Microalgal Biofuel Technology

Kunn Kangvansaichol, Ph.D.

Researcher / THINK ALGAE Project Manager

Petroleum Products and Alternative Fuels Research Department

PTT Research and Technology Institute

In Collaboration with CU-BIOTEC, KMUTT, MU, and TISTR

25 March 2011 NAC2011

Disclaimer

- The information contained in our presentation is intended solely for your personal reference only. In addition, such information contains projections and forward-looking statements that reflect our current views with respect to future events and financial performance. These views are based on assumptions subject to various risks and uncertainties. No assurance is given that future events will occur, that projections will be achieved, or that our assumptions are correct. Actual results may differ materially from those projected.

Outline

- Introduction with lots of questions
  - Why Next Generation Energy?
  - Why Biofuels?
  - Why Microalgae?
- Introduction to Microalgal Biofuel Technology
  - Multiple Pathways for Microalgal Biofuel
  - How do we get from microalgae to biofuel?
- Why PTT and Microalgal Biofuel Technology
- Current Status on Microalgae Technology
- Current Status on Microalgal Biofuel Technology Development
  - World Status
  - Thailand Status
- THINK ALGAE Consortium
  - THINK ALGAE : Vision
  - THINK ALGAE : Microalgae Biofuel Roadmap
  - THINK ALGAE : Capabilities
  - THINK ALGAE : Project's Key Figures
- Microalgal Oil Cost?
- And..when?
- Conclusion

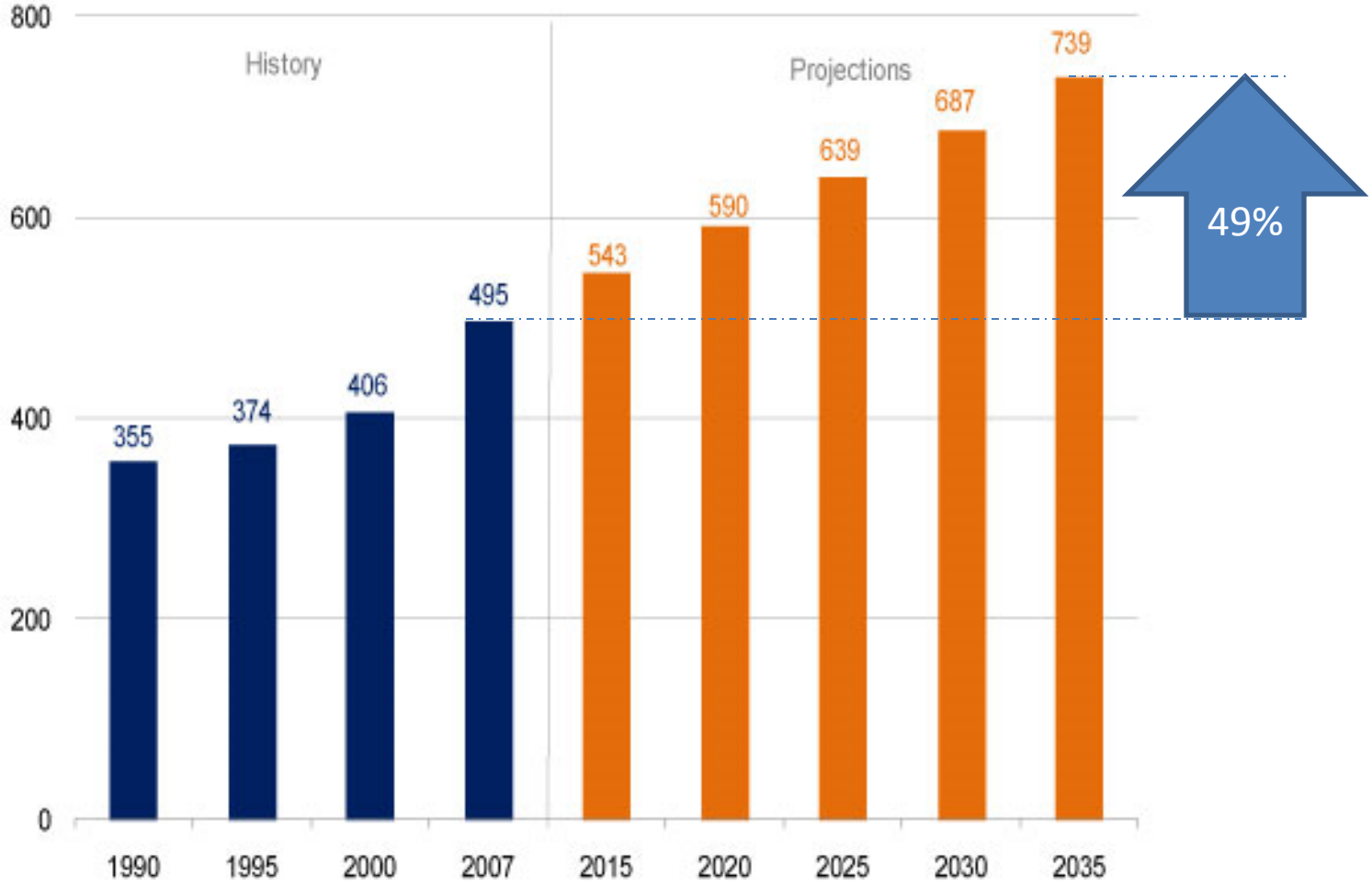
1. Why Next Generation Energy?
2. Why Biofuels?
3. Why Microalgae not other crops?

INTRODUCTION WITH LOTS OF QUESTIONS

1.1 World Energy Outlook : 1990-2035

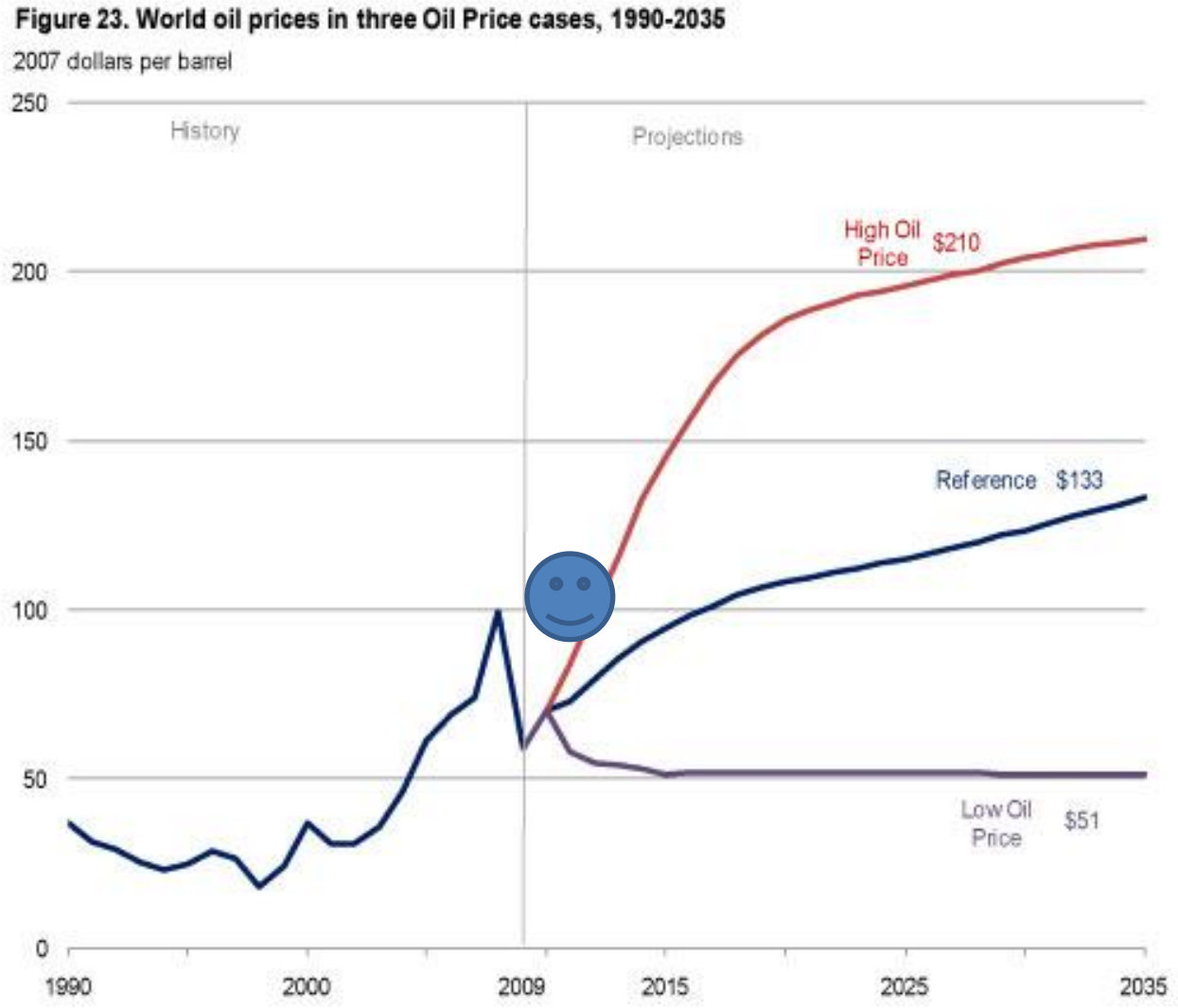
Figure 12. World marketed energy consumption, 1990-2035

quadrillion Btu



Source: International Energy Outlook 2010, EIA

1.2 World Oil Prices : 1990-2035



Source: International Energy Outlook 2010, EIA

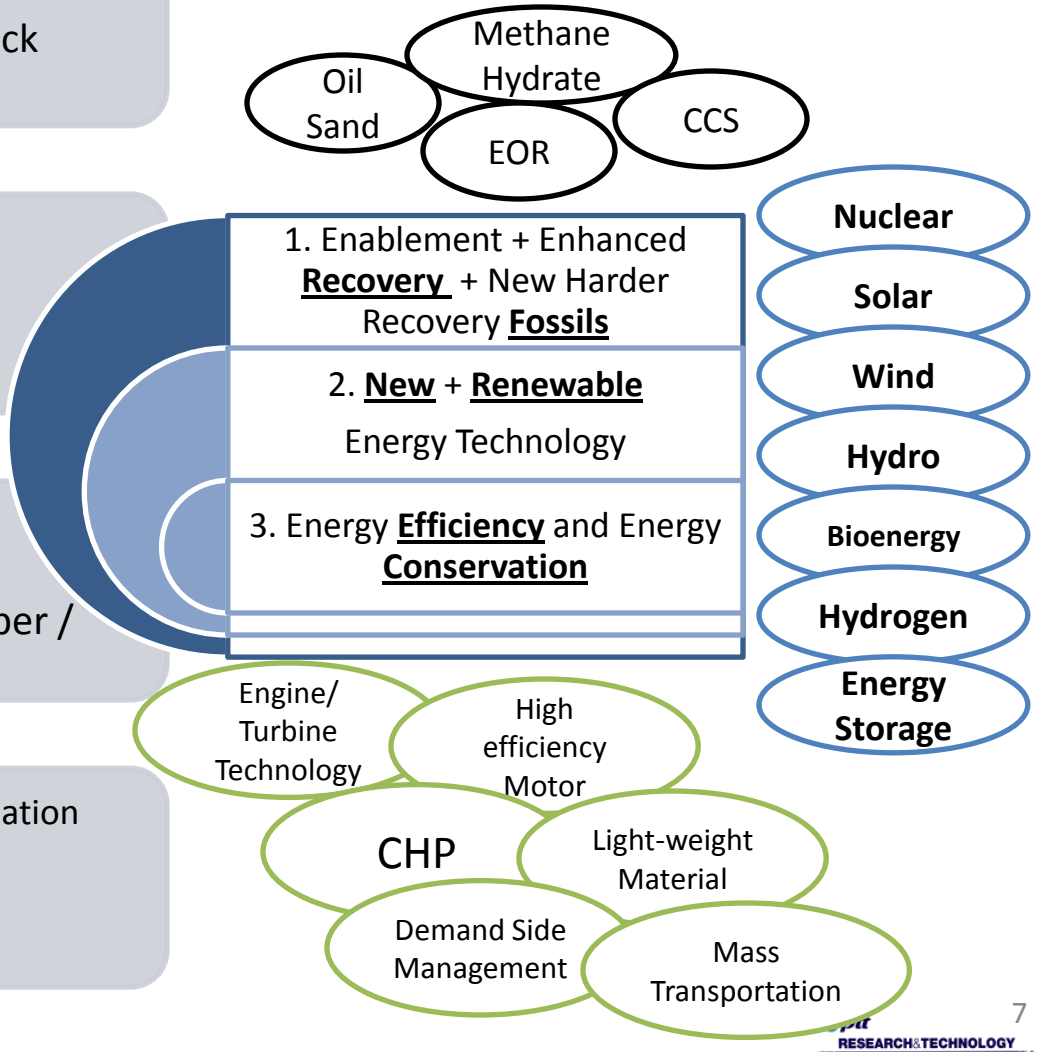
1.3 Key Drivers for Next Generation Energy Technology

Energy Security
- Demand Increases while supply limited
- War and Terrorist Attack
- Natural Disaster

Environment Concerns
- Global Warming
- Kyoto / Copenhagen

Sustainable Issues
- Fresh Water Scarcity
- Land Use
- Food / Fuel / Feed / Fiber / other issues

Economy
- Growing economy & Population → Increasing demand
- Slowing death rate → Maintaining demand



Source: PTT RTI analysis

1.4 Four Mega Trends in Bio-Energy Business

National Agenda / Regulations	• EU : Bio-jet in 2012, 10% of transportation biofuel in 2020 • USA, FEB 2010 : RFS2 36 million gallons by 2022 • Thailand : Renewable Energy as National Agenda 20% alternative fuels/energy by 2022
Petroleum Companies invest in Renewable Energy esp. Biofuels	• Brazil : Petrobras to become top-5 biofuel producer by 2020 with investment of 2.3 billion USD till 2013 + biofuel pipeline project • Brazil : Shell + Cosan on 12 billion USD on JV ethanol business • USA : Valero bought Verasun, ethanol company, now > 1.1 million gallon production capacity
Agro-companies become a major player in Bioenergy esp. EtOH/B100/Power	• ADM→ world top biofuel producer (ethanol + biodiesel) • Animal Producer → Tyson Food JV to produce Renewable Diesel / Jet fuel → Others become biogas + power producers
Carbon becomes Credit	• Carbon exchange (Chicago, European, etc.) • Clean Development Mechanism

Source: PTT RTI analysis

2.1 Biofuel/Bioenergy benefits …

SOCIAL
- Support agricultural professions
- Support Sufficiency Economy

TECHNICAL
- Domestic technology available
- R&D on Biofuel and Bioenergy

ECONOMICS
- Reduce impacts from high oil price
- Stabilize agricultural commodity price

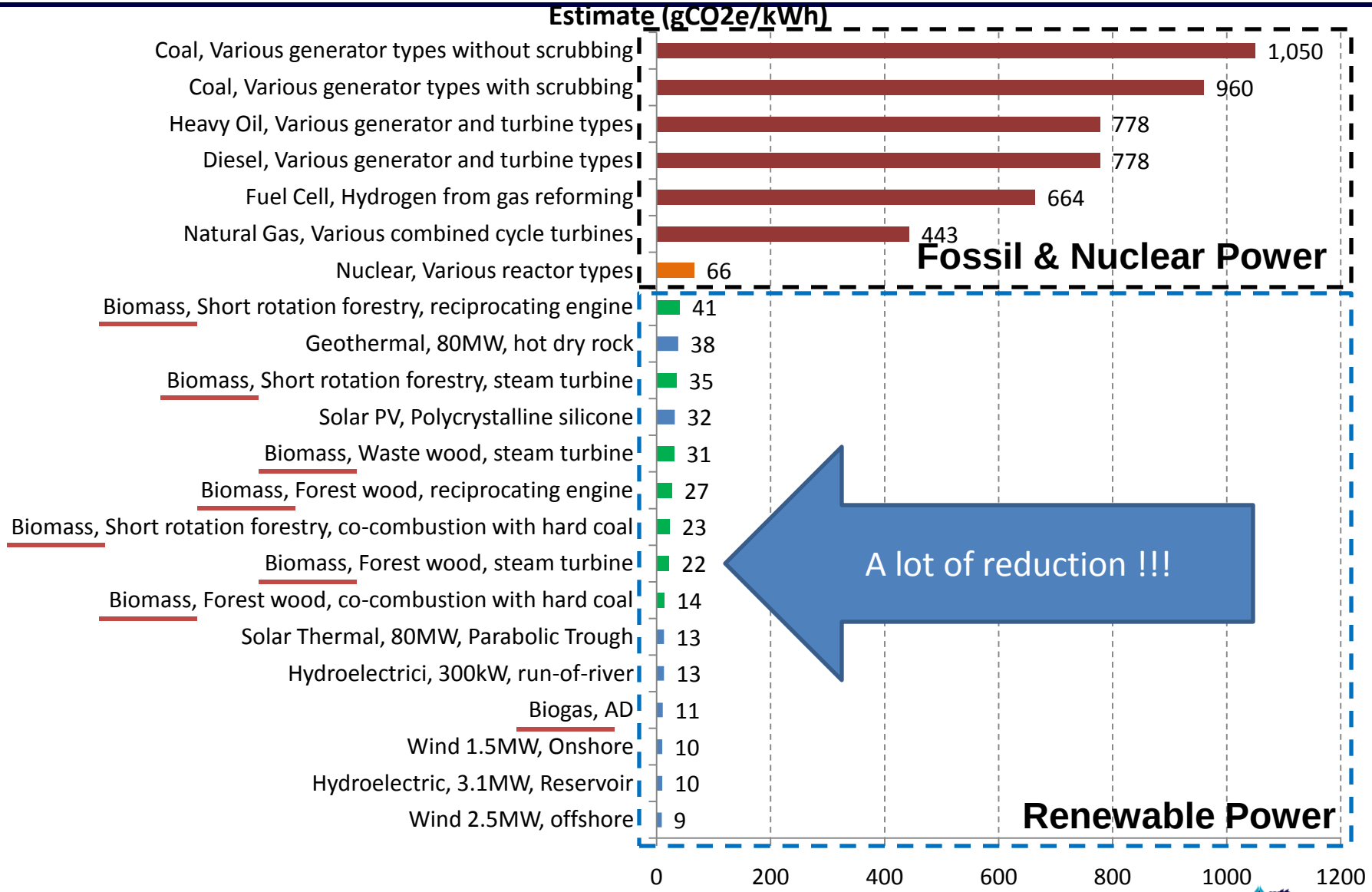
ENVIRONMENT
- Reduce air pollution in large cities
- Mitigate greenhouse gas emission

POLICY
- Support Kyoto Protocol
- Reduce dependence on Political unstable countries and imports

Source: PTT RTI Team Analysis

2.2 Focus on Environmental Benefits

All renewable energy emits less CO_2e than nuclear and fossil



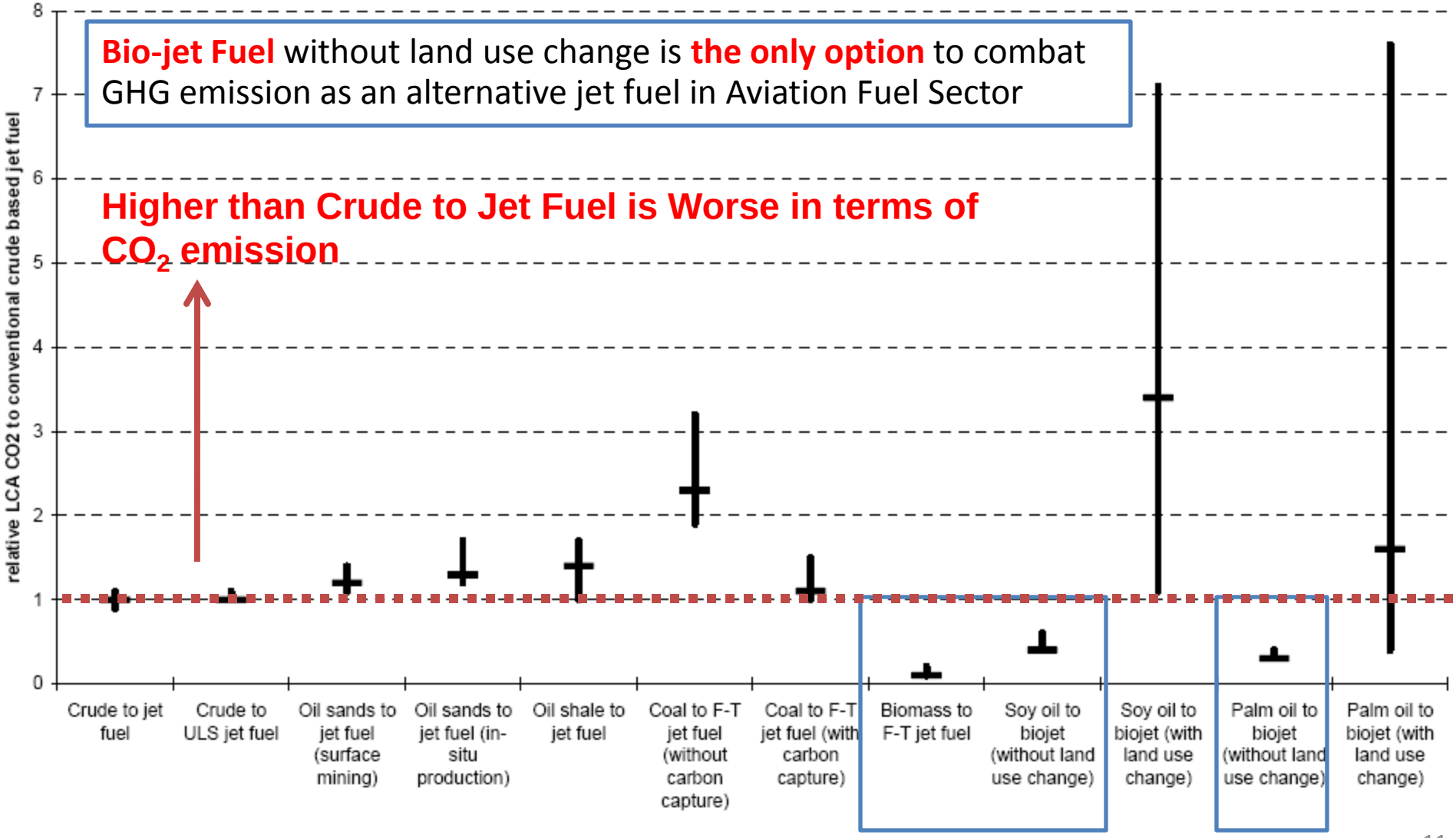
Source: "Nuclear Energy and Renewable Power: Which is the Best Climate Change Mitigation Option?," B.K.Sovacool, Singapore

2.3 In some applications, Biofuel is the only option to combat GHG esp. CO_2

Relative Results

Bio-jet Fuel without land use change is **the only option** to combat GHG emission as an alternative jet fuel in Aviation Fuel Sector

Higher than Crude to Jet Fuel is Worse in terms of CO_2 emission



Source: IATA 2008 Report on Alternative Fuels

3.1 High Potential with smallest landuse footprint

	Oil Palm (National Average 2008)	Oil Palm (Theoretical Limit)	Jatropha Curcas (Indonesia)	Algae (Current Spirulina)	Microalgae Potential
Productivity (T/rai/y)	3,025*	7,040**	1,280	8,760***	16,352 (@28g/m2/d)
Oil Yield (%)	20%	20%	40%	10%	45%
Productivity (kg/rai/y)	605	1,408	512	876	7,358
Advantage	High oil yield among commercial oil crops Commercial crop Well established crop		Drought tolerant Non-edible crop	Highest potential Contain high valued chemicals Cultivation anywhere CO2 abatement tool as other biofuels	
Disadvantage as energy crop	Food crop Location specific		New crop No knowledge Still not economical at current yield	New crop/No large-scale experience High energy input Still not economical for biofuel alone with current technology	
Area (ha) for 20% Diesel Fuel Replacement in Thailand Transportation Sector (50MMLPD)	2,000,000	900,000	2,300,000	1,400,000	200,000
Cost (THB/kg oil)	30-40		>80	>1,700	

Source: *OAE, ** Spatial-Temporal Yield Trend of Oil Palm as Influenced by Nitrogen Fertilizer Management, 2008, ***KMUTT

3.1 High Potential with smallest landuse footprint (cont.)

Exhibit 1.2 *Comparison of oil yields from biomass feedstocks*[a]

CROP	OIL YIELD (GALLONS/ACRE/YR)
Soybean	48
Camelina	62
Sunflower	102
Jatropha	202
Oil palm	635
Algae	1,000-6,500[b]

[a] *Adapted from Chisti (2007)*
[b] *Estimated yields, this report*

Approx. 2-10 times of Oil Palm

Source: NREL Algae Roadmap 2010

3.2 High Oil Content Potential

Table 2
Oil content of some microalgae

Microalga	Oil content (% dry wt)
Botryococcus braunii	25–75
Chlorella sp.	28–32
Crypthecodinium cohnii	20
Cylindrotheca sp.	16–37
Dunaliella primolecta	23
Isochrysis sp.	25–33
Monallanthus salina	>20
Nannochloris sp.	20–35
Nannochloropsis sp.	31–68
Neochloris oleoabundans	35–54
Nitzschia sp.	45–47
Phaeodactylum tricornutum	20–30
Schizochytrium sp.	50–77
Tetraselmis sueica	15–23

ELSEVIER

Available online at www.sciencedirect.com
ScienceDirect
Biotechnology Advances 25 (2007) 294–306

BIOTECHNOLOGY ADVANCES
www.elsevier.com/locate/biotechadv

Research review paper

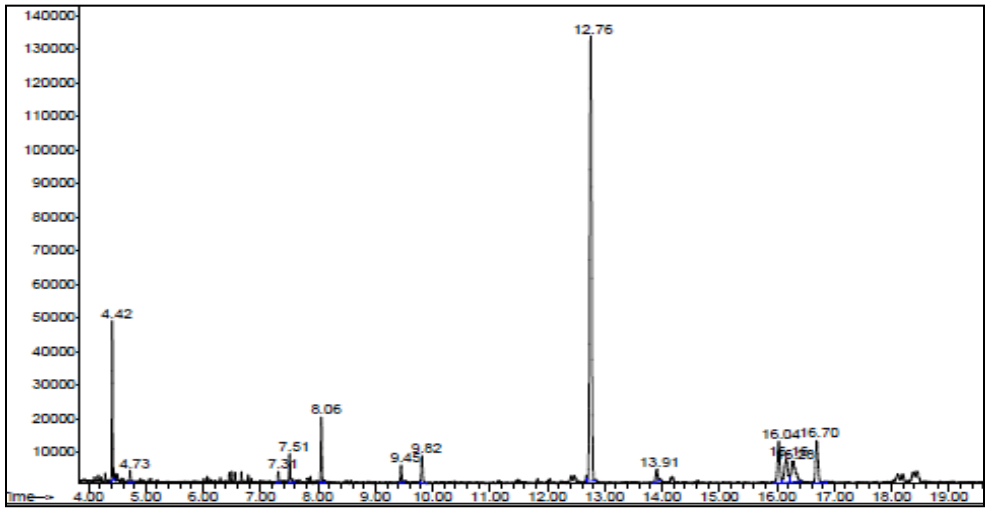
Biodiesel from microalgae

Yusuf Chisti *

Institute of Technology and Engineering, Massey University, Private Bag 11 222, Palmerston North, New Zealand

Available online 13 February 2007

3.3 Microalgal oil Characteristic is suitable for Biofuel Production



Organism : *Chlorella vulgaris*

From PTT RTI Fuel Formulation Team's experiences, with high SAFA, biodiesel will have very good oxidation stability

Type	Systematic Name	Common name	Isomer	Area %
Saturated fatty acid	Nonanedioic acid	azelaic acid	11:0	4.18
	Tetradecanoic acid	Myristic acid	14:0	2.68
	Hexadecanoic acid	**Palmitic acid**	**16:0**	**54.95**
	Octadecanoic acid	Stearic acid	18:0	6.44
Polyunsaturated fatty acid	*cis*-9,*cis*-15-Octadecadienoic acid	Linoleic acid	18:2	1.56

Source: MU, MAY 2009

3.4 Microalgae can be grown on non-arable land : No food vs fuel conflict

พื้นที่ดินเค็มจัด อ.โนนไทย จ.นครราชสีมา (19Jan2011)

Credit: สถาบันผลิตผลเกษตรฯ มก. กรมป่าไม้ และ กรมพัฒนาที่ดิน

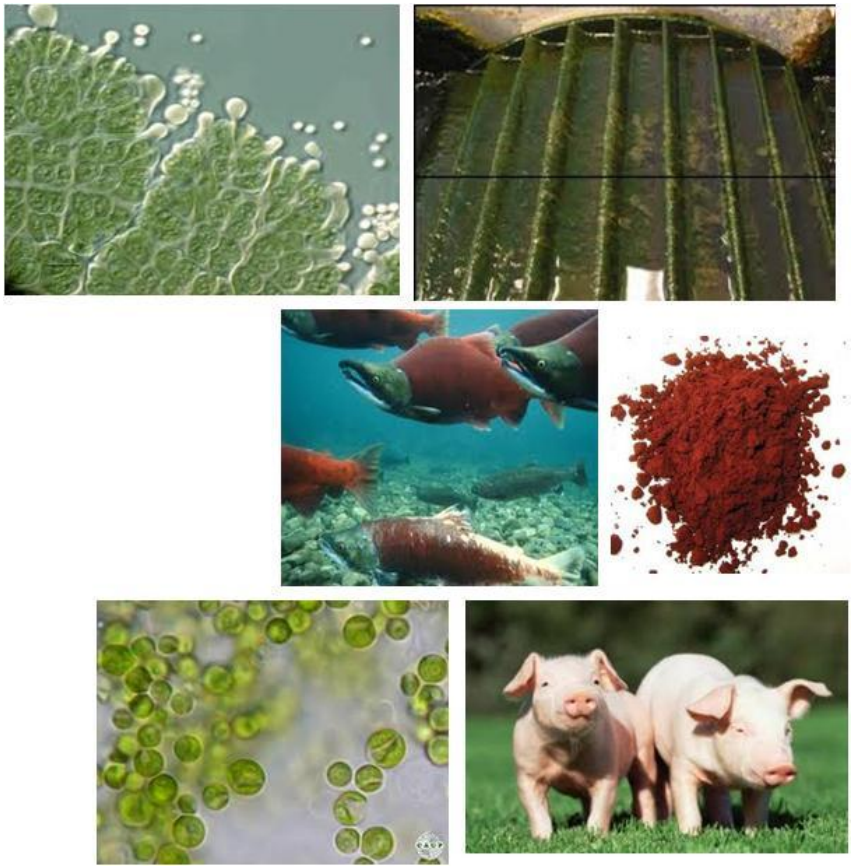
3.5 Microalgae can use many types of water for growing

- Freshwater
- Marine Water
- Underground Water
- Brackish Water
- Agro-industrial Waste Water
- Municipal Waste Water

- So.. Hopefully not compete with drinking water or irrigated water for food crops

3.6 Microalgae has many applications

- Renewable energy
- Waste water treatment
- Chemicals and bioactive compound
- Aquaculture and animal feed
- Agriculture
- Food

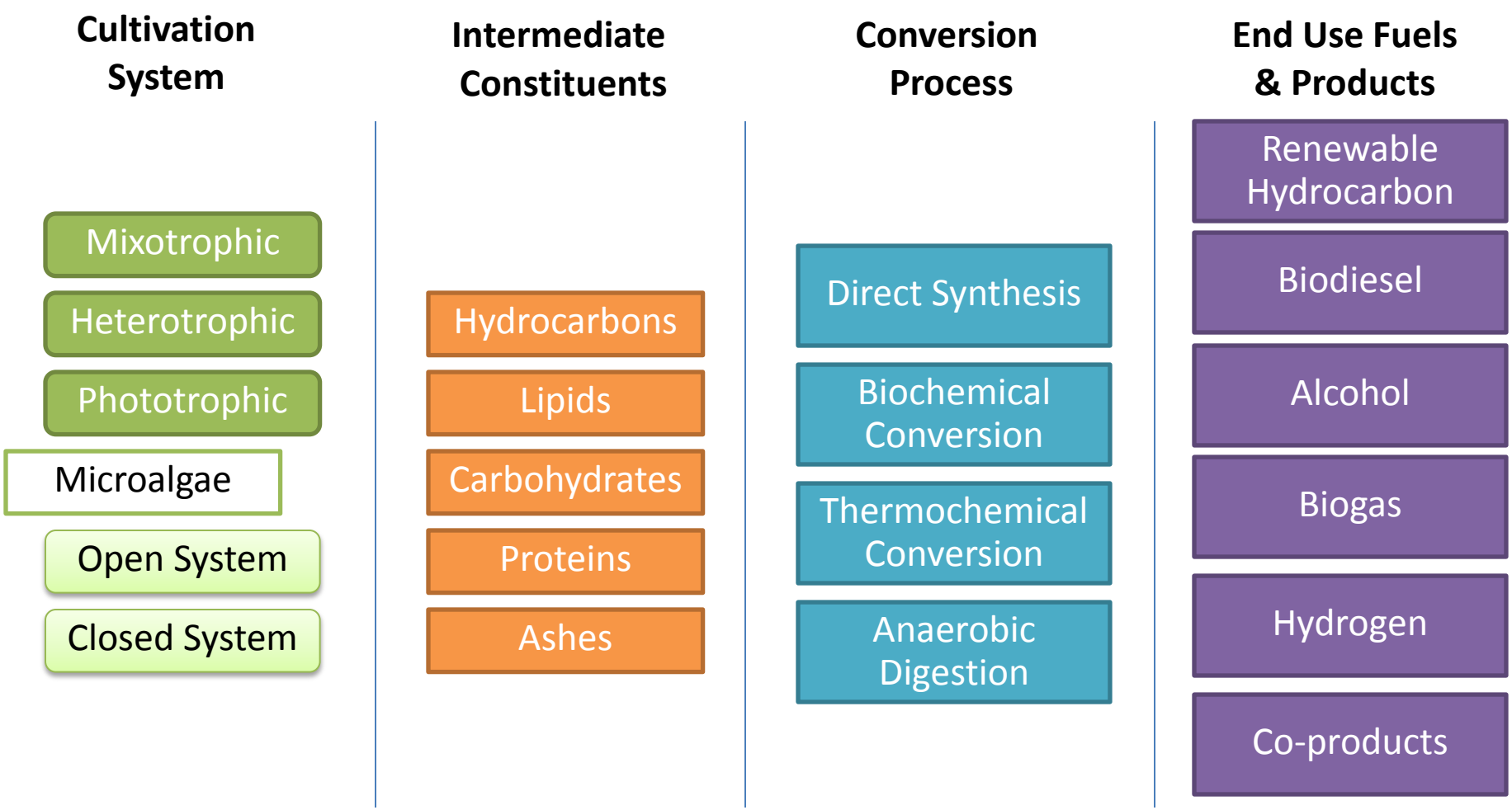


Credit: Supachai Reakasame, PTT RTI

1. Multiple Pathways for Microalgal Biofuel
2. How do we get from microalgae to biofuel?

INTRODUCTION TO MICROALGAL BIOFUEL TECHNOLOGY

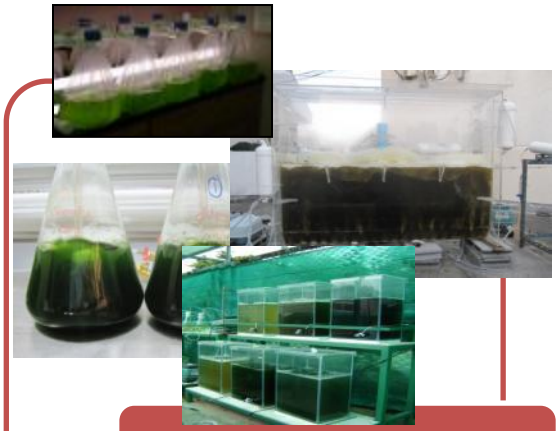
Multiple Pathways for Microalgal Biofuel



Adapted and Modified from "The Promise and Challenge of Algae as Renewable Sources of Biofuels , DOE-EERE-Office of Biomass Program

How do we get from microalgae to biofuel?

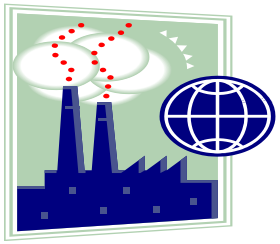
• Harvesting / Dewatering Technology
• Fractionation / Extraction Technology



Algal Cultivation

•Strain Biology / Selection
•Cultivation Strategy
•Resources and Sites

Harvesting and Processing

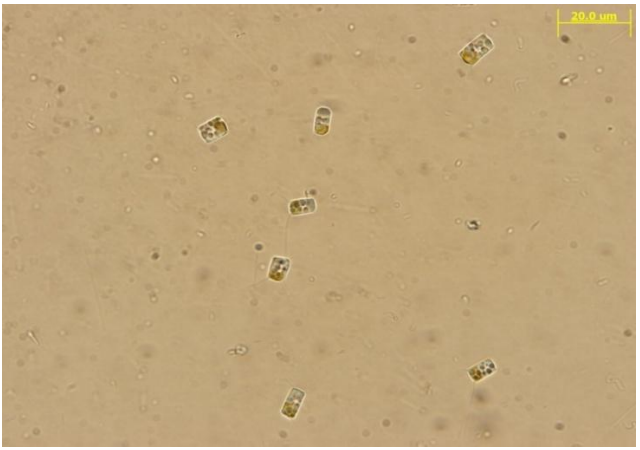


Processing & Formulation

• Fuel Synthesis, Conversion, or Upgrading Technology
• Fuel Formulation, Blending , Additizing

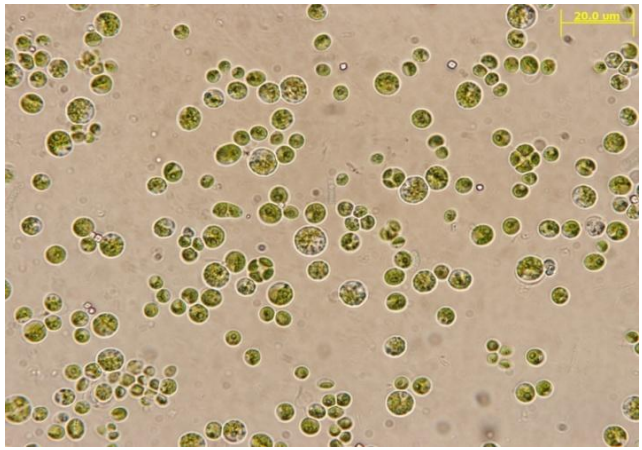
Adapted and Modified from DOE Algae Roadmap 2010

1.1 Strain Biology / Selection



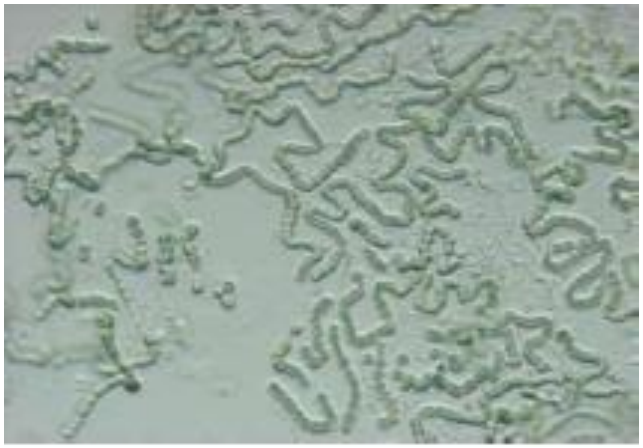
Chaetoceros gracilis

Perfect strain = Productive, Stable and Utilize low resources



Chlorella vulgaris

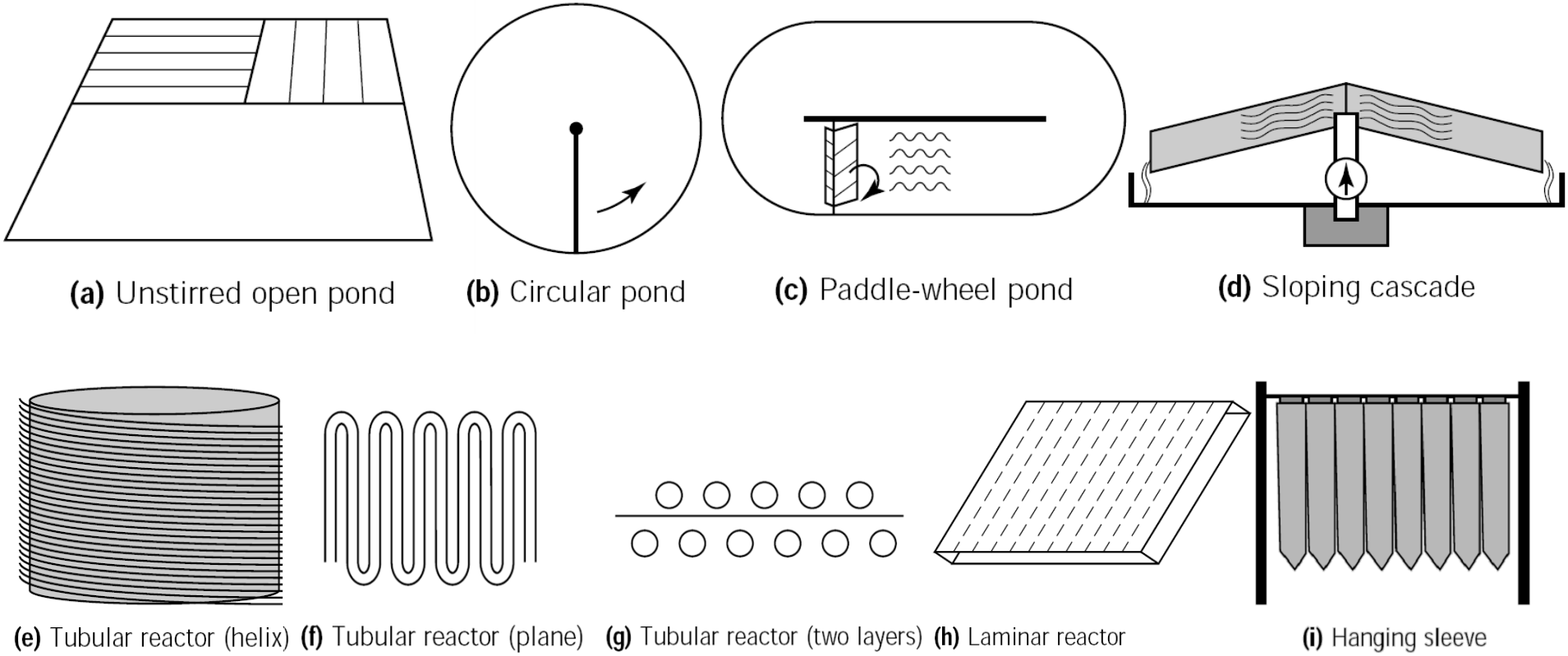
Dunaliella sp.



Anabaena ambigua

Adapted and Modified from DOE Algae Roadmap 2010

1.2 Cultivation Strategy : Open or Closed System / Phototrophic or Heterotrophic



Phototrophic : CO2 → compete with microalgae itself

Or

Heterotrophic : Other carbon sources (sugar, glycerol, etc.) → Compete with Fermentation tech.

Adapted and Modified from DOE Algae Roadmap 2010

1.3 Resources and Sites

- Basic Requirement
  - Solar
  - CO_2
  - Water + Nutrients
- Site Consideration
  - Locate near CO_2 source? Might be far from water and no land available
  - Locate near water source? Might be far from CO_2 source?
  - Note: Australia maybe a good choice, why?
    - Lot of desert area
    - Lot of sea water
    - Some industrial sites with CO_2

Adapted and Modified from DOE Algae Roadmap 2010

1.3 Resources and Sites (cont.)

Exhibit 9.5 *Major stationary CO_2 sources in the United States (NATCARB, 2008a)*

CATEGORY	CO_2 EMISSIONS (Million Metric Ton/Year)	NUMBER OF SOURCES
Ag Processing	6.3	140
Cement Plants	86.3	112
Electricity Generation	2,702.5	3,002
Ethanol Plants	41.3	163
Fertilizer	7.0	13
Industrial	141.9	665
Other	3.6	53
Petroleum and Natural Gas Processing	90.2	475
Refineries/Chemical	196.9	173
Total	**3,276.1**	**4,796**

Source: DOE Algae Roadmap 2010

2.1 Harvesting and Dewatering

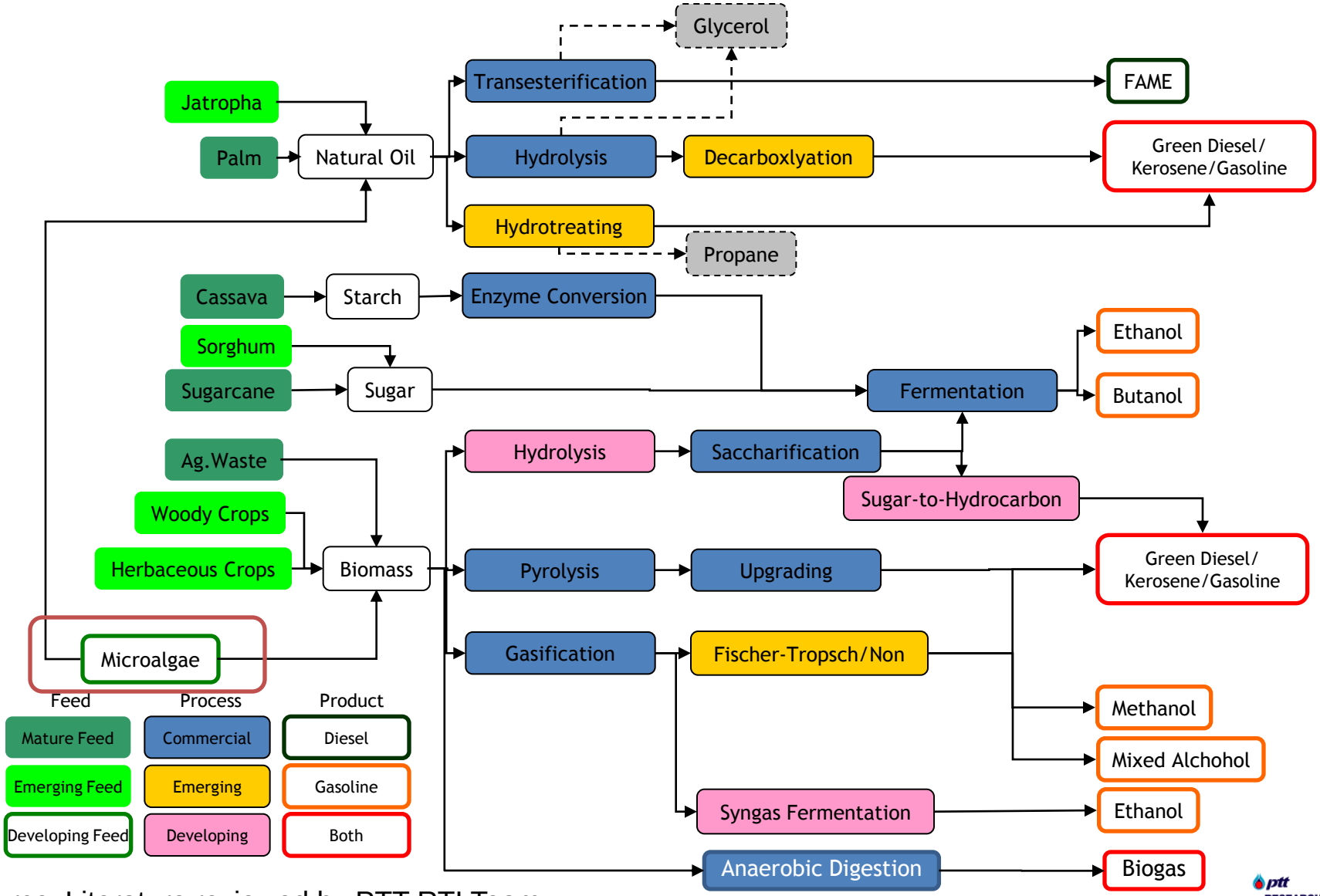
- Harvesting
  - Microalgae is small (few micron to less than 100 micron) → Difficult to filter
  - Technology
    - Centrifuge
    - Flocculation
    - Skimming

    } High Cost
- Dewatering
  - "Get water out of microalgae or get microalgae out of water"
  - Very low concentration
    - For example, 1 g/L → 0.1% wt
    - Meaning : every 1 kg algal biomass need to process > 1000L water

2.2 Fractionation / Extraction Technology

- Fractionation
  - Extraction
    - Mechanical Extraction (Squeezing)
    - Chemical Extraction (Solvent)
    - Novel technique (Micro-bubble Cavitations)
  - Conversion + Extraction
    - Subcritical Hydrolysis → Convert oil to free fatty acid by using high temp. water (by products include sweet water + residual biomass)
    - Hydrothermal Liquefaction → Convert the whole biomass to a mixture of various chemical compositions similar to crude oil

Multiple pathways to produce biofuel



Source: Literature reviewed by PTT RTI Team

General Concept

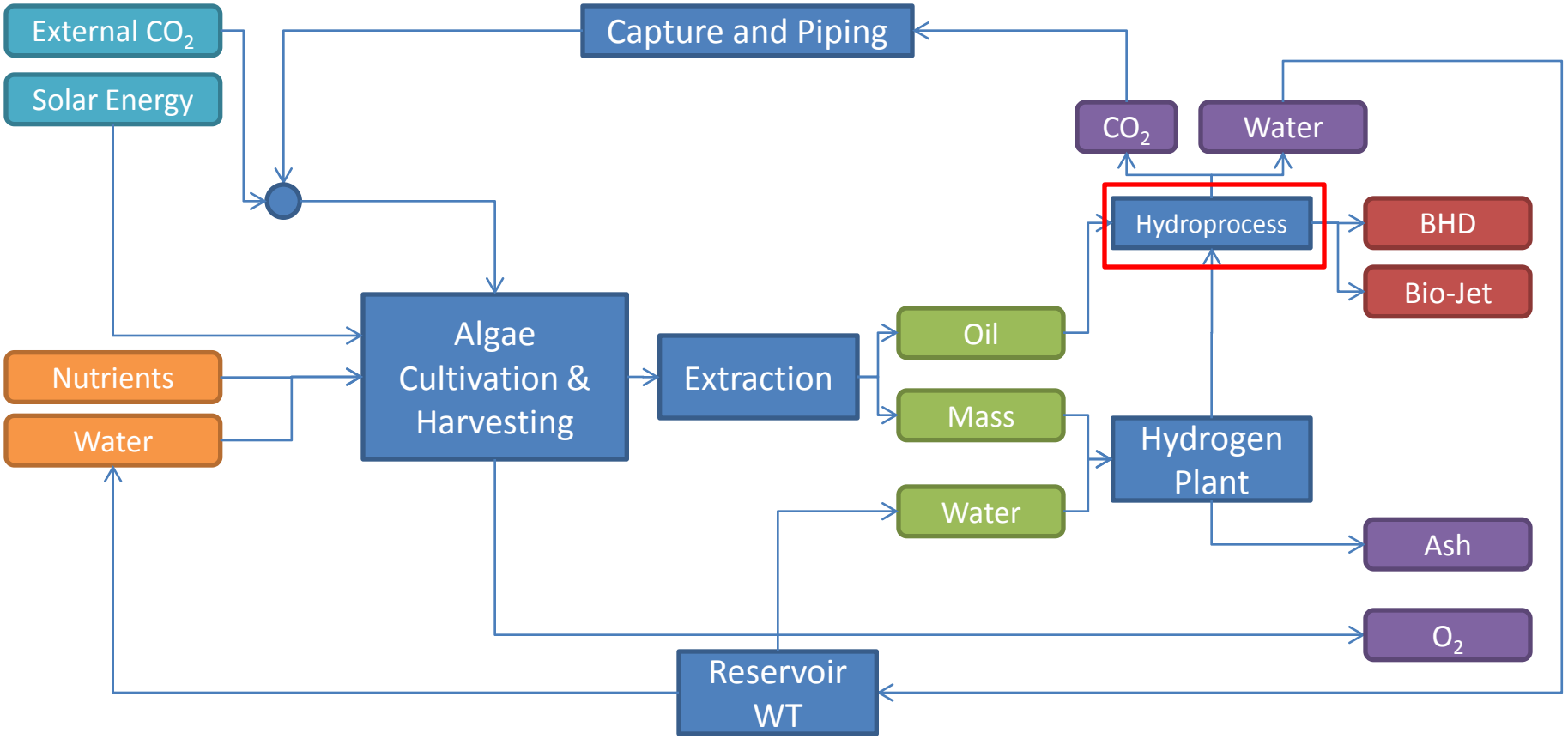
- Standalone as integrated Biorefinery
- Co-location with WWT, Aquaculture, etc.

Standalone : Integrated Algal BHD System

KEY:

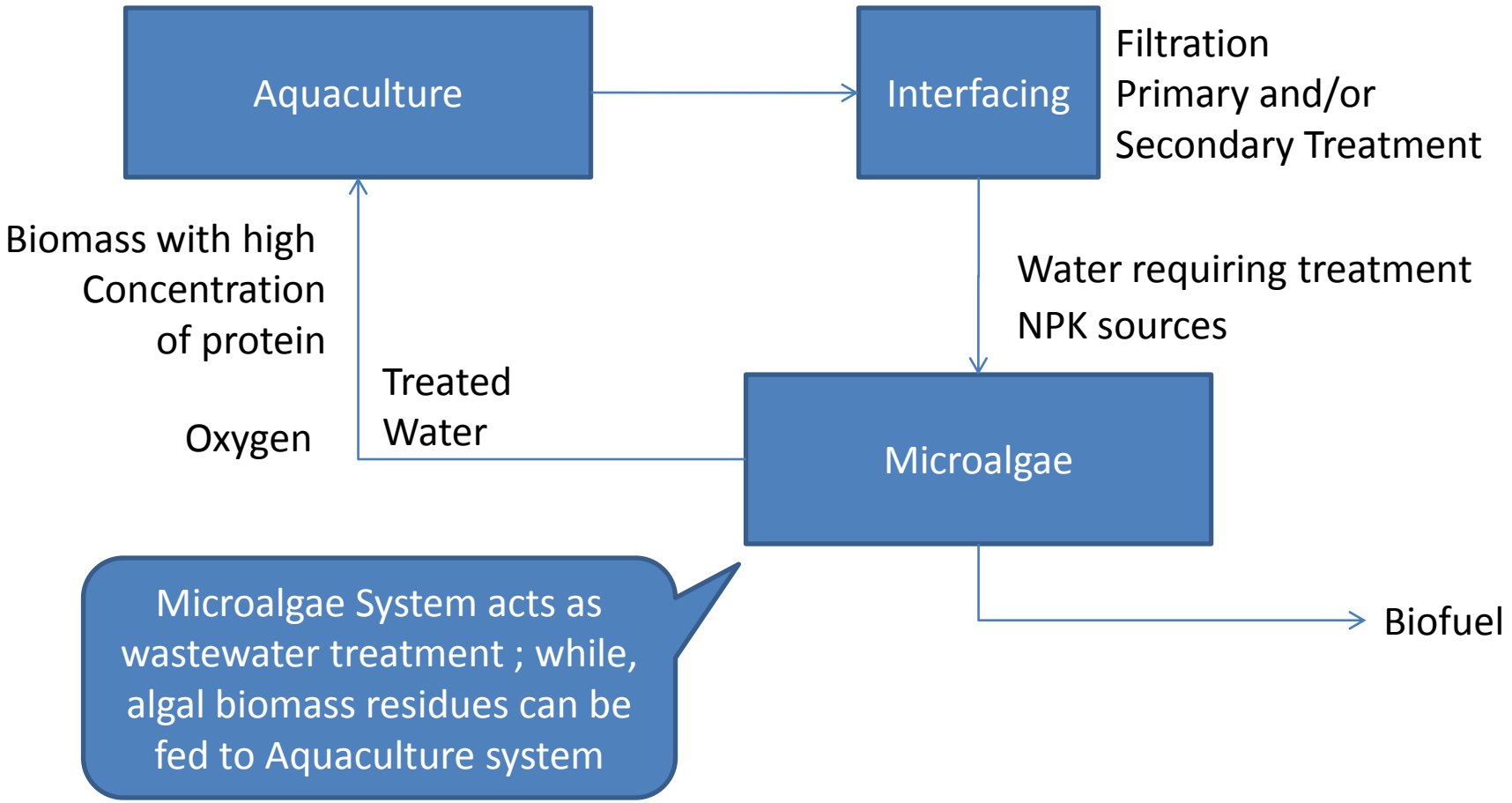
1. Minimal CO_2 and Water footprint
2. Standalone Biofuel / Bioenergy Production
3. Carbon neutral (not carbon capture and storage) (may have some capture with remaining C in ash)

Note: BHD (Bio-hydrogenated Diesel)



Note: Similar to UOP 2009 patent, but in this case H_2 is generated through algal mass + water instead of natural gas reforming

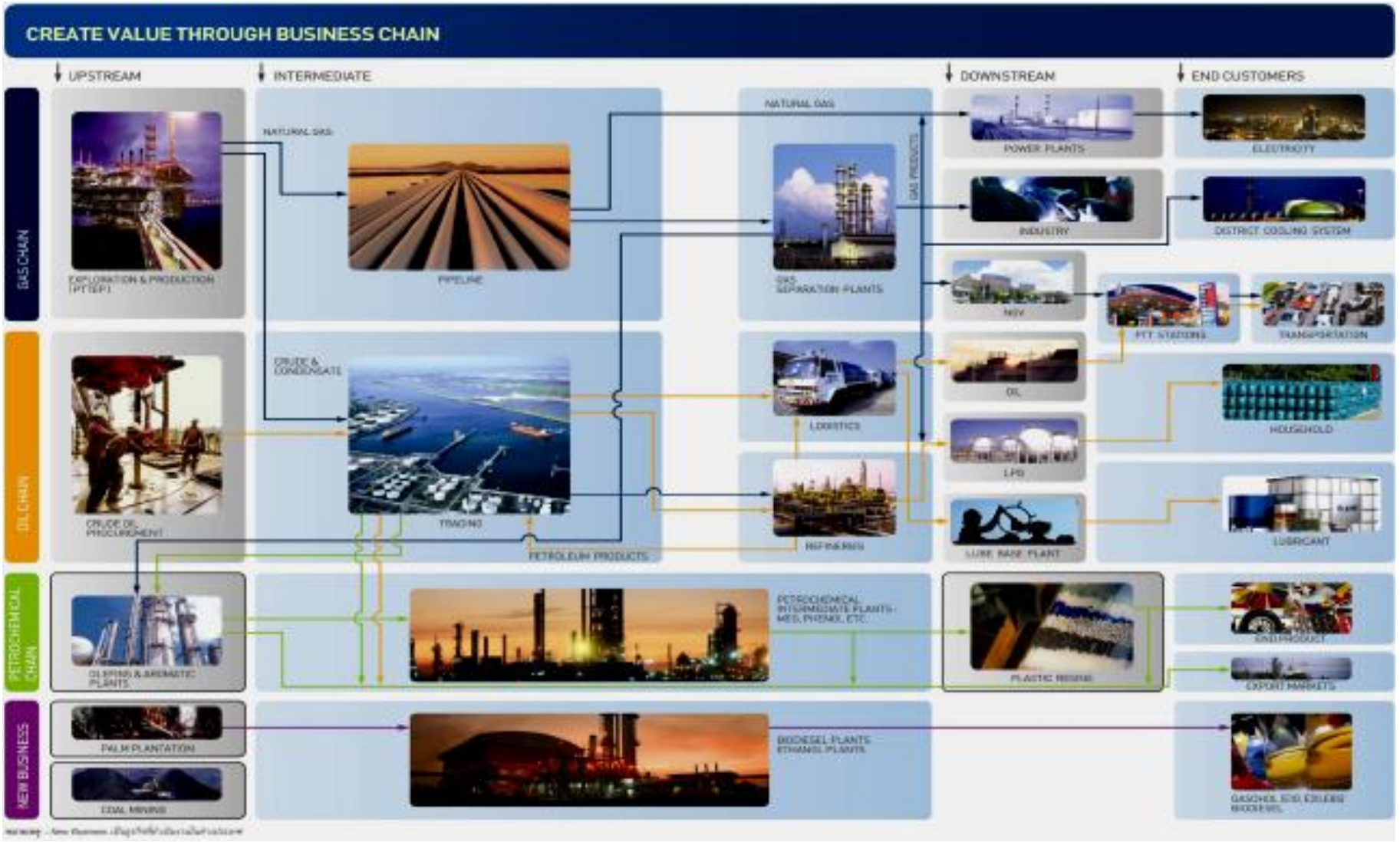
Co-location Concept : With Aquaculture



WHY PTT AND MICROALGAL BIOFUEL TECHNOLOGY

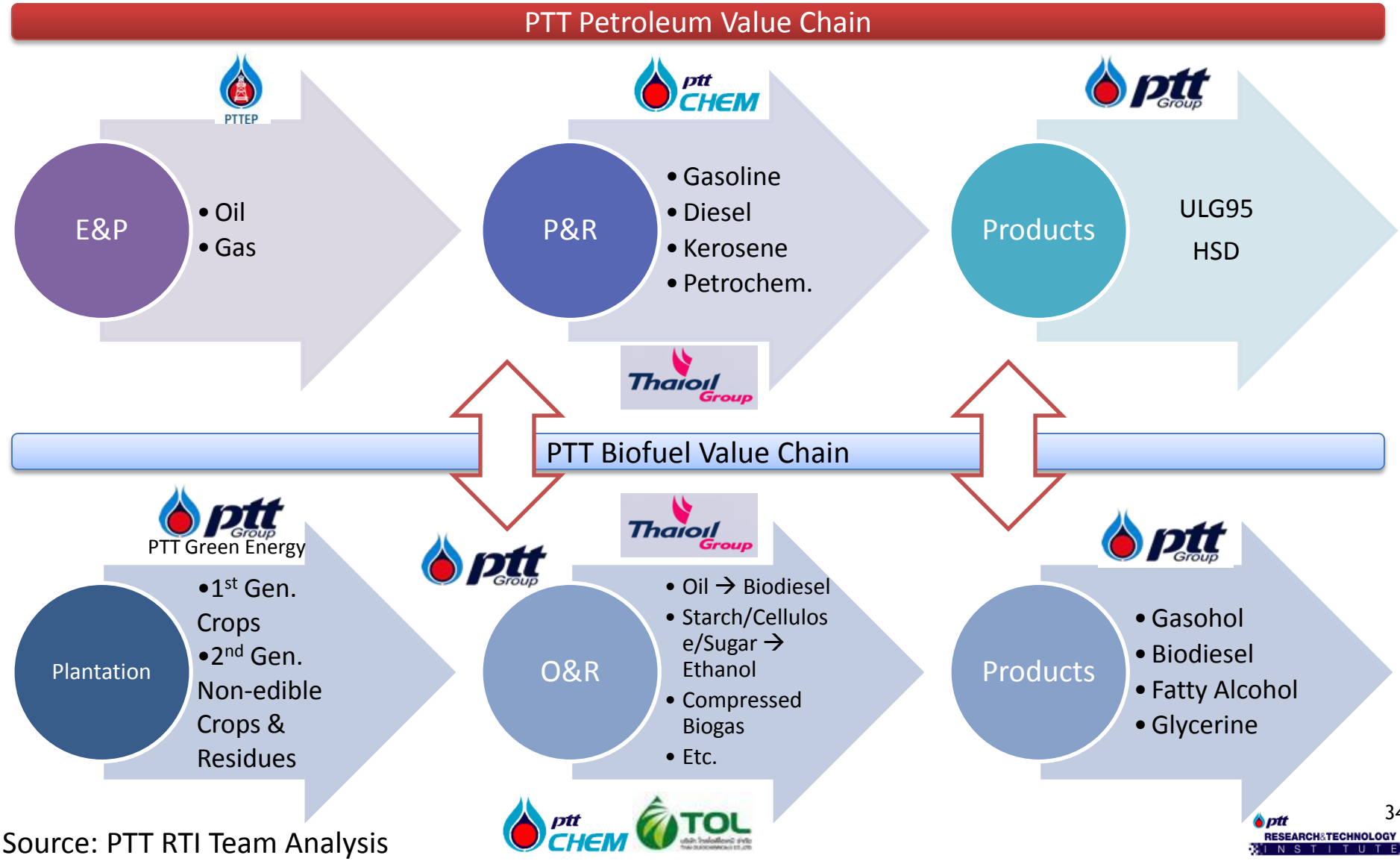
PTT Value Chain :

Fully Integrated Oil, Gas and Petrochemical Company plus new growing business i.e. Coal and Bio-based Businesses



Source: PTT Investor Update 2011

PTT Current Business Value Chain (petroleum & biofuel)

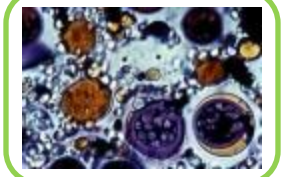


Source: PTT RTI Team Analysis

PTT's CO_2 to Microalgal Biofuel + Others

Microalgae is **Photosynthesis** Microorganism, which requires
Solar Energy + **Water** + **CO_2** + **Nutrients** + **Chlorophyll**

Microalgae

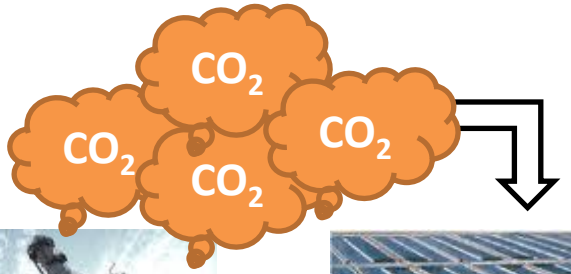


Biofuel

Animal Feed

Fertilizer

Health Supplements



Source of Carbon Dioxide and other wastes, e.g. GSP, Refinery, etc.

Carbon Dioxide and waste effluents can be converted to microalgae biomass through photosynthesis. The microalgae can then be converted to multiple products e.g. biofuel, animal feed, fertilizer and health supplement products.

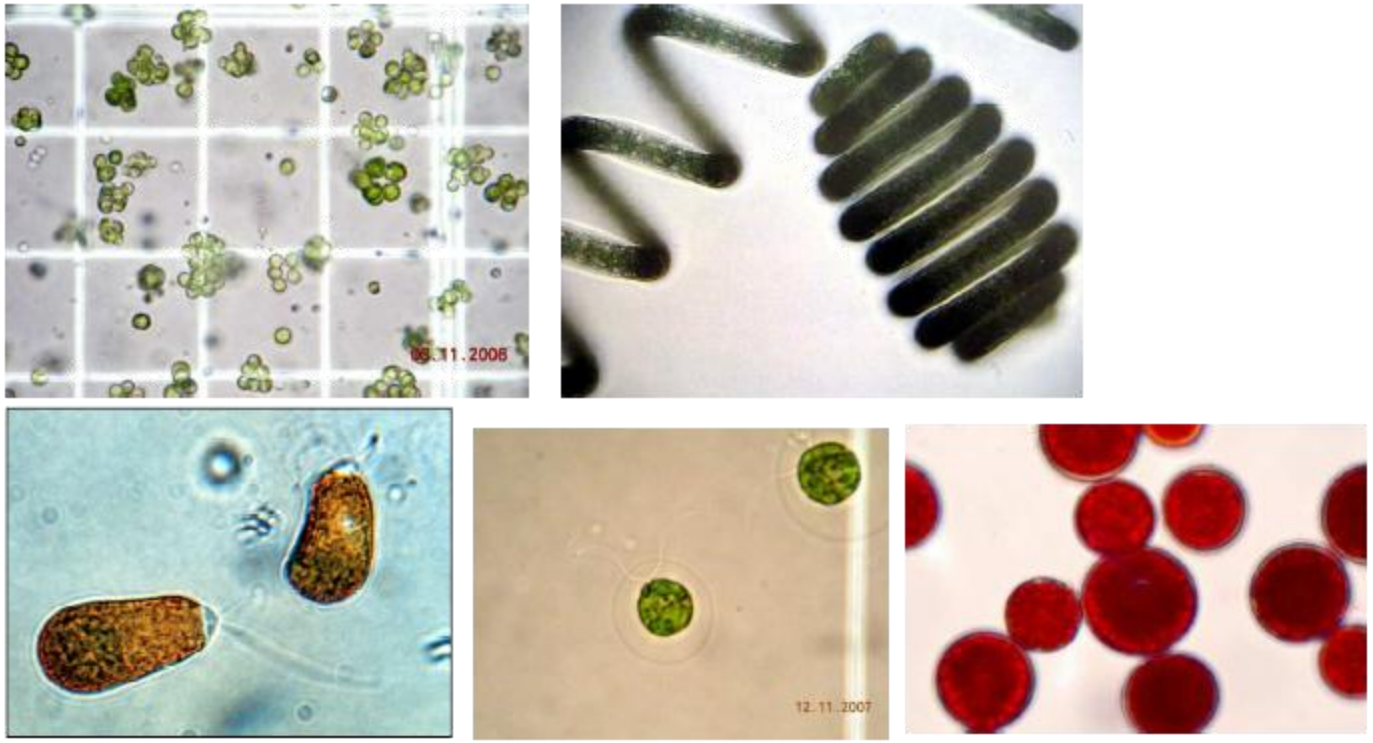
Source: PTT RTI Team Analysis

CURRENT STATUS ON MICROALGAE TECHNOLOGY

Industrial Scale Cultivation of Microalgae

Industrial Scale Cultivation of Microalgae

Chlorella, Spirulina, Dunaliella, Haematococcus



Food supplements and additives mainly

Credit: Sorawit Powtongsook

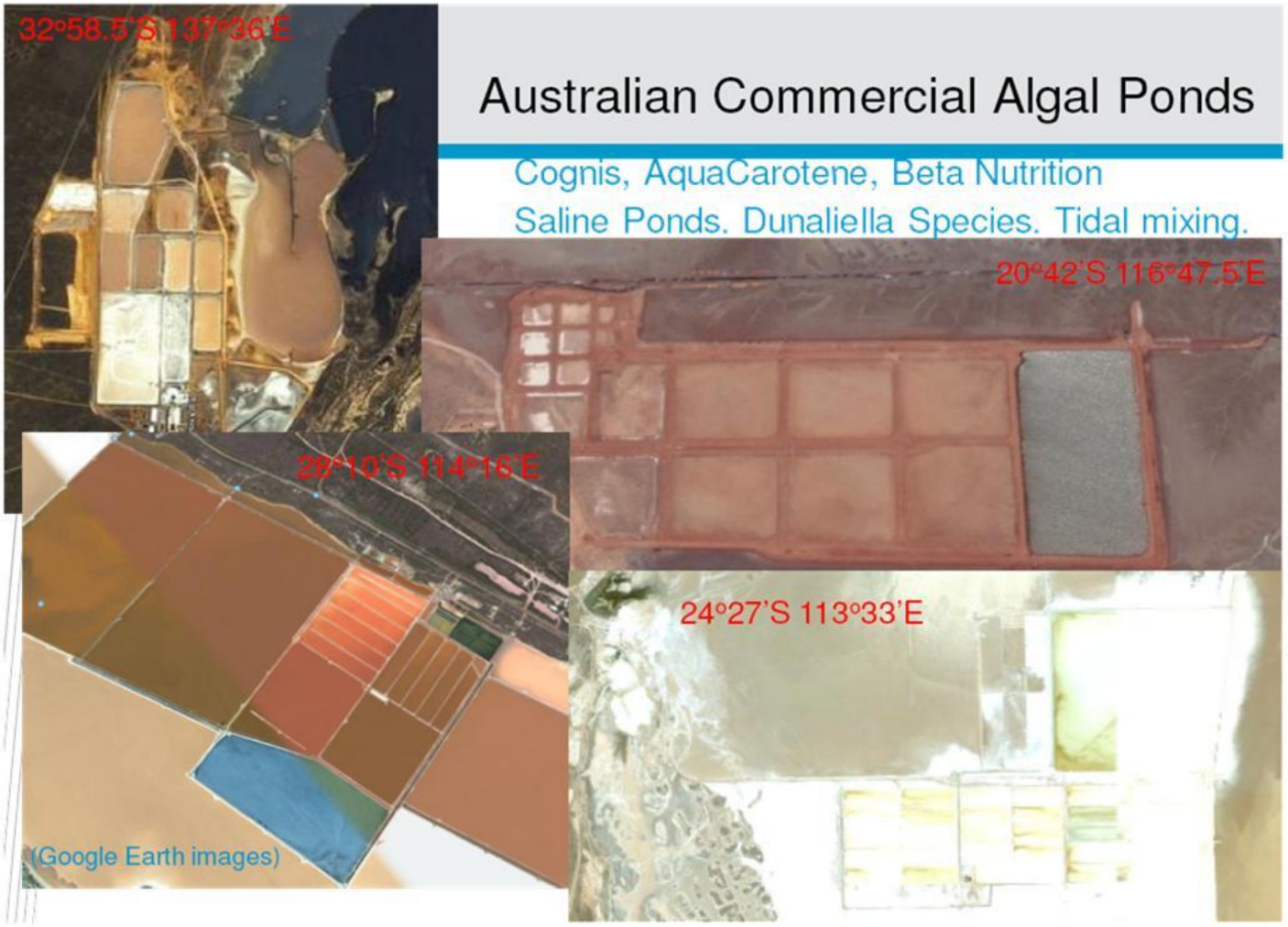
Cyanotech, USA

Source: Cyanotech, USA

Algatech, Israel

Source: Algatech, Israel

Cognis & AquaCarotene & Beta Nutrition, Australia



Source: Algae World Asia 2010

Spirulina Farm : Boonsom Farm, Chiangmai

Products

- Food Supplements
- Fancy but Healthy Food (Ice-cream, waffle)
- Snacks
- Spa

On-going R&Ds

- Medicine function
- Animal feeds
- etc.

(credit: Ajarn Jeamjit Boonsom)

Credit: Sorawit Powtongsook

Spirulina Farm : Nathong Farm, Chachoengsao

Products

- *Spirulina* to dog food ingredient formulator/producer

Credit: Sorawit Powtongsook

The Royal Chitralada Projects

Sorawit Powtongsook (2010) Recent Advances in Microalgal Mass Culture

Credit: Sorawit Powtongsook

CPF : Photobioreactor Project

Products

- Chaetoceros sp. for shrimp nursery

Credit: Sorawit Powtongsook

Smaller Scale in Thailand

Products

•Chaetoceros sp. for shrimp nursery to local shrimp farmers

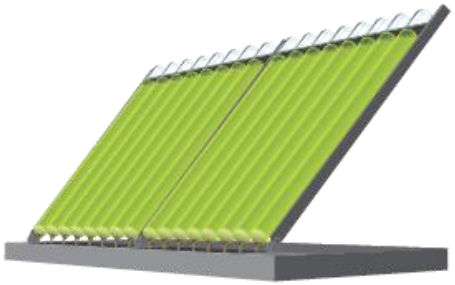
Sorawit Powtongsook (2010) Recent Advances in Microalgal Mass Culture

Credit: Sorawit Powtongsook

1. World Status
2. Thailand Status

CURRENT STATUS ON MICROALGAL BIOFUEL TECHNOLOGY DEVELOPMENT

International oil companies are investing in Algae Oil (1 of 2)

Company	Research and Development (Samples)
EXXON MOBIL ExxonMobil	   • In July 2009, ExxonMobil joined with **Synthetic Genomics**, Inc (SGI) to launch new program to research and develop next-generation biofuels from photosynthetic algae. •The ExxonMobil Algae Biofuels Research and Development Program is a new long term investment focused on biofuel production from photosynthetic algae. If successful, these next generation biofuels could augment the world's transportation fuel supply and assist in reducing greenhouse gas emissions in the decades to come. •ExxonMobil's expected spend for this program, which includes a strategic alliance between ExxonMobil Research and Engineering Company (EMRE) and Synthetic Genomics, Inc. (SGI), is more than **$600** million if research and development milestones are successfully met. •July 14, 2010 •ExxonMobil and Synthetic Genomics Inc. Advance Algae Biofuels Program with New Greenhouse •ExxonMobil → Largest Investor amongst International Oil Companies to bet on algal biofuel •SGI → J. Craig Venter (first human genome sequenced) (first not-of-this-world microorganism)

Sources: http://www.exxonmobil.com/Corporate/energy_climate_con_vehicle_algae.aspx, www.syntheticgenomics.com

International oil companies are investing in Algae Oil (2 of 2)

Company	Research and Development (Samples)
Chevron	• Chevron Forms a Biofuels Business Unit (May 2006) • Chevron and NREL to Collaborate on Research to Produce Transportation Fuels, Including Jet Fuel, using Algae (October 2007) – To identify and develop algae strains that can be economically harvested and processed into finished transportation fuels, such as jet fuel. – "Chevron believes that nonfood feedstock sources such as algae and cellulose hold the greatest promise to grow the biofuels industry to large scale" stated by Don Paul, VP and Chief Technology Officer, Chevron Corporation • Chevron Technology Ventures (A division of Cheveron, USA) and Solazyme also announced that they have signed a feedstock development and testing agreement • Chevron expects to spend approximately $2.5 billion on alternative and renewable energy technologies and energy efficiency services between 2007 and 2009 (www.chevron.com)
BP	• Energy Bioscience Institute (EBI) - BP have selected Berkley Consortium for funding $500 million over the next 10 years on finding new applications for bioscience in the energy industry, including better ways to produce the biocomponents that can be blended into traditional fossil-based transport fuels • Butanol: BP and DuPont partnership to develop, produce and market next-generation biofuels to help meet increasing global demand for renewable transport fuels. The first product from the partnership is to be biobutanol • Microalgae (Blue-green algae): BP, SFAz and Arizona State University Launches Cyanobacteria Biodiesel Research Project
Shell	• Shell and HR Biopetroleum form Joint Venture for Algal Biofuel Production • Claim 60T/hectare/year (or around 33g/m2/day at 50% oil content) • Sea Water Algae • Joint-Venture called Cellena • The JV will construct an algae-oil production facility to produce feedstocks for biodiesel immediately **• NOW QUIT THE MICROALGAE BUSINESS → Focusing on Sugarcane-based Industry in Brazil**

Sources: www.chevron.com, www.bp.com, and www.greencarcongress.com

World Status (1): USA is the most active country

Affiliates	Research and Development (Samples)
DOE	•$24 Million •Algal Biofuels Research (3 consortia) •Sustainable Algal Biofuels Consortium (Mesa, Arizona): •Led by Arizona State University, this consortium will focus on testing the acceptability of algal biofuels as replacements for petroleum-based fuels. •Tasks include investigating biochemical conversion of algae to fuels and products, and analyzing physical chemistry properties of algal fuels and fuel intermediates. (DOE share: up to $6 million) •Consortium for Algal Biofuels Commercialization (San Diego, California): •Led by the University of California, San Diego, this consortium will concentrate on developing algae as a robust biofuels feedstock. •Tasks include investigating new approaches for algal crop protection, algal nutrient utilization and recycling, and developing genetic tools. (DOE funding: up to $9 million) •Cellana, LLC Consortium (Kailua-Kona, Hawaii): •Led by Cellana, LLC, this consortium will examine large-scale production of fuels and feed from microalgae grown in seawater. •Tasks include integrating new algal harvesting technologies with pilot-scale cultivation test beds, and developing marine microalgae as animal feed for the aquaculture industry. (DOE funding: up to $9 million)
DOE	•$44 Million • > 30 members (Universities, National Lab, Companies) •Our technical vision is based on several key concepts: 1) the development of agronomic systems for sustainable cultivation of oleaginous microalgae using non-arable land and sustainable water sources; 2) the creation of efficient methods for harvesting and extracting fuel feedstocks; and 3) the establishment of an integrated process to support widespread commercialization of valuable coproducts resulting from algal biomass.
DOE	•DOE released Algal Biofuels Roadmap (May 2010) •http://www.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf

World Status (2) : Automakers and more also invest in Algae

Affiliates	Research and Development (Samples)
Ford	•October 01, 2010 : Ford researchers visited Wayne State University's National Biofuels Energy Lab. •The Ford researchers, part of the company's Systems Analytics and Environmental Sciences Department, also have conducted in-house research on the opportunities and challenges of producing biodiesel from algae oil.
TOYOTA/ DENSO	•2010 •DENSO → In-house developing microalgal biofuel technology •DENSO •DENSO claims to have good candidate (fast growing, thermal tolerant, and producing oil-droplet) •DENSO is looking for partners in southeast asia for R&D collaboration especially pilot scale trials •Toyota Motor Corp.'s research and development unit, Hitachi Ltd. and more than 40 other Japanese companies and institutions have joined a national study into algae's potential for producing biofuel and chemicals. Autoparts maker Denso Corp., refiners Nippon Oil Corp. and Idemitsu Kosan Co. and soy sauce maker Kikkoman Corp. will also join the study led by Tsukuba University into producing motor fuel, cosmetics and food from the microorganisms, according to a joint statement released at Tsukuba City near Tokyo today.
Biojet International Ltd.	•BioJet International Ltd. announced today that it has received a US $1.2 Billion funding facility from Cayman based Equity Partners Fund SPC. • Camelina, Jatropha, and Algae as Feedstocks • Integrated Value Chain from Feedstock Production to Bio-Jet Fuel Production

Source: http://media.ford.com/article_display.cfm?article_id=33338 , 1st AOAIS 2010, www.biojetcorp.com

World Status (3) : Other Countries Initiative

Affiliates	Research and Development (Samples)
Mexico	February 14, 2011 **OriginOil to Help Mexico Industrialize its Algae Production** *Government-funded 'Manhattan Project' to pursue aggressive national jet fuels goal* OriginOil, Inc. has agreed to participate in a pilot scale algae project to be funded by the Mexican government. The project will demonstrate industrial algae production, paving the way for substantial investment by the Mexican government in large-scale jet fuels production. • The project operator, Genesis Ventures of Ensenada, Baja California create the site • Ensenada's Center for Scientific Research and Higher Education (CICESE) operate the Genesis site. • University of Baja California (UABC) algae researchers collaborate in the project • OriginOil's provides core harvesting and extraction technology 

Source: OriginOil, USA

World Status (4) : Other Countries Initiative

Affiliates	Research and Development (Samples)
UK	• Carbon Trust : 30 Million Pounds

The Algae Biofuels Challenge (ABC)

CARBON TRUST

Vision	To accelerate the development of algae biofuels towards commercialisation by 2020
Technology Focus	Mass-cultivation in open ponds in favourable climates outside of the UK using seawater
Targets	➢ Carbon savings up to 80%# ➢ Oil yields of >20,000 l/ha/yr *
Investment Required	Up to £30m

relative to fossil fuels
*>60 ton/ha/yr dry biomass, >30% oil

Source: Carbon Trust, UK

World Status (5) : Other Countries Initiative

Affiliates	Research and Development (Samples)
Australia	•The initial stages of the $3.3 million project led by Murdoch and involving the University of Adelaide, received $1.89 million funding from the Australian Government as part of the Asia-Pacific Partnership on Clean Development and Climate.

http://x-journals.com/2009/clean-algae-biofuel-project-leads-world-in-productivity/

Source: http://media.murdoch.edu.au/tag/algae-pilot-plant

Examples

Algalfuel, Portugal

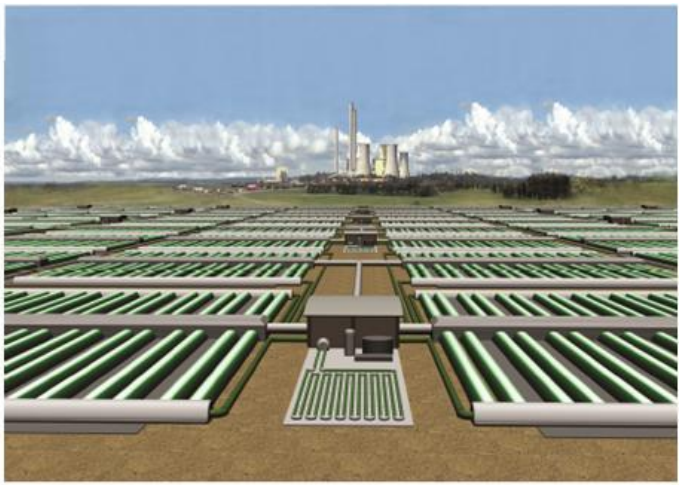
Pilot production Unit - *Dunaliella*
Necton, Portugal (1996)

Tubular Photobioreactors
Necton, Portugal (2005)

PBRs flat panel flow trough
Necton, Portugal (1999)

MBD Energy, Australia

MDB, JCU Research and Development



Drawing of Power Station with Commercial Scale expansion

Source: Algae World Asia 2010

Examples

NIWA, New Zealand
Largest HRAP in the world, 5ha

Aquaflow, New Zealand

Microalgae for Biofuel from Wastewater Treatment; biomass is processed for biofuel applications

Seambiotic, Israel
1st flue-gas to microalgae pilot plant

Solix Biofuel, USA
CO2 and Wastewater from Coal-bed Methane

Microalgae for Biofuel and other high value chemicals with Integration with CO2 source such power plant, coal-bed plant, etc.

Source: Algae World Asia 2010, 1st AOAIS JAPAN, Seambiotic

Many companies and startups

Company	Aurora Algae	Seambiotic	Algenol	Solazyme
Look				N/A
Type	• Marine Algae • Race-way Open Pond • Horizontal	• Race-way Open Pond • Horizontal • Marine Algae	• Closed • EOH production 	• Fermenter (fermenting algae in the dark using sugars as a feedstock)
Claim	• $50/bbl • No need to dry algae (using wastewater treatment tech.)	• First company in the world that is utilizing flue gas from coal burning power stations for algae cultivation	• 6,000 gallons / acre / year • EtOH @ $1/gallon	• Bio-petroleum and Triglyceride
Status	• Seawater Algae Bio Diesel Demonstrated in Florida • Complete 18-Month Algae Biodiesel Pilot Project • Ready to Commercialize • Expect to begin operating its first commercial plant in 2012	• Pilot plant comprising about a 1,000 m^2 of ponds at the power plant of the Israeli Electric Corporation in Ashkelon • JV with Inventure Chemical to construct a pilot commercial biofuel plant in Israel • Establishing a 5 hectare algae farm • Dec 09, Seambiotic and China Guodian, power company, to build $10 million commercial microalgae farm in China	• Algenol's first commercial project for ethanol production will begin sales in Sonora, Mexico in 2009 by partnered with BIOFIELDS	• Microalgae-derived renewable diesel fuel that meets D-975 specifications for petroleum diesel fuels • Partner with Chevron • Solazyme to begin commercial algae sales in '09/ nutraceutical market first, fuel later
Note	• CO_2 fed helps mixing the algae without using paddle wheel or other equipment • www.aurorabiofuels.com	• Marine Algae • Flue gas from Power Plant • Oil = Omega 3 • www.seambiotic.com/	• Direct-to-Ethanol • Expect to produce 10,000 gallons / acre / year • www.algenolbiofuels.com	• Sugar/glycerol/cellulose to biopetroleum/ triglyceride • www.solazyme.com

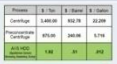
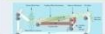
Source: Aurora Algae, Seambiotic, Algenol, Solazyme, Green Car Congress, Biofuels Digest, PTT RTI Analysis

Company	Sapphire	Joule Unlimited	PetroAlgae	Synthetic Genomics
Look				N/A
Type	• Race-way Open Pond	• Closed Photobioreactor	• Race-way Open Pond	• CO_2 -> Fuels & Chemicals • System type not decided
Claim	• Green Crude Production • Proprietary process of turning algae into crude • 2011: producing 1 million gallons of diesel and jet fuel per year • 2018: producing 100 million gallons of diesel and jet fuel per year • 2025: producing 1 billion gallons of diesel and jet fuel per year	• SolarConverter™ • + Engineered product-specific photosynthetic organisms in non-freshwater solution + Direct-to-Product Process • Modular + Scalable • Costs as low as $30 per barrel equivalent	• 80-100 MT/ha/yr • 5,000 hectares per Unit • Unit produces ~225 thousand metric tons of bio-crude/unit/year • Unit produces ~90 thousand metric tons of protein/unit/yr	• If research and development milestones are successfully met, ExxonMobil expects to spend more than $600 million on the algae biofuels program over the next decade, $300 million of which will be allocated to SGI. • New life synthesized
Status	• Integrated Algal Bio-Refinery in Southern New Mexico, a project that was awarded more than $100 million in federal grant money from the American Reinvestment and Recovery Act	• 2 patents on the technology • April 10, Raised $30 million • Proven the direct production of diesel & will begin pilot production by end of 2010 • Proven the direct production of ethanol at rate of 10,000 gallons/acre/year, 40% of its ultimate productivity target, & pilot operations underway in Leander, Texas	• Test biomass firing with Foster Wheeler • $4 million in licensing revenue from sale of a one-year master license for development of PetroAlgae projects, and sub-licenses, in Egypt and Morocco	• Microbial-Enhanced Hydrocarbon Recovery - Collaboration with BP • Algae Biofuels Research and Development Program --Collaboration with ExxonMobil Research and Engineering Company (EMRE) • New greenhouse opened
Note	• www.sapphireenergy.com	• Founded in 2007 by Flagship Venture Labs	• www.petroalgae.com	• www.syntheticgenomics.com

Source: Sapphire, Joule Unlimited, PetroAlgae, Synthetic Genomics, Green Car Congress, Biofuels Digest, PTT RTI Analysis

Company	OriginOil	Aquaflow	Cellana	Solix Biofuels
Look				
Type	• Artificial Light Closed PBR • + Live Extraction Technology	• Settling ponds of standard Effluent Management (EM) Systems and other nutrient-rich water • Integrated open-air waste water treatment and algae production	• Closed-culture tubular PBRs coupled with open ponds in a two-stage process	• Algae screening, optimization and photobioreactor (PBR)
Claim	• Single-step extraction • Multiple claims	• Partnered with GTI and UOP for hydrocarbon biofuel projects funded by DOE	• Process is covered by issued patents and patent applications, including U.S. patent #5,541,056	• >5 times the amount of fuel (per area per time) than agriculture-based fuels
Status	• Quantum Fracturing™ / Helix BioReactor™ / MultiReactor™ / Hydrogen Harvester™ / Modular and Scalable Growth System / Cascading Production / Low Cost Oil Extraction / Live Extraction™ / MAX ONE / The OriginOil System • Delivers Second Product To Strategic Customer	• Demonstrated proof of concept (Dec 2006) • Commercial-scale continuous harvesting at Marlborough oxidation ponds (March 2008) • Commissioning of a prototype commercial plant (March 2008) • Synthetic paraffinic kerosene (SPK) produced (Dec 2008)	• Kona Pilot Facility (complete 2010, 2.5ha) • Currently producing 1MT/month • Develop new strains • Optimize conditions • Evaluate novel harvesting, dewatering lineups • Demonstrate co-product as fishmeal replacement • Develop updated design, cost & LCA for 1000-ha facility	• Technology partner of Colorado State University in Fort Collins, Colorado • Completes $20.5 Million Series A Funding Round
Note	• www.originoil.com	• www.aquaflowgroup.com • NZ-based	• N/A	• Partner with many chemical producers including BASF, FITCH

Source: OriginOil, Aquaflow, Cellana, Solix, Green Car Congress, Biofuels Digest, PTT RTI Analysis

Company	GreenStar	Algae Link	Algae Venture Systems	Pond Biofuels
Look				
System Type	• Covered pond • Horizontal	• Closed-tubular • Horizontal	• Hybrid system + low cost harvester	• (Possibly) Race-way Open Pond • (Lab-scale tested in tubular photobioreactor)
Claim	• Test at 40,000L • Claim to be largest demon. in this field • Nutrient formula to boost productivity	• Claim 48,667kg/rai/y dry mass (at 4kg/unit/49m2)/d • Automatic Cleaning System	• Key: Harvester 1.925/Ton drying process • Harmful Algal Bloom Inversion Technology (HABIT) • Rapid Accumulation Concentration (RAC)	• Capture a cement plant's carbon emissions in algae • The algae would then be turned into a biofuel and used to fuel cement kilns and company trucks. • $4 million algae-growing demonstration facility
Status	• Signs Contract to Build 100-Acre Algae-to-Biodiesel Facility in Midwest to begin in MAR 08 (13 NOV 07) • Continuing two 500-acre algae to biodiesel commercial production facilities	• Sell its demo plant at 69,000Euro • Sell System upto 100T/day dry mass at 10 million Euro • Main crude oil supplier for the Air France/KLM jet fuel project • Sell solar dryer system	 	• Pond Biofuels will grow its algae right next to Ontario's St. Mary's cement plant
Note	• + Carbon Credit • + Diversified company (crop yield booster, algae, electric car) • www.greenstarusa.com	• + Training Course on Algae Biodiesel • (claim may exceed theoretical limit)	• Harvester data extrapolated from 3g/L (lab-scale) • www.algaevs.com	• Canada-based • pondbiofuels.com

Source: GreenStar, AlgaeFuels, Algae Venture Systems, Pond Biofuels, Green Car Congress, Biofuels Digest, PTT RTI Analysis

Company	A2BE Carbon Capture	Diversified Energy	Vertigro	GreenFuel
Look				
Type	• Covered -raceway • Horizontal	• Air-relief , Closed Polyethylene trough, Horizontal	• Closed-bag/flow • Vertical	• Closed-tubular • Vertical, 3D Matrix System
Claim	• CO2 Consumption: 110 tons CO2/acre-year • Product Generation: 60 tons/acre-year • CC&R Farm Return: 6 -10 year payoff • Water use: 3 inches/year equiv.	• Less than $20K per acre • ~22 tons of dry algae mass per gross acre (25 g/m2-day) • 20-30 % Oil Yield • Traditional Equipment and Practices Used for System Architecture Fabrication and Installation	• 71 USD/Barrel of Crude Algae Oil • 276 Ton/acre/year or 186 g/m2/d (149 kg oil/d) (12 DEC 07) • Requires 5% of the normal water requirements for field crops	• 98 g/m2/d (or 57,232kg/rai/y dry mass) (ranging from 62 and 174 g/m^2/d) (ash free, dry weight basis) • CO2 concentration at 2-4%
Status	• Expect to move from pilot scale to full scale bioreactor operation within 24 months with their first carbon capture projects within 48 months Not quite active on algae anymore	• Plan to conduct multiple Singae™ demonstrations in Arizona beginning in fall 2007 and continuing into 2008 • Pre-commercial Demonstration planned with partners • Goal to increase yields to > 40 tons/acre	• Testing the pilot plant at Vertigro Algae Research Facility, El Paso Texa	• Testing its pilot plant in many power plants • To Develop a $92M, 100-Hectare Algae Greenhouse at Holcim (Aurantia-GreenFuel Partnership) (Oct 2008)
Note	• + Carbon Credit • www.algaeatwork.com	• + Nutraceuticals markets • www.diversified-energy.com	• N/A • Status not sure	• + Carbon Credit

Source: Algae@Work, Diversified-Energy, Vertigro, GreenFuel, Green Car Congress, Biofuels Digest, PTT RTI Analysis

Company	Bionavitas	Blue Marble Energy	LiveFuels	Solena Group
Look			N/A	N/A
System Type	• Light immersion technology (LIT) for open-pond and PBR • LIT from high efficiency LEDs	• Harvest wild algae (both micro/macro) + wastewater treatment by algae cultivation • Anaerobic Digestion producing biogas	• (possibly) open water system • (possibly) mixed culture • (information based on Algae Biomass Summit 2008) • Algae grazer as harvesting method	• Plasma gasification producing syngas for electricity generation • Industrial bioreactors, artificial light photosynthesizes the algae
Claim	• 10 to 12 time increase in yield over conventional methods	• N/A	• The largest and most intensely focused group in U.S.	• 400 times the amount of biomass feedstock on the same acreage of land compared to standard energy crops
Status	• Patent-pending Light Immersion Technology	• Harvesting operation in Washington State and has currently removed 10,000 lbs. of pollution fueled algae for testing and distribution to research partners.	• LiveFuels Alliance With Sandia National Laboratory to Make Algae-To-Biocrude by 2010	• N/A
Note	• Not much info from their website • www.bionavitas.com	• Generate bio-chemicals and natural gas from algae and other cellulosic biomass • Not focusing on biomass production	• To transform algae into biocrude by the year 2010	• Not really an Algae company • Diversified renewable energy company

Source: Bionavitas, Blue Marble Energy, LiveFuels, Solena Group, Green Car Congress, Biofuels Digest, PTT RTI Analysis

Company	PetroSun	Bodega Algae	NIWA
Look			
System Type	• (possibly) Race-way Open Pond	• Scalable algae photobioreactor • Closed continuous-flow reactors • Light distributing throughout the cultivation tank	• High rate algal pond (HRAP) – Open pond • Wastewater as cheap feedstock / nutrient
Claim	• N/A	• Demonstrated in increase of more than 300% in biomass production over simultaneous side by side control testing, exceeding expectations. The company will develop a commercial version of the BOW1000 PBR during the next 12 months.	• 5 ha Wastewater treatment HPAP with carbon dioxide addition is the cost-effective production technology • Gravity settling is our low-cost harvesting technology • 20 g/m2/d (with CO2)
Status	• JV with Shanghai Jun Ya Yan Technology in China • Provide 5 Drums of Algae Derived Biodiesel for Emissions Studies	• N/A	• Partner with Solray (Liquefaction company in NZ) • Produce bio-petroleum • Research Org.
Note	• N/A • Not much info at website • www.petrosuninc.com	• N/A • www.bodegaalgae.com	• Christchurch • In connection with PTT RTI • www.niwa.co.nz

Source: PetroSun, Bodega Algae, NIWA, Green Car Congress, Biofuels Digest, PTT RTI Analysis

Company	Oil Fox S.A.		
Look			
System Type	• Race-way Open Pond + Greenhouse + rain water • Anaerobic digestion effluent as a source of nutrients for the algae to grow • Produces biogas is burnt to generate electricity (for paddle wheels, light, harvesting and drying process). • Bubble flue gas emitted from a thermal power station	• After harvesting the algae, the water from the culture medium is potable for human consumption • After oil extraction from the algae sludge, the remaining biomass can be used for animal o human consumption after bacteriological analysis • To grow algae at night, we use artificial Light (LED) which have high efficiency and low cost and consumption of energy	
Claim	• Low-cost Biodiesel from Algae (<2 USD/gallon) (from EU meeting 2009)		
Status	• Operational plus Biodiesel Plant		
Note	• Argentina-based	• http://www.oilfox.com.ar	

> 30 companies tracked

Source: PTT RTI Internal Analysis

Thailand : Microalgal Biofuel Technology Activity

Affiliates	Research and Development (Samples)
PTT + TISTR + BIOTEC (NSTDA) + CU + MU + KMUTT *(THINK ALGAE Consortium)*	• September 14, 2010 • **Th**ailand Collaborat**i**ve Research **N**etwor**k** on Micro**alga**l **E**nergy **(THINK ALGAE)** • Approx. 5 million USD investment for 2008-2015 (R&D phase) • Screening, Optimization, Harvesting, Extraction, LCA, Metabolic Engineering etc.
PTTCH + Microalgal Biotechnology Laboratory + NSTDA	• R&D from upstream to downstream • Energy, Nutraceuticals, Animal feed, essential fatty acids, etc. • Agreement with MBU, Ben Gurion University of Negav on **"DGLA – Omega 6"**
Other groups	• Vegetable Oil/Biodiesel Plant with Wastewater facility • Wastewater Treatment company • Cement/Chemical Company • Shrimp / Feed company

Source: PTT, PTTCH, http://www.bangkokpost.com/business/economics/193818/authorities-may-finance-algae-biofuel-research

Thailand : Microalgal Biofuel Technology Activity

Affiliates	Research and Development (Samples)
Chiangmai University and Maejo University	• Botryococcus braunii screening and R&D • Local isolates : Screening and Optimization • Outdoor Cultivation and Economics Analysis
Kasetsart University	• Screening and Optimization • Metabolic Engineering • Outdoor Cultivation • Processing and Fuel Processing • LCA and other economics analysis • Both Microalgae and Microalgae
Other universities	• KKU, KMITL, BUU etc.

Source: PTT and National Algae and Plankton #5 at Sonkhla

1. THINK ALGAE : Vision
2. THINK ALGAE : Microalgae Biofuel Roadmap
3. THINK ALGAE : Capabilities
4. THINK ALGAE : Project's Key Figures

THINK ALGAE CONSORTIUM

THINK ALGAE: Overview

THINK ALGAE

- PTT with the role of national oil/energy company
- This consortium consists of the most strongest and most active partners in Algae R&D in Thailand

Key representatives from Thailand also presented in this photo

THINK ALGAE : Vision

Commercialize the **sustainable** and **cost competitive** algal biomass and oil as biofuel feedstock **within 2017**

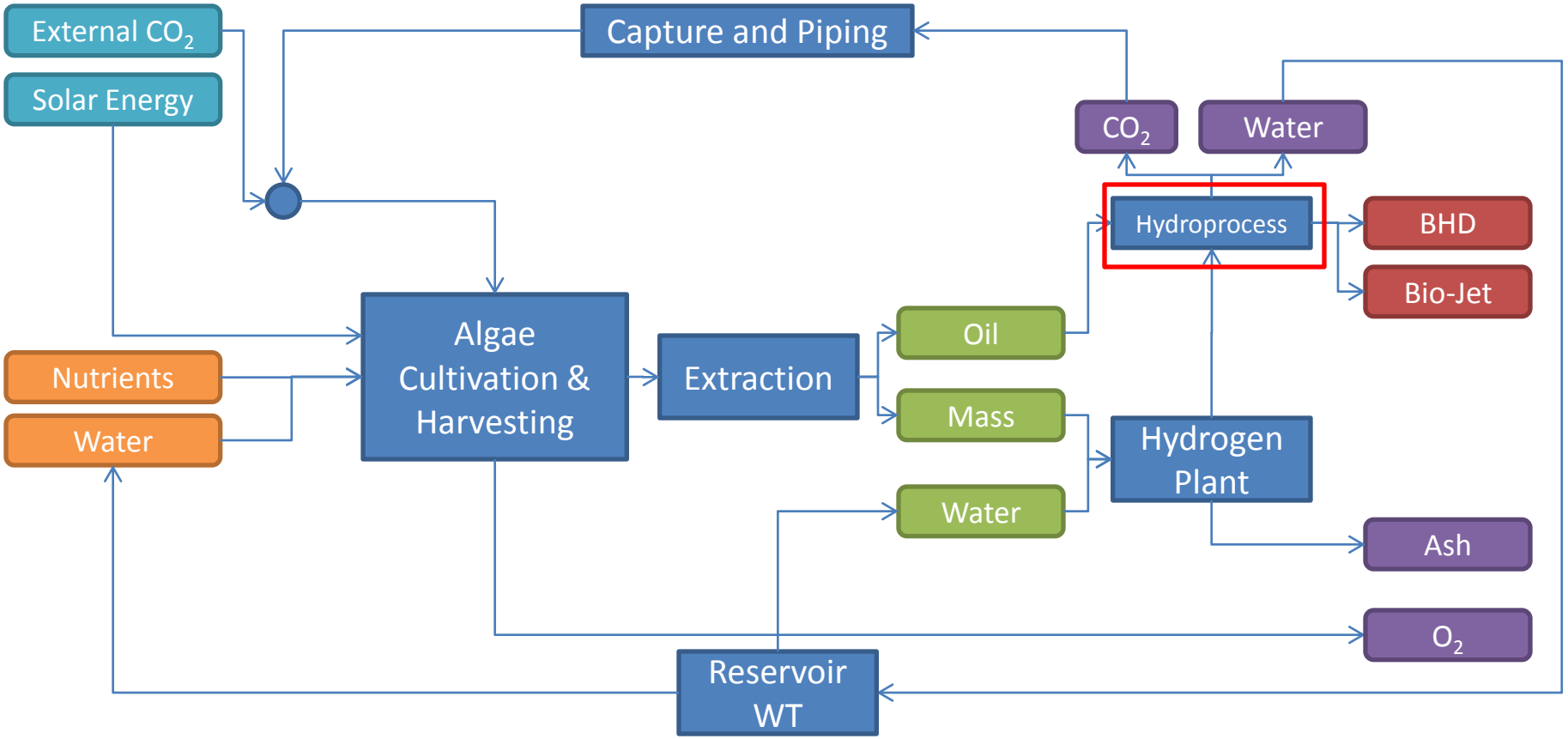
- Focus on biofuel application
- Algal could be produced as low cost biomass or low cost triglyceride/hydrocarbon or other raw materials

THINK ALGAE : Integrated Algal BHD System

KEY:

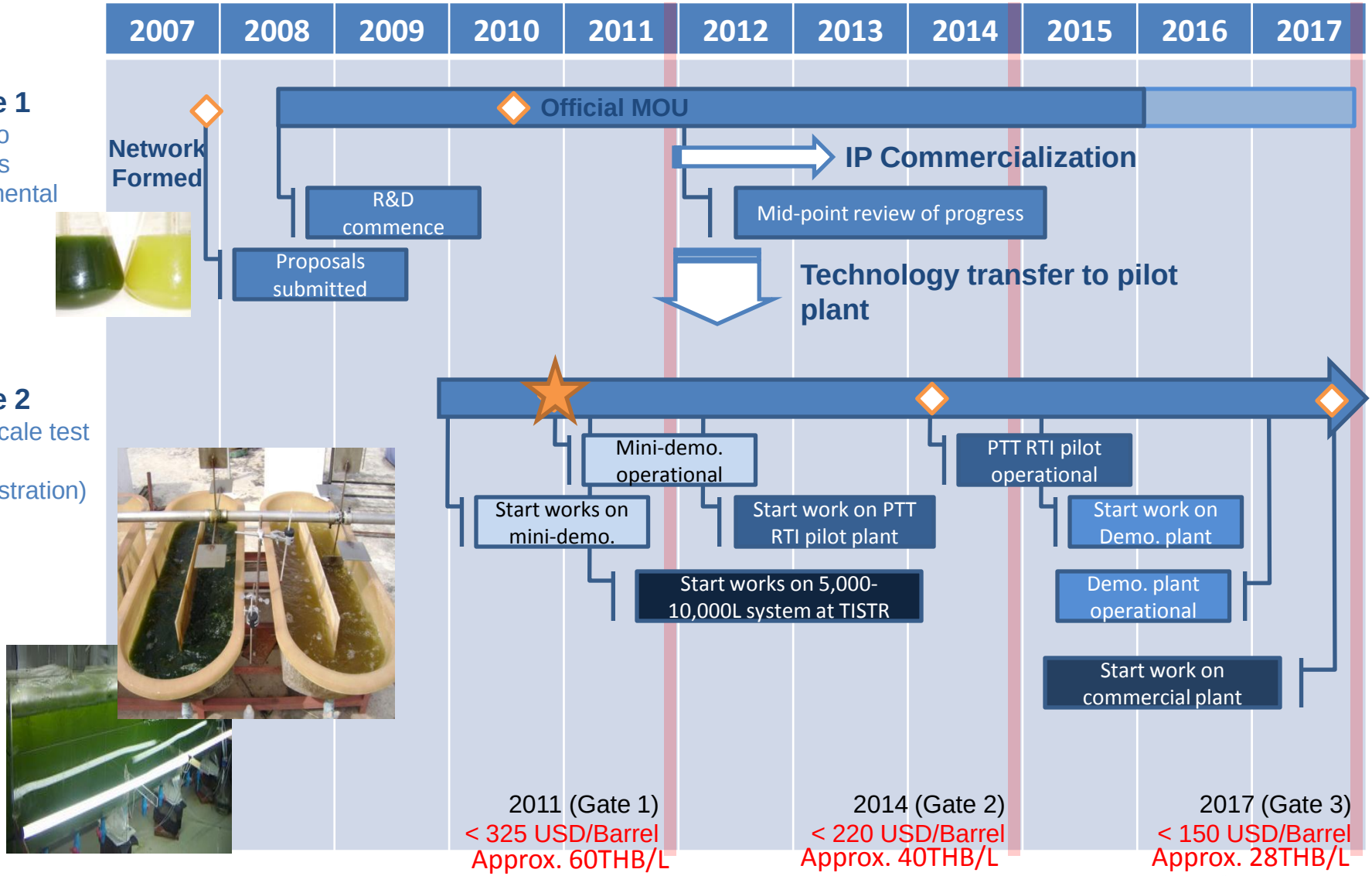
1. Minimal CO_2 and Water footprint
2. Standalone Biofuel / Bioenergy Production
3. Carbon neutral (not carbon capture and storage) (may have some capture with remaining C in ash)

Note: BHD (Bio-hydrogenated Diesel)



Note: Similar to UOP 2009 patent, but in this case H_2 is generated through algal mass + water instead of natural gas reforming

THINK ALGAE : Microalgal Biofuel Roadmap



Maintain fundamental issue research while progressing to bigger scale for experience gaining

PTT RTI Outdoor Microalgae Cultivation Units

Sorawit Powtongsook (2010) Recent Advances in Microalgal Mass Culture

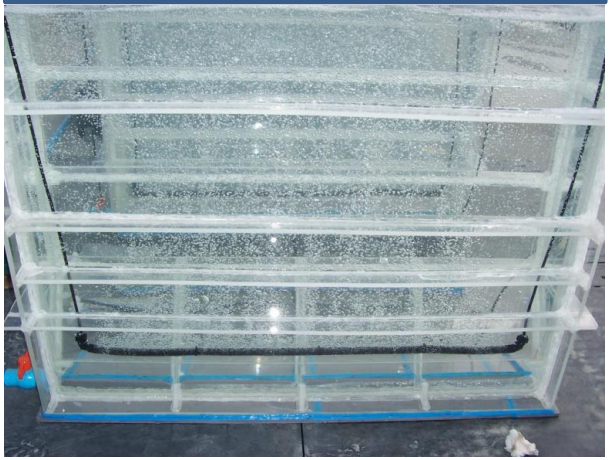
Credit: Sorawit Powtongsook

PTT RTI Outdoor Microalgae Cultivation Units

Hybrid Open Raceway Pond

Open Raceway Pond

Flatplate Photobioreactor



Bubble Column Photobioreactor

- 4 Units (600L each)
  - ✓Raceway Open Pond
  - ✓Hybrid Raceway Pond
  - ✓Flat-plate PBR
  - ✓Bubble PBR
- Total 2,400 L working volume
- Purposes
  - ✓Outdoor Performance Comparison
  - ✓System Comparison
  - ✓Biomass/oil Production
- ✓Space > 1 ha prepared for larger pilot-scale facility

Designed and Constructed by BIOTEC/CU

Commissioning the System : Feb 2011

Credit: Sorawit Powtongsook

TISTR Microalgae Laboratory

Mahidol University Laboratory

- Algal isolation and screening

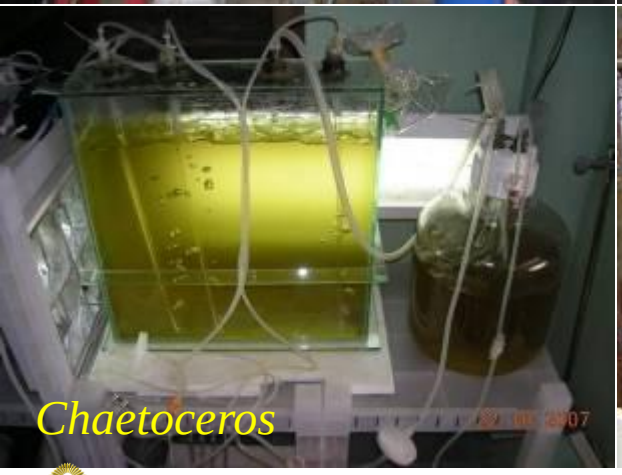
King Mongkut University of Technology Thonburi

0.5 m x 1.5 m x 0.3 m (0.15 m), Working volume ~ 100 L

0.6 m x 3.0 m x 0.3 m (0.15 m), Working volume ~ 200 L

Fully equipped microalgae lab.

CU-BIOTEC Laboratory



PTT THINK ALGAE : Project's Key Figures

- **1-2-3** : 1 Public Company, 2 National Laboratories, 3 Universities
- **5** : 5 million USD from 2008-2015 (after 2015, budget to be determined based on the results)
- **8** : 8 strains under cost optimization (6 freshwater, 2 marine) and tested for outdoor cultivation
- **1,000** : More than 1,000 strains currently being screened for the most desirable strain (freshwater and marine) (high growth rate & oil yield, etc.) + Nile Red as High Throughput Screening Method
- **10,000** : → System size ranges from 1mL to 10,000L working volume (actually together > 100,000L working volume); planning for > 240,000L system
- **System**: Open and closed systems are studied and utilized together
- **Development**: Conventional Approach (cultivation, harvesting, extraction, processing) with new concept under investigation
- **Focus**: Low cost algal mass and/or oil

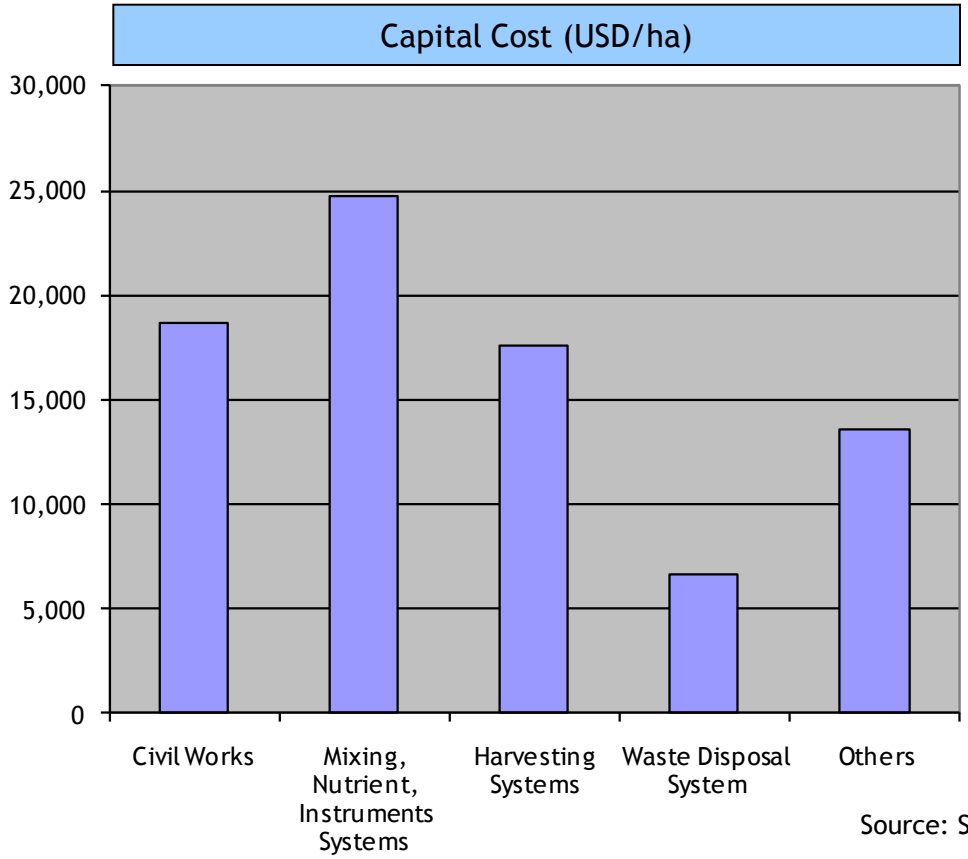
MICROALGAL OIL COST?

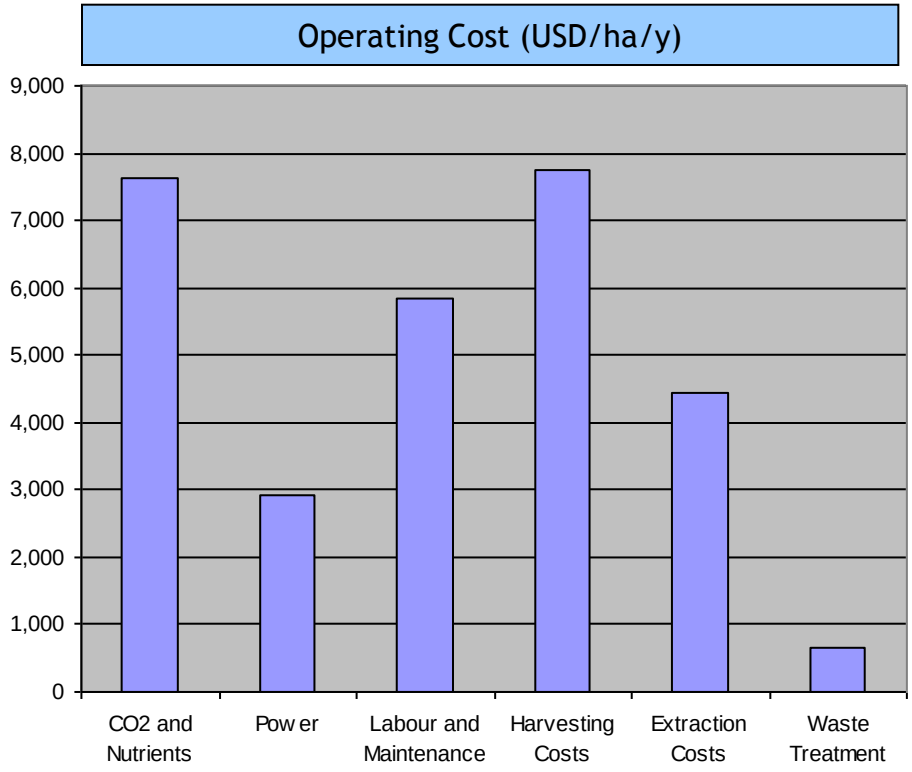
From 3 studies during last decade, Algae oil costs around 214 USD/barrel*

214 USD/barrel or 1.35 USD/L

* Calculation based on US Inflation rate from 1994-2007, www.inflationdata.com

1. Capital Costs lie evenly amongst Civil, Mixing & Nutrient, and Harvesting portions
2. Operating costs lie mostly in Havesting Cost, CO2&Nutrient, and then Labor & Maintenance portions





Source: System and Economic Analysis of Microalgae Ponds for Conversion of CO2 to Biomass, DOE USA, PTT RTI Analysis

Cost : Recent Announcements?

Phototrophic

"We have already dropped the cost from $12 a litre down to $3 a litre in the past year, but our aim is to get it down to less than $1 a litre," he said.

Professor Michael Borowitzka

Murdoch University

Source: http://media.murdoch.edu.au/multi-million-dollar-algae-biofuel-plant-opens-in-wa%E2%80%99s-north-west

Heterotrophic

Solazyme says it will be able to produce algae oil for the fuels market at "below $1,000 per metric ton ($3.44 per gallon or $0.91 per liter). The company claims to have decreased its cost from almost $10,000 ton in 2007 which certainly seems quite impressive.

Source:
http://greenworldinvestor.com/2011/03/16/algae-biofuel-green-company-solazyme-100mm-ipo-financialspartnerscostspros-and-cons-tempting-though-risky/

Solazyme

Cost : Recent Announcements?

'Even with relatively favourable and forward-looking process assumptions (from cultivation to harvesting to processing), algae oil production with microalgae cultures will be expensive and, at least in the near-to-mid-term, will require additional income streams to be economically viable,'

Algae Report, EBI sponsored by BP,
Nigel Quinn and Tryg Lundquist of Lawrence Berkeley National Laboratory (Berkeley Lab)

Sale of algae co-products, such as pigments or animal feeds, could improve the economics of algae biofuel, but it is not considered in this analysis because the higher value co-product markets would likely become saturated before significant biofuel quantities were produced, while commodity animal feed co-production would likely not have a decisive effect on biofuels production costs without other production improvements in addition.

And... When?

Team	Timeframe
Exxon-Mobil (USA)	10 years Approx. 2009 – 2018
Carbon Trust (UK)	10 years Approx. 2010 – 2019 Vision : to commercial by 2020
NREL (USA)	10 years Approx. 2020
PTT (Thailand)	10 years Approx. 2008 – 2017
OriginOil + Mexico (USA + Mexico)	< 5 years Approx. 2015 Commercialization 1% National Jet Fuel from Algae

Source: NREL Algae Roadmap 2010, PTT, OriginOil, Biofuel Digests, etc.

Conclusion

- Algal Biofuel Technology will play an important role in the future
- The world is developing Algal Biofuel Technology in order to become independent from oil addiction
- THINK ALGAE, focuses on upstream to produce low-cost feedstock while other (fuel conversion) downstream processing technology are currently developed with other partners with separate budgets
- THINK ALGAE, will invest > 5 million USD for the 1st and 2nd phase (until 2015) aiming for the commercial ready technology within 2017
- Thank you for the opportunity to present here today
- In microalgae area, PTT is still young but growing. We believe that, with our strong partners, with same vision and goal, and with solid roadmap we can make it happen (finger cross)

Acknowledgement

- Dr.Songkiat Tansamrit
- VP Mrs.Ratanavalee Inochanon
- PTT RTI and Department's members
- THINK ALGAE TEAM includes
  - PTT Research and Technology Institute (Mr.Supachai & Ms.Tasanee)
  - CU-BIOTEC Team (led by A.Prasert, A.Kasidit, A.Athiwan, A.Sorawit)
  - KMUTT Team (led by A.Boosya, A.Marasri, A.Wipawan, A.Kulayanee)
  - MU Team (led by A.Prayad, A.Kittisak, A.Metha)
  - TISTR Team (led by A.Aparat)
- NSTDA for today's opportunity

THINK ALGAE

Thailand Collaborative Research Network on Microalgal Energy

เครือข่ายวิจัยพลังงานจากสาหร่ายขนาดเล็ก

แห่งประเทศไทย (คพท.)

Thank you
for your kind attention

Kunn Kangvansaichol

Researcher
PTT Research and Technology Institute
PTT public company limited
Email: kunn.k@pttplc.com