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Biodiesel from Algae:
challenges, opportunities and the way forward

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CSIRO Energy Transformed Flagship
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United Nations ESCAP
APCAEM
Asian and Pacific Centre for Agricultural Engineering and Machinery

Aviation interest in algae

If the world airline fleet used 100% biojet fuel from soybeans, it would require 322 billion litres.

World fleet in 2004

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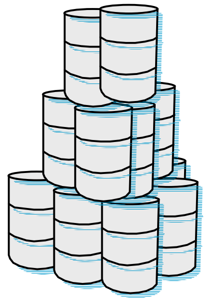
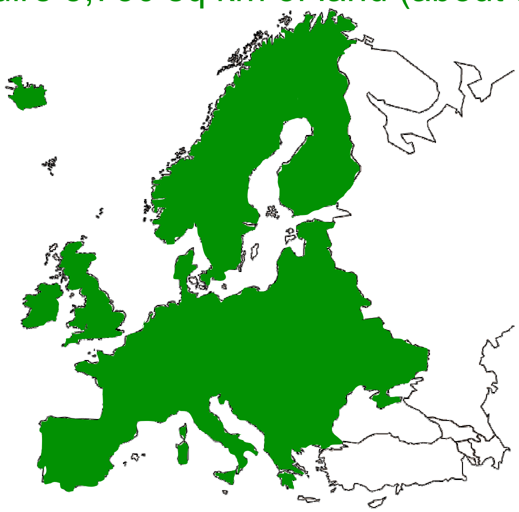


322 billion litres of biojet fuel
(85 billion gallons)

This would require 5,750 sq km of land (about the size of Europe)

Planted with soybeans



575 million hectares
(5.75 million sq km) soybeans

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To meet aviation’s fuel demand

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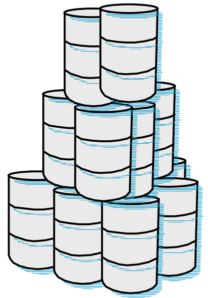
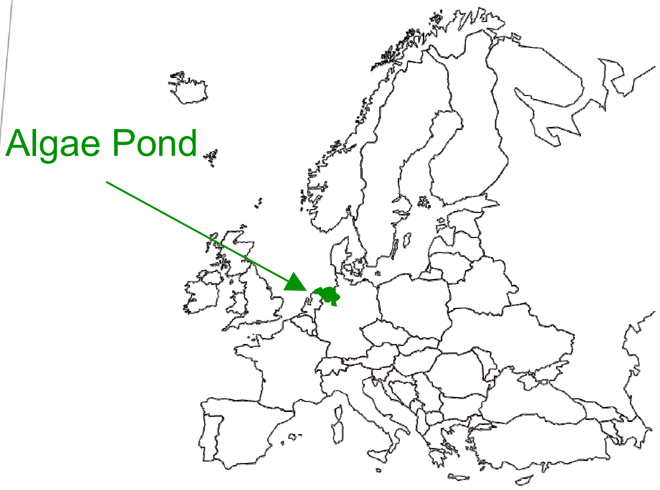


322 billion litres of biojet fuel
(85 billion gallons)

This would require 35k sq km land (about the size of Belgium)



34,250 sq km (3.4 million hectares)
algae ponds

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Independent Financial Review
18/07/2007
Page: 1
Business News
Region: NZ National Circulation: 8908
Type: National
Size: 258.63 sq.cms
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World first: Flying high on pond scum

DENISE MCNABB

AIR New Zealand and airliner manufacturer Boeing are secretly working with Blenheim-based biofuel developer Aquaflow Bionomic Corporation to create the world's first environmentally friendly aviation fuel, made of wild algae.

If the project pans out the small and relatively new New Zealand company could lead the world in environmentally sustainable aviation fuel.

It's understood Air NZ is undertaking risk analysis. If everything stacks up it will make an aircraft available on the Tasman to test the biofuel.

The fuel is essentially derived from bacterial pond scum created through the photosynthesis of sunlight and carbon dioxide on nutrient-rich water sources such as sewage ponds.

Air NZ would most likely test the fuel on one engine while normal aviation fuel would drive the other engine. Fuel is held in cells on the aircraft that can be directed to a specific engine.

None of the parties involved will talk about the joint venture development because of confidentiality agreements but whispers about the project were circulating at the roll-out of the Boeing 787 Dreamliner in Seattle in the US last week.

Local Marlborough media reported a visit by Boeing to Aquaflow earlier this year and Boeing has stated publicly since then that it believes algae is the airline fuel of the future.

Virgin Fuels announced in April it was working with Boeing to demonstrate biofuel in a 747-400. The focus is on testing algae-derived jet fuel, especially its freezing point.

Boeing's Dave Daggett was reported this year as saying algae ponds totalling 34,000 square kilometres could produce enough fuel to reduce the net CO2 footprint for all of aviation to zero.

Until now the relatively new Blenheim company's focus has been on biodiesel for cars, trucks, buses and boats.

Environment Minister David Parker drew public attention to the company in December when he test drove a Land Rover around Parliament's forecourt that was powered by Aquaflow's blend of algae biofuel and diesel (5% algae fuel and 95% conventional fuel) just a year after it was developed.

Virgin Airline boss Richard Branson met Parker in January to discuss biofuel, including Aquaflow's technology for wild algae.

Aquaflow director Vicki Buck said yesterday that she couldn't talk about

Continued on PAGE 2

MEDIA MONITORS
INCISIVE INSIGHT

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Continued on PAGE 2

Objective of the Presentation

- To seek partners to determine the amount and location of algal biomass in the ESCAP region that could be suitable for the production of biodiesel

- To offer the possibility of a sustainable, low GHG emissions feedstock that
  - **grows rapidly**
  - **yields more biofuel per hectare than oil plants**
  - **contains no sulfur and is non-toxic**
  - **is highly biodegradable**
  - **does not compete with food, fibre or other uses**
  - **does not involve destruction of natural habitats**

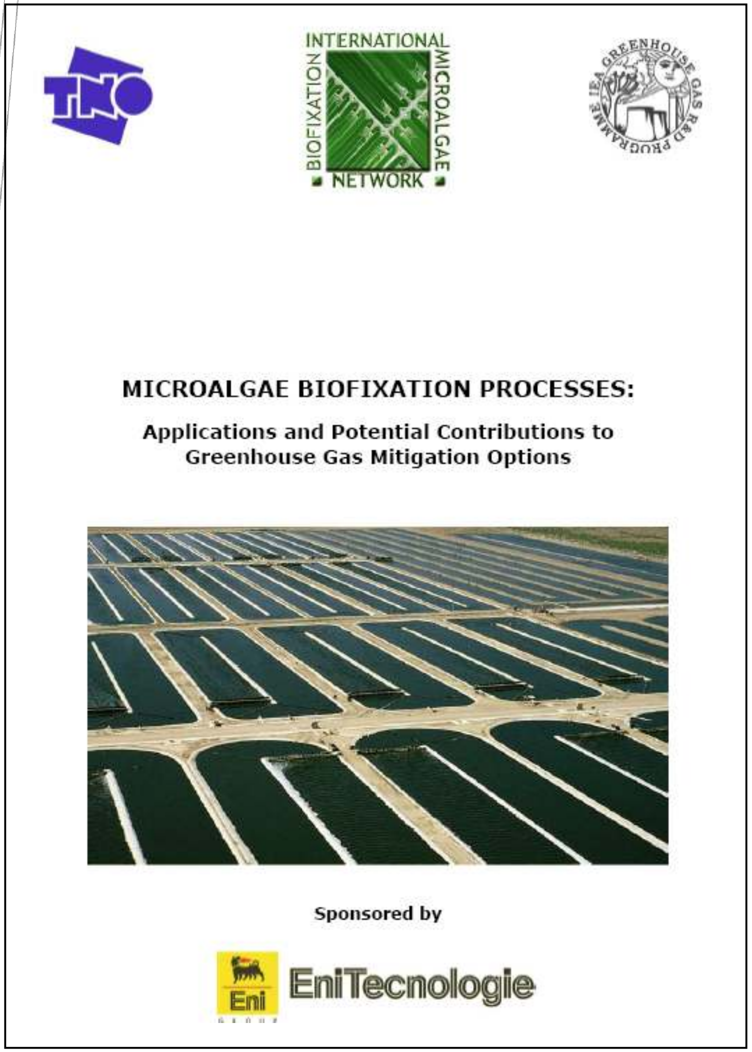
About Microalgae

- They contain lipids and fatty acids as
  - membrane components
  - storage products
  - metabolites and
  - sources of energy
- They contain up to 40% of lipids/oils by weight
- They need light, nutrients and warmth to grow

Sources of Microalgae

- Large-scale, natural sources:
  - Bogs, marshes and swamps
  - Salt marshes
  - Salt lakes
- Small-scale sources:
  - Wastewater treatment ponds
  - Animal waste
  - Other liquid wastes

Resource Potentials


INTERNATIONAL BIOFIXATION MICROALGAE NETWORK

IEA GREENHOUSE GAS R&D PROGRAMME

MICROALGAE BIOFIXATION PROCESSES:

Applications and Potential Contributions to Greenhouse Gas Mitigation Options

Sponsored by

EniTecnologie

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Methodology

T > 15°C and availability of:

- **water body or wastewater pond;**
- **flat, low cost land;**
- **infrastructure.**

CO_2 resources

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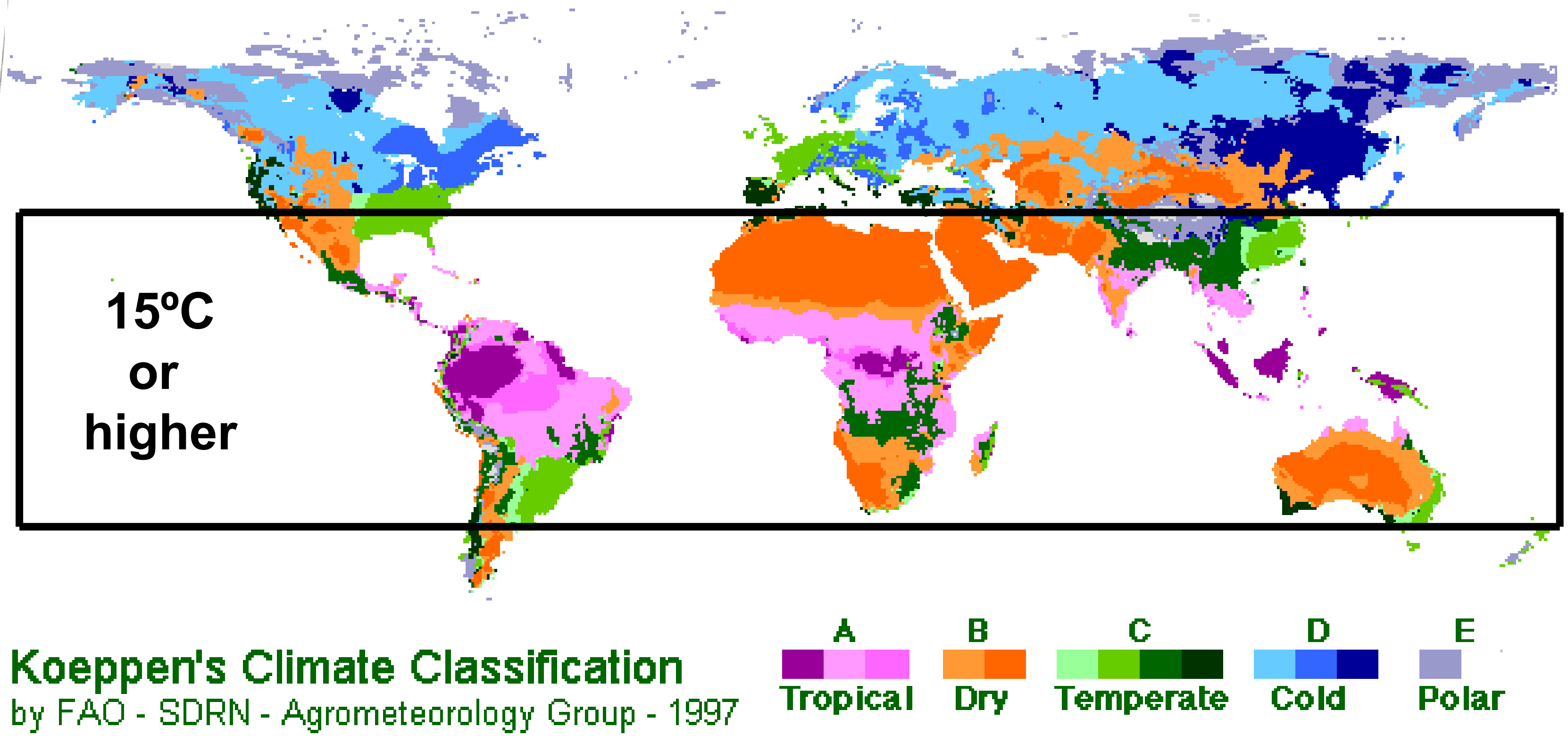
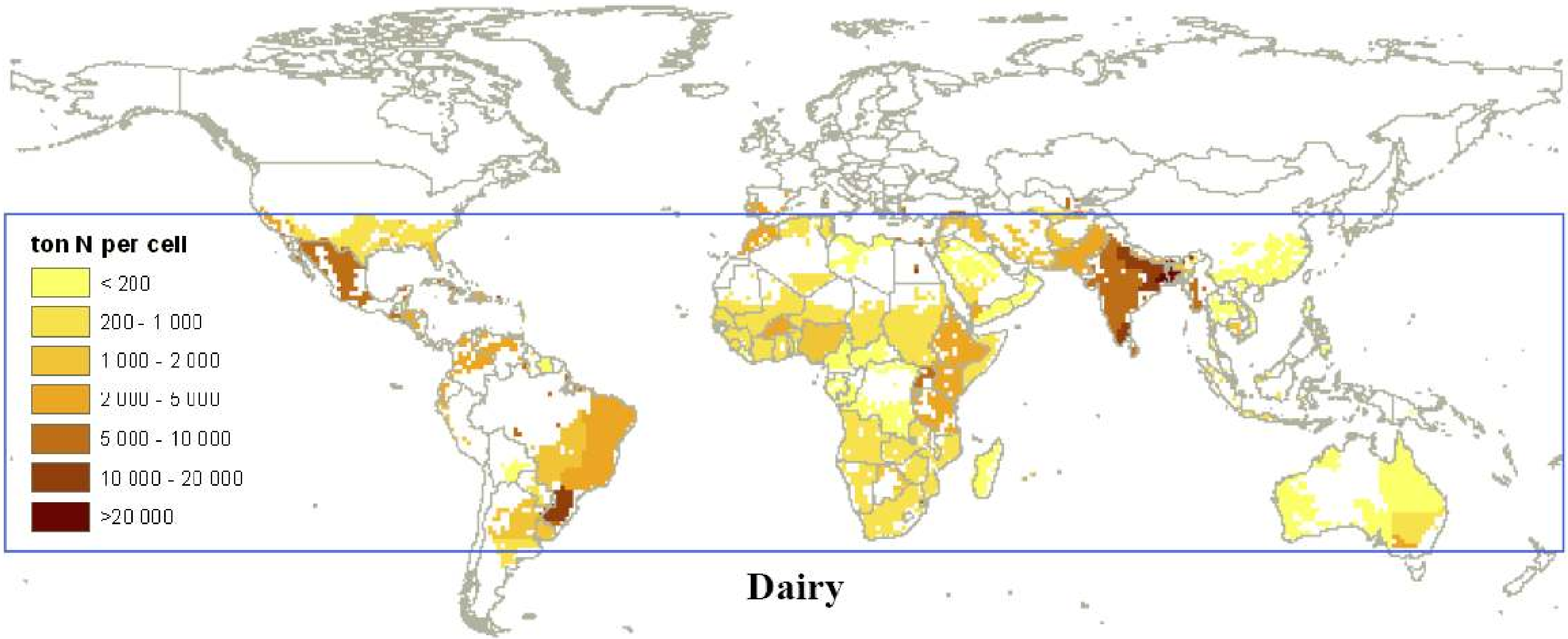
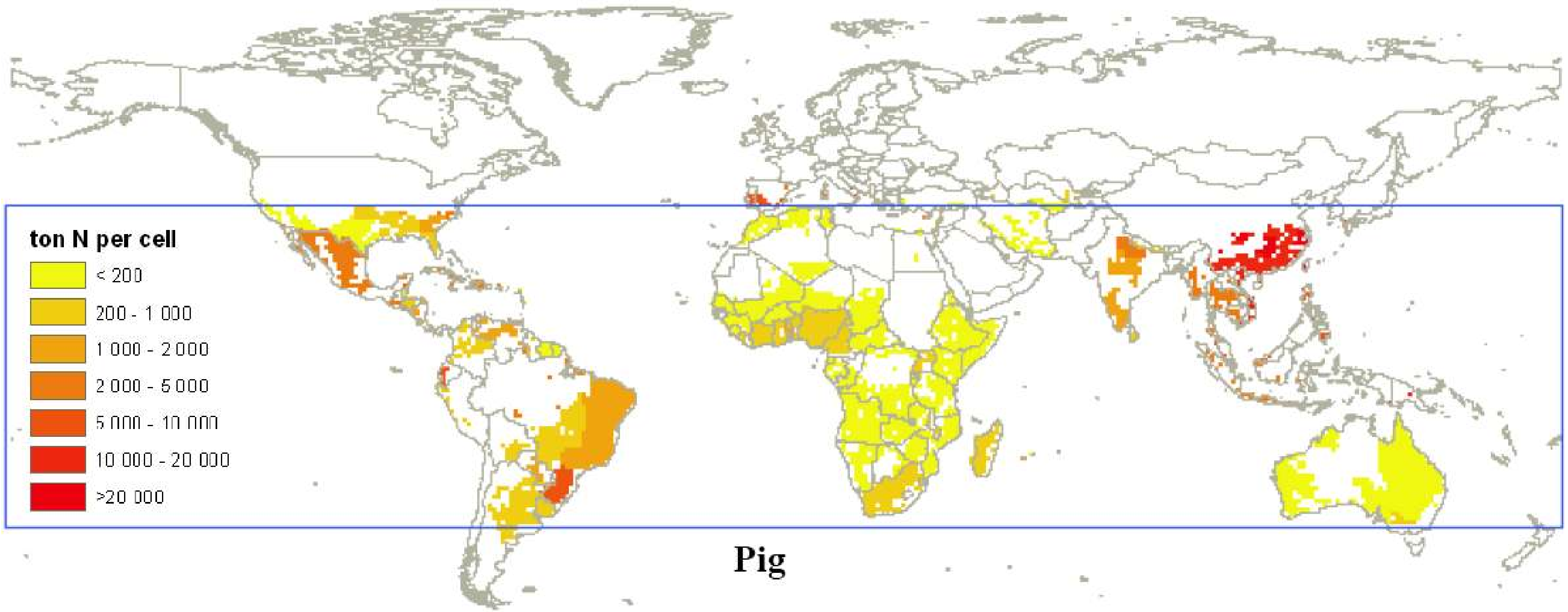
Suitable Climatic Areas



Dairy feedlot potential

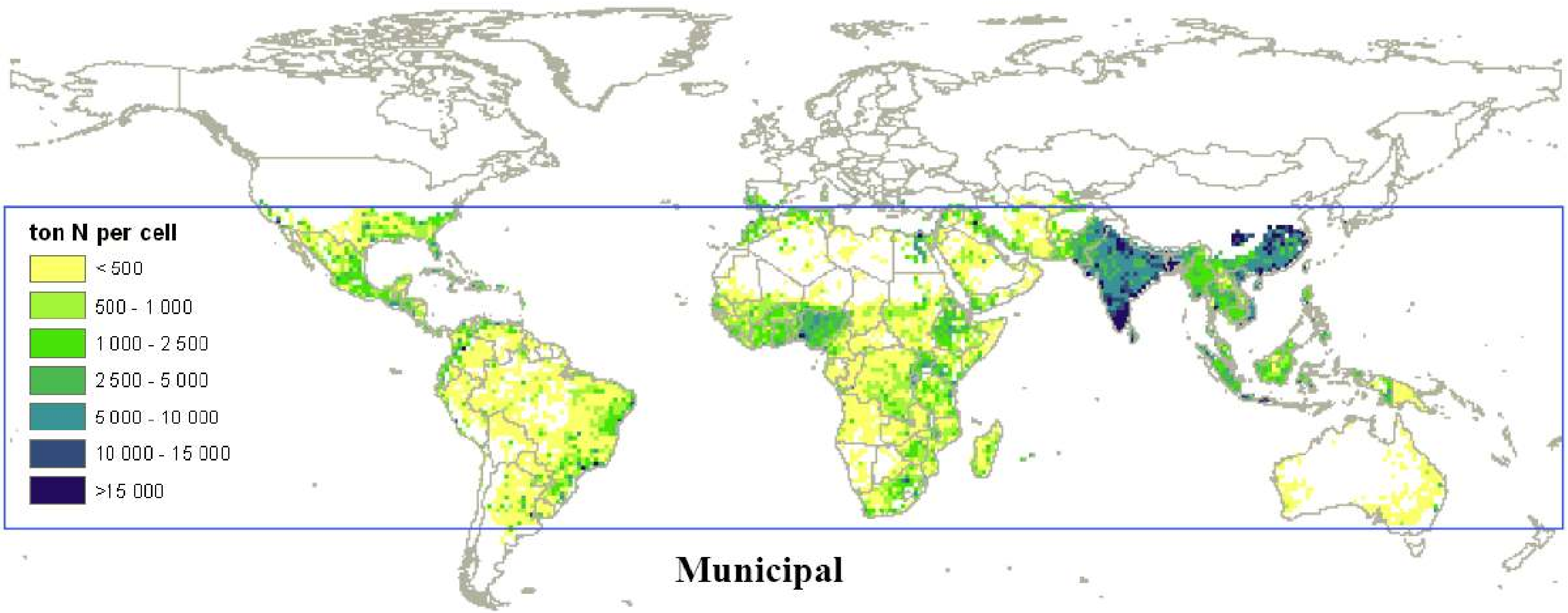


Pig feedlot potential



Pig

Municipal wastewater potential



Waste/water Potentials

- ESCAP countries with large wastewater or animal waste potentials:
  - **Southern China (wastewater, pig wastes)**
  - **Thailand (wastewater, pig wastes)**
  - **Indonesia (wastewater)**
  - **Malaysia (wastewater)**
  - **Philippines (wastewater, pig wastes)**

Theoretical resource potentials by 2020

Continent	Municipal wastewater [Mton algae]	Dairy cow wastes [Mton algae]	Pig wastes [Mton algae]	Total [Mton algae]
Africa	**28**	**31**	**3**	62
America	**20**	**46**	**23**	89
Asia	**84**	**53**	**56**	193
Europe	**2**	**3**	**3**	7
Middle East	**2**	**1**	**0**	3
Oceania	**7**	**2**	**2**	11
Total	142	137	87	366

Source: van Harmelen and Oonk (2006) "Microalgae biofixation processes"

Algae to Biodiesel Pathway

- **Selection of micro algae species** → **Growth of micro algae** → **Harvesting of micro algae** → **Extraction of oil from micro algae** → **Oil for processing into biofuel** → **BIODIESEL**
- **Harvesting of micro algae** → Waste liquor → **Further treatment to recover other valuable material?**
- **Oil for processing into biofuel** → **Residual micro algae** (*High protein content (up to 35%)*)
- **Residual micro algae** → **Dewatering and extrusion** →
  - Aquafeed
  - Animal feed
  - Pet feed
- **Residual micro algae** → **Extraction of protein** → Incorporate into human foods

Algal biomass yields

Reported algae biomass yields of field experiments, Aquatic Species Program

Project	Date	Algae species	Stable?	Sustained growth	Average yield ($g/m^2/day$)	Annual yield (MT/ha/yr)*
"Species control"	1976	Spirulina	no	NA	"not encouraging"	
		Oscillatoria	no	1 week	15	
Ryther	Late 70s	"Many"	no	no	too low	"below 50"
"Large scale"	1977-79	NA, pond 1	no	8 months (except winter)	13	[31,6]
		NA, pond 2	no	8 months (except winter)	13	[31,6]
		NA, pond 3	yes	1 year	12	43,8
		NA, pond 4	yes	1 year	14	51,1
Hawaii 1980-87	1981-82	Tricornutum	yes	2 months (winter)	3,3	
	1982	"	yes	2 months (spring)	11	
	1984-85	Tetraselmis cuecica	yes	78 days	37,5	
	1985-86	"	yes	NA	24	
	1986-87	"	yes	120 days	30	[54,75]
California 1981-86	1982	Mix (1)	no	2 days	5	
	1983-84	S.quadricuada	yes	8 months	15	[36,5]
		"	yes	10months (except winter	13,5	[41]
	1985-86	Cyclotella	no	21 days	28,1	
		"	no	33	29,6	
		"	no	10 days	35,2	
		"	no	10 days	27,6	
		"	no	6 days	28,2	
		"	no	12 days	26	
		Chaetoceros gracilis	yes	39 days	22,5	
		"	yes	39 days	25,6	
		"	yes	6 days	29,1	
		"	yes	6 days	26,9	
		Chlorella pyrenoidos	no	24 days	13,1	
		"	no	24 days	14,1	
		T.Suecica	yes	21 days	18	
		"	yes	17 days	20,3	
		Nannocloropsis	no	26 days	14,9	
		"	no	29 days	15,4	
		Amphora sp.	yes	20 days	30,5	
		"	yes	14 days	31	
		Chaetoceros sp.	yes	28 days	24,3	
		"	yes	28 days	22,6	
Ben-Amotz, Israel	1984-85	C.gracilis, N. atomus	yes	Summer month	40	
		"	yes	Winter month	20	
Negev, Israel	1984-86	N.Salina	yes	"Summer", optimal	24,5	
		Isochrysis galbana	yes	"Summer", optimal	28,1	
Technion Univ.,Israel	1984-86	I.Galbana	yes	One month	23,6	
OTF, New Mexico	1987	C.crytpica	yes	August	30	
		"	yes	September	15	
		"	yes	October	15	
		M.minutum	yes	November	10	
		"	yes	December	3,5	
	1988	S.Suecica	no	August	11	
	1989	M.minutum	yes	1 year	9,8	35,8
		"	yes	1 year	8,3	30,3
	1990	"	yes	1 year	10,5	38,3
		"	no	summer months	19	
		"	no	summer months	18	

37.5 $g/m^2/day$

137 T/ha/yr

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Bioreactors or Ponds

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Bioreactors or Ponds

Spirulina and *Haematococcus* Cultivation at Cyanotech Corp., Hawaii.
Spirulina: blue-green ponds; *Haematococcus*: orange-red ponds)

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Peel Inlet, Western Australia

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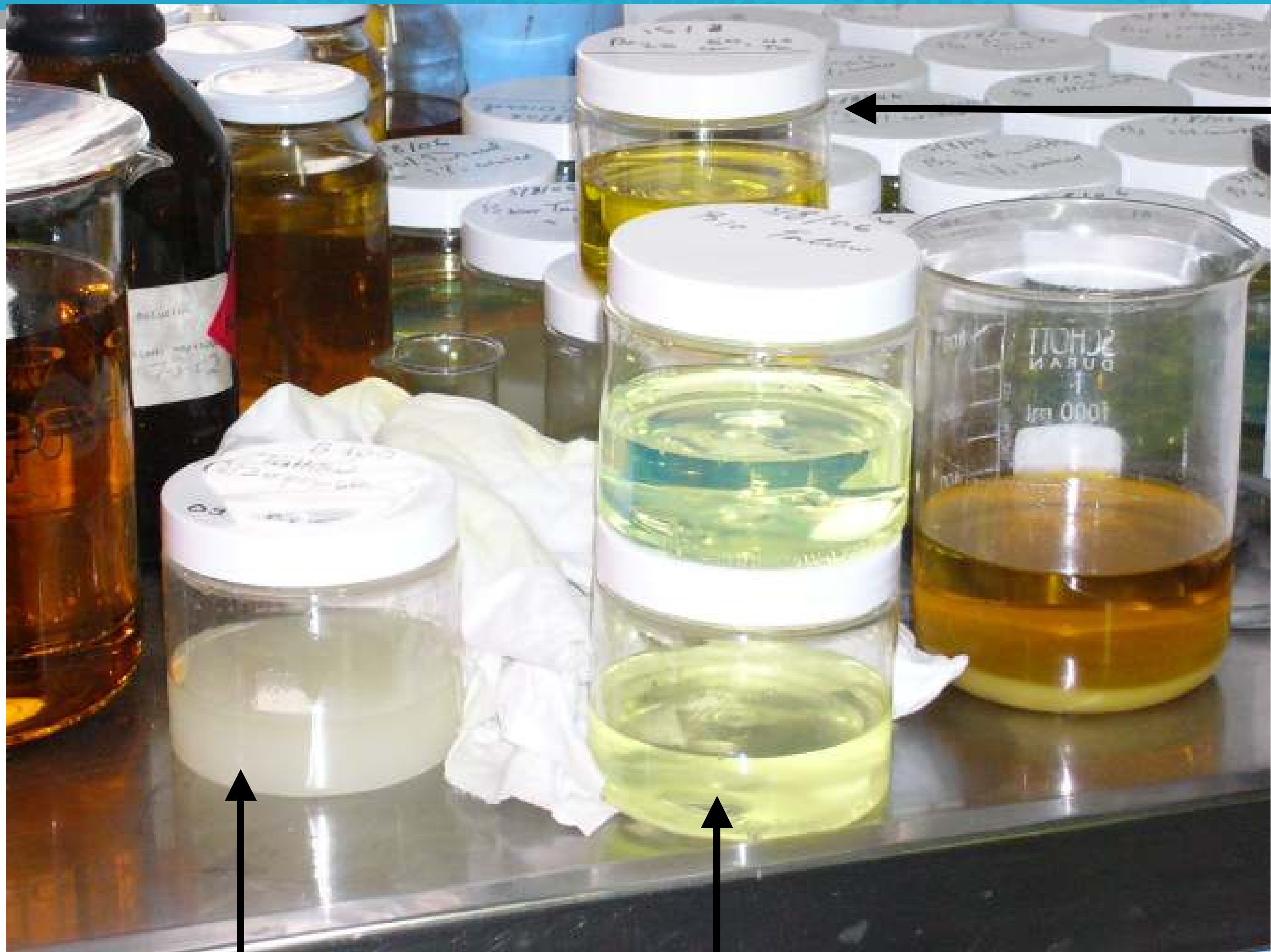
Peel Inlet, Western Australia

Peel Inlet, Western Australia

Biodiesel manufacture in WA (Picton)

Biodiesel manufacture in Darwin (NT)

Biodiesel from various feedstocks



B25
Canola

B100 Tallow

B10 Tallow

Fatty acid composition

Fatty acid	BDF from			Lipids from			
	Crude palm oil	Crude coconut oil		*Duniella maritima*	*Duniella salina*	*Chlorella vulgaris*	*Polytoma Oviforme*
Caproic acid, C8:0	-	7.42		-	-	-	-
Capric acid, C10:0	-	5.78		-	-	-	-
Lauric acid, C12:0	0.35	49.75		-	-		-
Myristic acid, C14:0	0.92	18.75		0.4	0.5	2.0	-
Palmitic acid, C16:0	44.11	8.60		11.8	17.8	19.6	39
Stearic acid, C18:0	4.36	2.65		0.4	1.5	3.3	3
Arachidic acid, C20:0	0.09	0.18		0	0	0	0
Sum of Saturated FA	**49.83**	**93.13**		**12.6**	**19.7**	**25.7**	**42.0**
Palmitoleic acid, C16:1	-	-		4.2	2.5	8.8	2
Oleic acid, C18:1	38.97	5.53		2.5	3.4	7.3	31
Linoleic acid, C18:2	11.21	1.26		4.1	6.1	11.8	5
Linolenic acid, C18:3	-	0.07		45.8	39.4	22.6	8
Sum of Unsaturated FA	**50.18**	**6.86**		**87.4**	**80.3**	**74.3**	**58**

Sums for algae include other fatty acids

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Thank you

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