel put in the market must contain 1% biodiesel; free market and import is allowed.	All diesel in the market to contain 2% biodiesel.

Source: adapted from Yuan and Lee, 2011.

Whereas MOEA (and its BOE) is responsible for the energy policy and market regulation in Taiwan, another governmental ministry, Council of Agriculture (COA), is in charge of the policy-making of energy crops, including their development and subsidizing. Acting upon the second NEC in 2005 and the Executive Yuan decisions made in its 2992nd (June 2006) and 3010th (October 2006) meetings, COA announced the 'Support Program for the Development of Energy and Landscaping Crops on Fallow Land' which was to provide financial support to domestic energy and landscaping crops production, with an emphasis on indigenous cultivar and a sustainable policy objective targeting at rural employment, agricultural structural development and rural landscaping at one goal. The implementing agency of this program was COA's Agriculture and Food Agency (AFA). This program encouraged the cultivation of energy crops, such as soybeans and sunflowers, on fallow land for biodiesel feedstock production. Each hectare of plantation could receive an 'environmental subsidy' of NT$45000 and in addition maximum NT$15000 as the 'production subsidy', depending on the actual oil seed harvest and the types of cultivar; this was a better incentive than the cultivation of rice, food crops and herbs, the subsidies for which ranged from NT$22000 per hectare to NT$34000 per hectare (Chang, 2007).

From the perspective of COA, developing biofuels was interesting because it could tackle the multiple challenges faced by Taiwan's agriculture with the country's accession to World Trade Organization since 2002 (Wen, 2007). Once the market was opened to the world, growers could in the short run suffer from lowered income as a result of competition; subsidies had to be abolished due to WTO obligations and growers forced to leave fellow their land in the absence of financial incentives. Developing biofuels was then seen as an opportunity for the growers and also for the agricultural sector to advance in biotechnologies. Thus, COA encouraged the production of energy crops as a comprehensive policy instrument to reach multiple goals, including agricultural development, energy security and environmental protection. In 2008, however, the subsidies had to be terminated due to altered policy priorities placed by the newly formed Cabinet after the Presidential election in May. The new government was faced with a mounting international financial crisis coupled with skyrocket rise in the import prices for food and feed. Food security and price stability preoccupied the policy agenda of COA. The Executive Yuan decided in its 3093rd meeting (May 2008) that fallow lands should resume production for food; and to avoid competition between different causes the subsidies for energy and landscaping crops will be stopped.

The cost-effectiveness of growing energy crops and producing biofuels in Taiwan was (and still is) much lower than countries like Brazil, USA, Thailand and even the European Union, that without subsidy and as well in the absence of strong market incentives the progress of the development of biofuels remained slow. The cost for biodiesel production with soybean was estimated at NT$55-57 per liter oil equivalent; the cost for ethanol production was NT$25-29 per liter with sugar cane, NT$28 per liter with feed corn, NT$34 per liter with sorghum and NT$39 per liter with sweet potato. These were at least 2-3 times more expensive than major biofuels producing countries in the world. Therefore, at the moment, biodiesel production in Taiwan is economically interesting only with used cooking oil; with ethanol production there are limited market players, for instance CPC and TSC using sugar cane, sorghum and imported molasses as feedstock. (Chang, 2007; Lee, 2011) Research and private sectors are interested in developing second generation ethanol, for instance from dry straws. Second generation feedstock is cheaper than the first generation, but the installation fees for the production facilities are higher and therefore requires government supports. Although COA no longer subsidizes energy crop plantation, funding such as 'Agricultural Development Fund' is available and other support programs are under way to be passed by the Parliament.

In 2009, the third NEC, MOEA made an inventory of the implementation results of the bioenergy policies and measures. Reports from BOE showed that in 2005-2006 there was very little bioethanol in Taiwan; production was increased to 1.08 MLs in 2008, which reached the 2010 target of 1.0-3.0 ML. Biodiesel seemed to be less developed and by 2008 there was merely 0.0023 ML (Table 6). AFA also reported on the plantation of energy crops under the subsidy scheme, which showed uncompetitive of biofuels production in Taiwan. During 2006-2008, 24 townships farmers' association in 5 Counties across Taiwan (Tainan, Chiayi, Yunlin, Taoyuan and Taipei Counties) and contract refineries such as Taiwan NJC Corp. and Chant Oil Co., Ltd. participated in the trail production. In 2006, 1479 hectares of mainly soybean and sunflower was planted; in 2007 there was 2517 ha. and in 2008 only 154 ha. due to the termination of the subsidies. A total surface of 4150 ha. of plantation has yielded 2100 oil seeds and produced 0.44 ML biodiesel, which was exclusively supplied to eco-cars involved in the MOEA's demo plan. As for ethanol crops there was little plantation applied for by the farmers. In 2006 AFA trial planted 30 ha. of sweet potatoes and produced 0.025 ML ethanol from there, which was supplied to MOEA demo plan.in 2007 National Chung Hsing University also participated in trial plantation and produced 0.01 ML ethanol for research purpose and COA policy references. (Chang, 2007; Kao, 2011).

Table 6. Biofuels production in view to the targets set at the 2005 NEC

	2005	2006	2007	2008
Bioethanol	0.0007 ML	0.002 ML	0.11 ML	1.08 ML
Biodiesel	0	0	0.0006 ML	0.0023 ML

Source: Bureau of Energy (2009)

Although COA no longer prioritizes financial support for biofuel development, COA agencies maintained research programs on biofuels. For instance, the Taiwan Livestock Research Institute researches on biogas production from farm waste and the several District Agricultural Research and Extension Stations experiment on the crop-fuel efficiency issues of different plants. The main crops under research include *Jatropha* and *Miscanthus.* The COA's Fisheries Research Institute, on the other hand, has research works on microalgae as a source of biofuels.

2.2. Current Situation by Subsector

a) Biodiesel

As has been illustrated in the earlier paragraphs, the development of biofuels has been largely policy-driven. In July 2008 the sales of B1 has become obligatory, which created a market demand for annually 50,000 KLOE biodiesel; and in 2010 the sales of B2 has been in place, creating a demand of 100,000 KLOE. ITRI/GEL's Green Energy Industry Information Net gave an account of the trial market players; since October 2004 the first demonstration biodiesel factory was in operation, a collaboration between ITRI and Taiwan NJC Corp, with technical transfer from ITRI and financial support from MOEA. It has an annual capacity of maximum 3,000 KLOE. Taiwan NJC Corp is one of the eight major pioneer commercial players in the production of biodiesel in Taiwan, outputting approximately 76,000 KLOE; these other players include Chant Oil Co., Ltd., Great Green Co., Ltd., Year Fortune Corp. and Gibson Chemical Corp.

Major feedstock involved includes oil seeds such as soy, sunflower and rapeseed, and waste cooking oil. In 2006 AFA planned for the cultivation of 2,000 ha. of soy, sunflower and rapeseed to output up to 480 KLOE biodiesel. In 2008 the cultivation area was increased to 8,000 ha to output 3,200 KLOE biodiesel. In 2009 the domestic feedstock market was liberalized and COA turned to encourage the use of waste cooking oil as biodiesel feedstock, while at the same time also increased biodiesel crop cultivation area to 20,000 ha to supply 8,000 KLOE biodiesel. In 2011 the cultivation area was further increased to 80,000 ha to supply 32,000 KLOE. In fact, the majority of Taiwan's biodiesel commercial practices are based on waste cooking oil as the feedstock. The retail price is around NT$45-50, which is higher than conventional diesel and also much higher than biodiesel produced in other countries, for instance Brazil, Germany and USA, and the biodiesel is mainly purchased by governmental agencies to be used in eco-cars. (Wen, 2007)

b) Bioethanol

BOE publication, 'Developing Sustainable Renewable Energy' (in Chinese) accounted that, as a phase one pilot project for the BOE's promotion of bioethanol, from September 2007 to December 2008 Taipei City carried out an 'E3 green office cars' campaign for all service cars in use by the city government which are technically applicable. The average monthly demand for E3 was at that period of time 220 KLOE and E3 was supplied in 8 gas stations in the Taipei metropolitan area. Entering into phase two of bioethanol promotion, since July 2009 E3 became available in 13 gas stations in Taipei and Kaohsiung cities. CPC published on their websites that the price of E3 was the same as conventional gasoline, although during the promotional period the BOE provided an incentive of a NT$2 per liter discount.

Researchers in Taiwan studied the use of indigenous sugar crop, sugar canes, and starch crop, sweet potatoes, for the production of bioethanol. AFA planted in 2007 a 30 ha. of sweet potatoes for the provision of starch and from which 150 KL ethanol was produced. The plan was to increase the planting area every year up to 2010 and in 2011 import would become permitted. The planned cultivation area and target ethanol volume in 2008 was 100 ha and 500 KL; in 2009 it was 3,000 ha for 15,000 KL; in 2010 it was 20,000 ha for 100,000 KL. However, as mentioned here above, since 2008 biofuel crop production was no longer encouraged by COA policy, the planned cultivation did not all take places although research work remained at several of the COA agencies.

The production cost in Taiwan for bioethanol based on sweet potatoes was estimated to be between NT$19.62 to 20.35, slightly lower than the cost by using sugar canes. Sweet potato is important source of food, fiber and other functional supply as well as feed ingredients, that the cost of it as ethanol feedstock would be pushed up as a result of competition. However, there is strategic reason to grow sweet potatoes because they can be supplied to pig feed when international feed ingredients such as corn and grains prices are raised, and they can be used as ethanol feedstock when feed price is low. They can also be supplies of functional food. By these multiple applications and market possibilities, growers would be motivated to invest in sweet potato cultivation. Such was a strategy inspired by Brazil's sugar cane production, that when the international commodity price for sugar is high the sugar cane could be made into raw sugar for exports, and when the commodity price is low the sugar cane could be processed into bioethanol both for the domestic market and export.

The net production cost in Taiwan for bioethanol based on sugar canes was estimated to be around NT$29.21, more than double of the net cost in US (around NT$14.09) and almost triple that in Brazil (around NT$10.56). This was mainly because the feedstock -sugar canes – cost around NT$25.39 which made up a dominantly 84% of the final cost, after considering the expected profits from the bi-products, and the bi-products themselves were also less profitable than was the case in the US and Brazil. Researchers also modeled scenarios where Taiwan would import starches and produce the ethanol locally, the net production cost would then be around NT$22.4; if Taiwan would import cane sugars for the production of ethanol the cost would then be around NT$20.3; but if Taiwan would simply import bioethanol the cost would instead be approximately be NT$14.4. (Wen, 2007)

While there are limited feedstock choices in Taiwan for ethanol production and the production cost from first generation biofuel crops is not economically viable, and for second generation the technologies weren't commercially available yet, there has been less commercial practice of ethanol production in Taiwan than of biodiesel production. This was probably unforeseen by the time of the NEC in 2005. A limited number of market players, including the state-owned oil company, CPC Corporation Taiwan, agro-chemical company, Taiwan Fertilizer Co., Ltd., and food conglomerates such as Vedan Enterprise Corp. and Taiwan Sugar Corporation, nevertheless, have investments in ethanol research and attempts for commercialization; other enterprise did not have sufficient confidence in the government policy and tended to be more conservative. It was not until recently, December 2011, that there is a commercially-oriented demonstration ethanol factory using second generation feedstock. This factory, Taiwan Mother Cosmo Co., Ltd. (TMC), located in Changhua County, is a joint venture between the Taiwanese petro-chemical company, CPC Corporation, and a leading Japanese confectioner, Meiji Seika Kaisha, Ltd. On the Press Release of TMC (February 2012), The factory owner sees the potential of biofuels as an alternative to conventional car fuels, which is a trend happening in developed countries and also one that is in line with the government policy in Taiwan. However, Taiwan lacked the technical possibilities for producing cost-effective ethanol and this was the main reason why ethanol production in Taiwan remained low. In the demonstration factory, Taiwan Mother Cosmo offered a formula that would make local ethanol production economically feasible: with hydrolytic enzymes and an all-in-one large scale (1 ton) processing machine, which could greatly shorten the time needed for saccharification in the fermentation process and is cheaper than existing technologies such as high pressure-high temperature explosion (used for instance in US) and acidolysis (used for instance in China). The feedstock-ethanol conversion rate could be as high as 20% and the production cost for such all-in large scale processing machine is 80% cheaper than existing models. Feedstock came from agricultural and industrial wastes, such as cellulose from grains and sugar cane, recycled paper pulp, used green tea leaves and fruit peels. Taiwan Mother Cosmo presented its production model as a sustainable formula which is dramatically cheaper, resolve waste biomass, does not compete with food and feed and is commercially feasible. The demonstration factory is meant for attracting investors, government agencies and commercial partners.

The present productions of biofuels as seen are limited and supported by the government, among biofuels, microalgal biodiesel in particular shows potential thanks to reviewed strategies around the world, among which NREL (USA), to enhance the development of larger scale productions in Photobioreactors of advanced biofuels has been progressing in Taiwan too.

III. Microalgal Biofuels in Taiwan

3.1 Potentials advantages microalgae for biofuels production

Observation and advanced research on microalgae cultures by research laboratories (De la Noue et al, 1988) around the world has brought to the attention the positive aspects of the metabolism (Camacho et al, 2003) and interesting biomass production of microalgal cultures during their growth in harmony with their environment (Richmond, 2000). Microalgae, mainly unicellular and with very simple composition, offer such characteristics as rapid growth in a liquid medium, ability to capture atmospheric carbon through photosynthesis process (in the presence of chloroplast with chlorophylls content) during day time or under light exposure, fixation and conversion through a complex physiologic process that filters their liquid medium, and fix inorganic carbon. Atmospheric CO_2 diffused in water is captured and converted into sugar, starch, high content of fatty acids and other lipid oils with other metabolites, some of which offering high value applications in pharmaceutical and health food that are developed by industries for nutritional interests such as amino acids, proteins, carbohydrates, carotenoids, vitamins, iodine, potassium, magnesium, iron and selenium for human nutraceutical, pigments and food additives (Borowitzka, 1999), or various supplements in feed for fish, shrimps or larvae in aquaculture (Wen, 2009) and liberate microbubbles of oxygen. The biomass production of these eu- and prokaryotes has fast growth characteristics as they can be found in abundance and existed since the past millenaries thanks to solar energy, original atmospheric gas and mineral elements (Semin et al, 2003). Algae are in total symbiotic with higher level food chain which require oxygen, pure water and organic supply (Gaffron, 1940). Since 1980, their high oil content was exploited and found to have good performance and high productivity when they were abstracted into biodiesel, presenting sustainable short genetic cycles and absence of lignin (present in most species except some weeds) and allowing for easier harvest than terrestrial plants (Mondragon, 2003). It is however in the very recent years that algae became the center of genomics and metabolic content studies, confirming algae to be excellent source of advanced biofuels in biorefineries in the aim to replace the depleting and polluting fossil fuels (Spolaore & al, 2006; Christi, 2007; Crutzen, 2007). On the other hand, algae can also produce methane, coal, biogas, bioethanol and under certain anaerobic conditions bio-hydrogen. Hence, algae have become the subject of potential future clean energy (i.e. carbon neutral energy resources), in addition to the fact that they need much fewer land occupation and fresh water resource (hence algae processing can actually be combined with the recycling of waste waters). For the time being, world production of algae-based biofuels is not significant and still at prototype experimentation. This is the same case with Taiwan, where algae for fuels research also encountered several challenges due to biological and technological limitations; and despite the potential they may offer, commercialization could not be ready due to the lack of risk analysis for the possible impacts of high yield or large scale production (adverse effects are yet to be studied).

Total production in the West was estimated to be less than 10,000 tons / year for dry algal biomass (Benneman, 2008). Main practice of the production is in closed systems (Camacho Rubio et al, 1999) with controlled medium and with various types of tubular photoreactors (Sánchez Mirón, 1999; Camacho Rubio, 1999, 2003; Carvalho, 2006). In Asian countries, algae are typically cultured in large size, round shaped open ponds but they are more for the supply of nutraceutical, with China in the leading position for exportation (half of the production involved Taiwanese investment in southern China) and Taiwan ranking the second. Japan is in the third place and accounts for around one-fourth of the world production (although Japan actually is a major importer from Taiwan, in other words Japan's domestic production is less than Taiwan). USA ranked the fourth and is followed by Australia and India. Industrial productions are frequently operated in various types of outdoor pond systems (for the phototrophic microalgae) provided generally with aerating paddle wheels. These systems mean that very strict rules of hygiene and control of the production apply in order to avoid contaminations by less productive species, or grazers that may influence the productivity. The process is a careful mature method, seeding inoculums culture into the ponds (with shallow surface) under controlled medium and a certain growth period. The method fits well in Taiwan due to its sub-tropical climate and environment.

This way of commercial production of nutraceutical in open ponds originated from consultation with Japanese technologies and was well developed in Taiwan by the industries since several decades and laid the foundation for their present leading position in the global market. Open ponds can also be found in the US for the production of Omega3, antioxidant and pigments for paintings and vitamins, etc. (Belarbi, 2000). Compared to the open systems in the East, Western countries adopt mostly closed systems called photobioreactors due to their higher efficiency in laboratories, independence from the weather condition and well defined and controlled medium. Larger photobioreactors are prevailing and consist of transparent tubes exposed to light source (outdoor/LED) bearing nutrients and gas flow supply. In an ecological and economical point of view, however, they are much costly than open ponds which can run on aquaculture waste water or industrial waste water and thermal plant water, constituting an ecosystem in which the microalgal culture would operate like a water filter and release the water from ammonium (N), phosphates (P), potassium (K) and other substances (for instance heavy metal) resulting from the aquaculture production (Happe, 1994; Semin et al, 2003). Through the photosynthesis process algae aerate the ponds with O_2 production with micro bubbles that are well distributed and allow in some conditions which do not require the use the electrically animated paddle wheels. Microalgae's fast growth constitute a sustainable and excellent nutritive source for aquaculture (fish, clams, larvae, etc.) and is in practice in Taiwan for a long time under strict controls, in addition to the very positive economics of microalgae (a food chain is formed by the continuous division of the microalgae feeding the growth of the culture, thus recycling in the culture the waste in the water originating possibly from industrial waste water or thermal central flows). Large scale production of biofuels from microalgae has recently become under focus in many countries with promising prospects especially for international petroleum groups and airlines which have allocated significant budget for algae fuels related research. The potential of microalgae as renewable clean energy resources and their eco-friendly image serve as 'catalysts' to attract large investors with public funds to engage researchers in the study and production of advanced biofuels for different purposes, including polymers.

Biodiesel composition is close to kerosene and some countries are experimenting it as potential jet fuels. As a matter of fact, aircraft emissions are expected to rise corresponding to the increasing number of goods and passengers travelling by air. IPCC reports warned that aircrafts emissions can become really worrying by 2050 as kerosene constitutes an important proportion of total oil consumed yearly (at present it represents about 8% of it). Further reason for the quest for biodiesel or bioethanol application in the transportation sector is that, when in liquid forms, they are easy to store with higher energy density and less volatility, although biodiesel might tend to solidify at high altitudes. Moreoever, on an economical aspect, biodiesel and bioethanol can be produced in existing oil refinery plants and equipment (Czernik, 2004) and are compatible with existing distribution facilities and consumer oriented plastics by-products industries (Gavrilescu et al, 2005). In 2011, the main biofuels markets are North America (USA is the largest world producer with 45% market share) followed by Latin America (Brazil, 37%), Europe (14.5%) and Asia-Pacific (5.1%). For many of these countries (USA in particular) their 2022 target is to at least double their 2011 production. Finally, an important boosting factor is the new investments in green biofuels research by the world's largest oil companies (Shell, BP, Total, Exxon Mobil, and more) which look into the possibilities to produce tailored made 'advanced biofuels' (Fukuda et al, 2001) that would ideally present similar characteristics to long carbon chains of hydrocarburs (Meher et al, 2006; Ji-lu,2007), as well as jet oils that could be treated in existing refinery infrastructures and distributed by current operating gasoline pumps and delivery equipment. Oil supply volatility and progress in high-tech in the recent years have stimulated the demand for the production of jet fuels in a more competitive way and at high yields through ecofriendly systems. Such challenges have pushed researchers to work in different directions and under laboratory or prototype scales. Microalgae, with their high content in lipids and fast growth and division, show prospects in oppose to terrestrial plants (Christi 2002) using less land surface, water resources, energy investment and nutrients supply.

In Taiwan, 2011, ITRI biofuels laboratory observed 1 gram of microalgae in 1 liter of ocean seawater can, which, depending on the species, became 5 times the initial biomass. Further, recent studies with multilayer filters membranes technique can allow to boost the density to 120~150 gm per liter ocean seawater. These exciting discoveries encouraged researchers to go on in the interdisciplinary research. Many bottle necks are still in the way, however, for example the best adapted growth (production) system still needs to be identified (open ponds, photobioreactors, or combined types?) (Sánchez Mirón, 1999; Molina Grima et al 2000; Carvalho et al, 2006). Recycling of water resource is another challenge (e.g. how to keep boosting the yield while high content of fat conditions are met in critical conditions?) (Wang et al 2011), where as raising production yields is less of a bottle neck because it can be achieved by lowering the density and increasing phototrophy required for the growth. Other challenges include the harvesting, flocculation and extractions, which have to deal with very wet and small biomass and require energetic treatments or chemical solvents, centrifugations and processing equipment. Costly treatments for downstream extraction need to be optimized and enzyme catalysts from bacteria need to be produced to accelerate trans-etherification and higher dry lipid content for purification process. To decrease these high costs, extraction of the other components of the microalgae and applications could be used to balance them someway; and new techniques and innovative methods are required to help diminish the risks and costs to enhance biodiesel viability.

3.2 Current research and technological developments in Taiwan

There are several research programs in Taiwan for renewable energies with an emphasis on microalgal cultures for biofuels production. Three research directions can be categorized coinciding with researches abroad.

a) Selection of appropriate microalgal strains and improvement of their performance through metabolic factors control: They are conducted through microalgal biology study (Chen, 1993, 2007, 2011), understanding of lipid biosynthesis process and inter-laboratories cooperation for genomics engineering and modification of the saturation type of lipids or components content level, with applications for producing resistant strains to unwanted culture invasion. Behavior in critical starvation conditions like nitrogen 0.313g/l can manage to enhance lipid content to 55.9% on *Chlorella vulgaris* (Yeh et al 2011) hence enhance harvesting possibilities. Taiwan benefits from its subtropical climate with rich biodiversity in seaweeds thanks to its western Pacific coast and temperate streams on the strait side, offering large variety of resources (Metting, 1996) to be explored for microalgae in particular due their small size. Present researches are focusing on optimizing such characteristics as higher oil content (more than 50% dry matter), resistance to impurities in flue gas and high CO_2 concentration (Chang et al, 1997) and other abstraction for valuable by-products application (such as proteins, enzymes, DHA, oligosaccharides, vitamins for nutraceutical, cosmetic creams, pigments as food additives, immune-diagnostic reagent and viral products; most of which have been commercialized in Taiwan). Researchers from the Aquaculture Department of National Taiwan Ocean University (NTOU) have established a seed stock for the current and local microalgae, as well as pro- and eukaryotes and macro algae, in order to understand the biology for growth, division and metabolic contents, in particular the immobilization method and innovative techniques using beads (natural Calcium Alginate) to immobilize for long term pure strains and to find further applications for aquaculture feedstock, waste water treatment and biofuels harvesting research (Chen,2007). Carbon capture from diffused flue, or from waste water such as swine sewage is also under research. For example, ITRI's new energy technology division, Green Energy and Environment Research Labs (GEL) showed in 2011 the potential of different strains of Chlorella lipid content with growth rate of carbon capture, oxygen production, nutrients supply, biofuels (biodiesel, bioethanol, coal and methane), biohydrogen or electricity production, and water treatment.

b) Cultivation strategies and experiments for a most efficient culture system: The commercial production in Taiwan is under very strict hygiene control; with continuous production in shallow ponds, there are also photobioreactors from flask size to tubular forms for anaerobic production of biohydrogen or biodiesel. The elaboration of culture systems involves studies on liquid velocity, effluent remediation, energy and water resource recycling, cleaning methods and control systems, and new creative ideas such as building layered or floors of ponds in a multi-storey tower to capture more sunlight and decrease the land surface needed for the culture, thereby reducing dramatically the cost of engineering energy and water recovery. A tower building could also keep the culture in a continuous flue system under total control and independent of the weather conditions. Despite of interesting developments, researchers are faced with a perspective of future scale-up exploitation. These systems have important potential to bring down production costs but they need to be adapted to supplying biofuels and meeting the anticipated high production scale. Some combined systems are already running in Taiwan, for example the carbon capture tower experimented by Far Eastern Bio-Tech Co. (Febico) in a program collaborating with Taiwan's China Steel Co. for carbon emissions reduction through biofixation of flue gas CO_2. They designed and built a new type of ponds in closed system in a three floors tower, which according to the constructor can be further elevated to numerous more floors (system patent, 2003). The building is a transparent, closed, top-to-down bell-like tower where each floor has a limited surface of 15 square meter supporting shallow open trays on both sides, with the liquid medium, algae and nutrients brought in with the water (9 tons) circulating from a pump system down from the water tank at the basement to the top against inner glass wall. This experimental program was carried out successfully and showed high efficiency. Being built on the steel production site, the tower captured yearly total 150 tons/ha CO_2 in its hybrid bioreactor and pond system which occupy a very limited land surface against the chimneys of China Steel Co. plant. This may set an example for possible innovative, combined open-closed systems for lower cost algae culture. On the other hand, ITRI also experimented on the cultivation strategies combining with nutrient starvation to increase the lipid production on microalgae (Yeh et al. 2006). ITRI has been developing photobioreactors in open raceway system for 78 mg/L/day, experimented by Academia Sinica and resulting in a +40% enhanced production of lipids in vertical tubular photobioreactors. If allowing CO_2 carbon fixation at rate 132.4mg/L/day, the production of lipids saturated at 65% which can be suitable for biodiesel conversion (C16: palmitic acid; C18: stearic acid; and one monounsaturated acid C18: oleic acid); with CO_2 carbon fixation at rate 430mg/L/day (6.36g CO_2 fixed during 10 days) resulting 55.9% high lipid content when experienced *Chlorella vulgaris* ESP-31 optimized with nitrogen starvation at 0.313g/L KNO(3) (Yeh et al 2011).

c) Adaptation of lipids extraction and purification techniques (Tran et al, 2011) to improve energy efficiency and costs of the biorefineries to produce “advanced” biofuels (Miao et al, 2004) that could be facilitated through the development of a genetic platform. This transforming tool can increase the triacylglycerol (TAG) content from 20% to 40% by cloning the TAG synthesis related gene of overexpressed gene, according to tests on *saccharomyces* or *chlamydomonas* achieved by ITRI/GEL, extending this genetic platform to *Chlorella* and focusing on the possibility to transform the cell into a saturated TAG secretion “biorefinery” (CNA, 2011.08.26).

Life cycle assessments with economical evaluations for the impact on the environment, economic feasibility, scale size, efficiency evaluation such as Energy Return on Investment (EROI refers to the ratio of the bioenergy value produced to the amount of energy consumed in the production) and Energy Efficiency (EEF ratio refers to the Bioenergies value produced to the total energy, including the energy used and the one produced) (Zah et al, 2009) are however not available yet. There is no costs comparison and assessments of possible adverse effects and impacts on the environment in the publications. At this stage, no large scale economy production is running yet; cost comparison and impact assessments studies, if realized, can help the industry to evaluate, determine and quantify their productions.

In Taiwan, BOE has been working towards two sets of goals against the situation of the depleting oil supply, high pollution and escalating energy costs. The first goal is to cut energy consumption, reduce energy waste and improve energy efficiency. Effective recycling program, preventive measures and encouragement measures are in place, as have been described in the earlier part of this paper, which contributed to ranking Taiwan among the developed countries. The second goal is to enhance research and development (R&D) programs by allocating budgets and setting up industrial funds, and linking new energy policies to reduction of GHG emissions. Cooperating with the National Science

Council (NSC), BOE supports and funds different research projects aiming at energy saving (e.g. Alternative Energies Development and Sustainability) in the face of rising demand of transportation energy and worrying pollution situations. The government also supports related projects such as those promoting electric cars and liquid form biofuels (mainly biodiesel and bioethanol) by working together with major institutes, in particular the Green Energy and Environment Research Laboratories (GEL) of ITRI as well as the Fisheries Research Institute under the COA. Since 2009, ITRI has been working on a 4 year project on microalgal biodiesel involving US$7.67 million budget from BOE. It shows that the potential of microalgal biodiesel has been recognized by the government thanks to the efforts and advances made by ITRI: they use cell disruption method for extraction for harvesting, but high energy input is required to concentrate the biomass and to aim at higher productivity of microalgal oil; combining with the local potential of Taiwan, ie. Sunshine (3251-5238MJ/m2/year), open ponds mature industries experienced 4-12 gm/m2/day with 0.4g/liter density. Experiments also resulted in higher efficiency with tubular photobioreactors: 30 gm/m2/day, using waste water from swine farms and with local high lipid content (reaching more than 40% triglycerides) “engineered” *Chlorella* strains.

While meeting the same challenges and bottlenecks, interdisciplinary collaboration and exchange programs can help to stimulate breakthroughs as well as save costs. Past results lead to focusing on the screening for high oil content strains and their resistance to the impurities in flue gas and high CO_2 concentration, ad on the improvements of their characteristics; while other research laboratories are focusing on the determination of strategic cultivation methods and conditions and teaming up with academic laboratories, including Academia Sinica, National Central University, Da-Yeh University and Ming Chi University Of Technology in Taiwan, and National Renewable Energy Laboratory (NREL) in the US, for strain development. Further, for cultivation, ITRI/GEL is cooperating with COA’s Fisheries Research Institute and National Taiwan University. As for harvesting, cell disruption and oil extraction technologies, ITRI/GEL, Material, Chemical and Nanotechnology Lab (MCL) and Mechanical and Systems Technologies Lab (MSL) work in collaboration with National Cheng Kung University for the constructing of systems integration and simulation.

These 3 strategies coincide with the microalgal biomass concentration strategy as described in the US Department of Energy’s National Algal Biofuels Technology Roadmap (2009 draft), targeting at a maximum concentration while minimizing the energy input (5 times less energy spent in chemical or physical treatment to the microcells for separation and extraction or conversion). Production systems also need to be optimized, as much as possible the reuse or recycling of energy (calorific), water and strains culture. Nutrients supply might become short in large microalgal production; this could be resolved by sourcing waste water from local municipal or heavy industry. The specific waste water could be filtered for concentration and become a complement source of N, P, K nutrients combined to the waste water to be cleaned by the microalgae. In this way the waste water, which would otherwise be a polluting agent with heavy metals, could to utilized and devoted to non-food applications.

IV. Discussion and Conclusion

4.1 Advantages

Research has been taken place in several directions such as the selection of more adapted species or strains that show high lipids content. One example among many others is the Cyanobacteria microalgae study; this microorganism presents chlorophyll A in its cell which allows to store up to 50% or more than its own biomass dry weight under stressful conditions. Other research directions are geared towards new techniques for the production system, the harvesting and combinations of extractions methods.

Microalgae strains selection is considered as essential and continuous studies are made to screen local species and to improve their lipids productivity. Such efforts contributed to further knowledge on their metabolism, biosynthesis and performances, and have been subject to genomics engineering studies modifying their genome for optimizing triglycerides secretion, facilitated by their very short cycles and fast growth (a few hours or days) versus terrestrial plants (months or years). Comparisons made on the land occupation (productivity / surface used) also confirmed the dominating advantages of microalgal cultures over terrestrial cultures and the potential to replace first generation biofuels (first generations refer to those fuels derived from crops, or parts of crops, that can be consumed as food or feed; and second generations refer to those made from crops, parts of crops, or their wastes, which do not compete with food or feed supplies).

First generation biofuels became a highly disputable subject since 6 years ago with the crisis of food supply shortage and price volatility caused indirectly or directly by the production of fuel crops in Central and South America and Eastern Africa, where massive land surface was diverted from staple food crops (corn, soya, cereals, etc.) to driving car engines, while humanity was still suffering from starvation and food supply security still an issue, that has caused price escalation and inequality to the most impoverished. In the recent years, food crops continued to suffer from changing climate conditions in many countries, such as desertification, irregularities in the seasons and other extremities. The increase of biofuels consumption would raise seriousness of these situations in Asian countries, particularly those importing a lot to meet their food demands, including Taiwan, which pushes their governments to develop researches and cooperation on second generation biofuels that do not raise concern for food security and do not cause competition between food and energy (Koizumi et al, 2007). Algae, on the other hand, are not as much subject to climate conditions, as they can be cultured in waste water or sea water. Secondly, algal culture does not occupy any arable land and require less than one-tenth that of the land surface needed to produce biofuels from terrestrial crops. This means that 9 times of land and irrigation water could be released and made available for other land uses. Thirdly, microalgal culture has another advantage over territorial plants in terms of the estimated volume of water resources used and water quality reached. Algae growth can be satisfied by sea water, waste water, brackish (effluent) or unsalted water without the requirement for pretreatment, and the CO_2

source for photosynthesis needs not to be purified. In Taiwan, applications have been successful with waste water, swine sewage water and industrial waste water. Sludge accumulation and chemical water treatments in traditional aquaculture can be avoided because of the effective CO_2 capture in the microalgal culture and forming an ecofriendly system.

4.2 Challenges

Despite the advantages of microalgal culture and their very positive experiment results pushing for their further development, there are biological and technological bottlenecks and challenges to overcome in an economically feasible way. The production cost of biofuels from microalgae cannot be competitive at this stage and is higher than from terrestrial plants. Further, traditional waste water treatment is less expensive than cleaning in microalgal cultures and is much faster (in terms of time), although also less ecological due to the chemicals and the energy involved both in the waste processing and in the further treatment and transportation of the sludge.

In the last millenaries (350 million years), algae have been largely contributing to our present natural environment (seas, oceans and lakes) by reducing the concentration of CO_2 and other gazes and transforming the atmosphere to its present composition. Thanks to the larger proportion of sea surface to emerged land surface (70%), most of the CO_2 emitted have the chance to be diffused and balanced by microalgae, planktons and algae. However, due to climate change phenomena and the risks of global warming, IEA has urged nations to make CO_2 mitigation targets with the respects of managing and controlling their national GHG emissions in the coming decades. Although Taiwan was not officially represented at the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC), the Taiwanese government has voluntarily accepted the recommendations and targets made by the COP. Researchers are developing alternative energies to replace petrochemical fuels with cleaner and more sustainable options. These potential energy developments would gear up the production scale to meet the transportation energy needs in the coming decade. Continual efforts are underway in public and private institutes in Taiwan with the most advanced research portfolio, such as Academia Sinica, Taipower, Taiwan Sugar Corporation, Institute for Nuclear Energy Research of the Atomic Energy Council, which work towards intensive biomass exploitation to meet the fixed emission targets and implementation of Emissions Trading Scheme (ETS), alleviate carbon emissions by carbon capture processes and accelerate technological transfer to maximize the potential of microalgal biofuels, as an important source among other renewable energy sources such as solar, wind, marine, hydraulic and thermal.

4.3 Challenges for Microalgal Oil Production

There are more than 30,000 species of macro and microalgae on earth; there might be 1,000 in the oceans of Taiwan. Only a few of these species and their strains have been studied as not all bear the targeted capabilities for oil production. It means that there is not one unique super strain capable of producing the lipids for biodiesel and at the same time possessing other qualities such as high value by-products. At the moment different strains are cultured for their valuable abstractions; research needs to enhance the understanding of the biology, biosynthesis parameters and genetic to optimize the present productions; and the modification of genome to result in new metabolites equilibrium will require experiments to understand the possible impacts under scale up productions.

Moreover, the best environment for microalgal growth needs to be identified and optimized. Photobioreactors occupy less space but are much more costly than the open, shallow ponds. Photobioreactors are mostly in tubular forms but also other designs exist to allow nutrients and CO_2 flow with better control of the concentration and to allow better light exposure during night time. The difficulty to clean the inner tubes, which are often long and bent, has been an issue. In Taiwan, shallow ponds systems with paddles seemed more efficient and well adapted to the climate conditions and environment (with very strict hygiene control) allowing large scale production of commercialized nutraceuticals, health foods and others byproducts. Lipids-oriented systems, however, need to be readapted and possibly combined with existing models.

Harvesting and extraction are considered by ITRI to be the most costly processes. The dilution of the unicellular microalgae and the concentration process and facilitated thanks to their multilayer filter that avoid the drying step, but the process followed by disruption and high pressure CO_2 extraction or using solvent representing (through ITRI's energy saving process it requires only 3,800 kcal/kg against the usual route: 12,000 kcal/kg to extract the microalgal oil). ITRI has also published their compared studies: in 4,000 liter open ponds, the yield is 4 to 12gm/m^2/day thanks to Taiwan's abundant sunlight (3,251-5,638 MJ/m^2/year) and in photobioreactors the yield is 30gm/m^2/day.

4.4 Conclusion

Microalgal biofuels production is viable for the time being when per barrel crude oil price remains high, making the production cost relatively competitive; but to break through the various bottlenecks and to share the energy cost, intensive research cooperation and development investments are needed to carry on on an inter-laboratory, interdisciplinary and international basis. The progresses so far are encouraging but further efforts are necessary. Present techniques in Taiwan are not yet ready to fully replace fossil fuels for the transportation sector or partially for aircraft kerosene. Researches are stuck at the bottlenecks. For example, oil is secreted when the cells experienced high stress; but at that moment the growth of the cells and their divisions are slowed down, which become a limiting factor to the total yield of oil. Under normal conditions the cells growth rate is satisfying but the natural oil content is not so high. Further, the present harvesting method is very energy consuming as it involves numerous chemical solvents, high temperature or pressure, with pH modifications, and sometimes the need to flocculate the microalgae or the use of ultra sound methods which involves technical staff, equipment and a complex process. On the other hand, current harvesting method of the lipids needs to become more eco-friendly; and drying of the biomass produced is quite a challenge, too. Some original experiment led with immobilization of microcells in alginate beads retained in a fine nylon bag proved simple harvest and dewatering method before oil extraction at Taiwan Aquaculture production scale

(Chen, 2003).

This paper may help to give a short review of Taiwan's present microalgal productions, research development and directions. Considering the geographical location of Taiwan, pushing microalgal production capacities and high technological developments might bring about a new renewable energies strategy that may alternate in a shorter term the current polluting and depleting fossil energy system. This has been the same strategy for many HighTech-developed countries, that combined efforts through exchange and complementary cooperation may help to optimize the results, break through some of the present research bottlenecks and bring about the best solution for a sustainable environment.

There are very few publications on life cycle assessment for industrial microalgal biodiesel production and its energy balance compared to other clean or renewable energies has yet to be established along with its technological progresses. A complete assessment on the environmental impacts is also not available yet, such as analysis of the possible resulting N_2O emissions from large scale microalgal biodiesel production. Assessments as such can help to judge what proportion of the depleting fossil fuels should be replaced by biofuels (Lardon, 2009; Kelly et al, 2011). Biofuels trade may induce similar problems encountered by the conventional, intensive agricultural productions, with distorting price supports or aids, severe competition and risks such as surplus in storage production and price destabilization that would affect the investments and efforts of each producing country. Asian countries, in particular, would gain from developing local biofuels production, but they would also be the first to be hit if international biofuels prices become destabilized.

Further risk assessments would be very important to estimate the possible environmental impacts of high yield or high productivity microalgal biofuels production and to find out a new equilibrium for the natural strains ecosystems. It has been known that microalgae and macroalgae can offer promising multiple functionalities. One main reason is because of algae biodiversity and their presence in a large range of environments. Current research patterns seem to be confused between isolating or generating a modified, super microalgae that could produce both oils and high value products, while fixing the carbon (in the case of in outdoors system) in waste water treatment at the same time. To achieve all these at one goal would require more intensive methods, possibly less natural and with many chemicals, high temperature, acidity or pressure, to reach huge surface of ponds (hectares sized), which would mean monocultures as it has been practiced for agricultural trade purposes with terrestrial crops or with animal breeding. Is microalgal culture going after a same direction as conventional agriculture and eventually encountering similar problems? In the European Union, a return to reasonable sized farms with traditional and extensive production and with an accent on quality, biodiversity and sustainable local species is being discussed for smaller carbon foot and activating rural economy and employment. Is this pattern a better fit in terms of the biomass characteristics and a longer term environmental balance might be reached? These questions could not be answered sufficiently and thus research and policy actions could unfortunately not be determined in the absence of life cycle assessments and environmental impact evaluations of the high potential of the microalgae multiple capabilities and very interesting biofuels production during their experiments and processing.

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