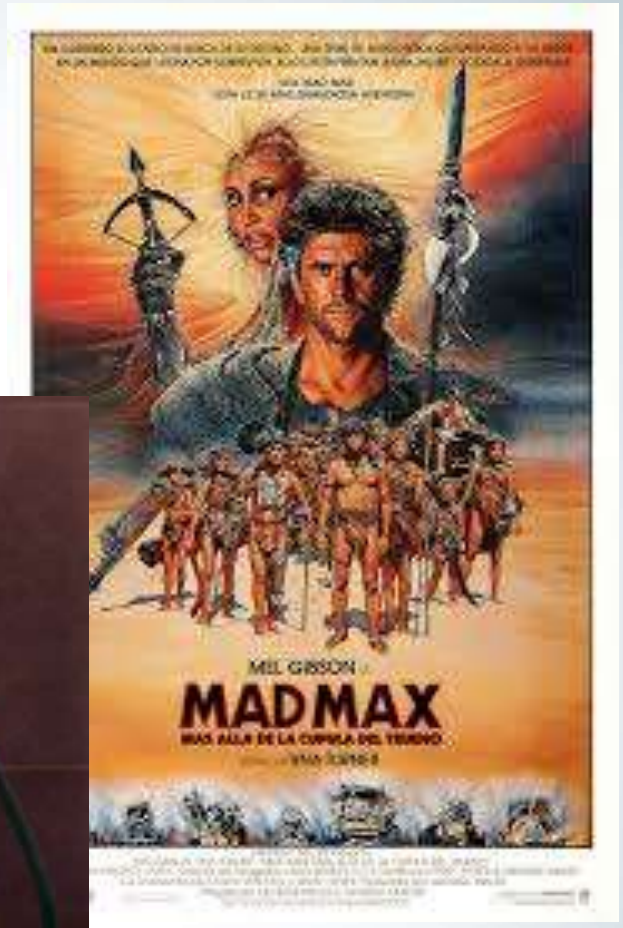
EU FP 7 Project All-gas:

Large Scale Production of Algae Biofuel From WasteWater

Frank Rogalla
Director of Innovation
Madrid
aqualia

Science fictión… to Reality

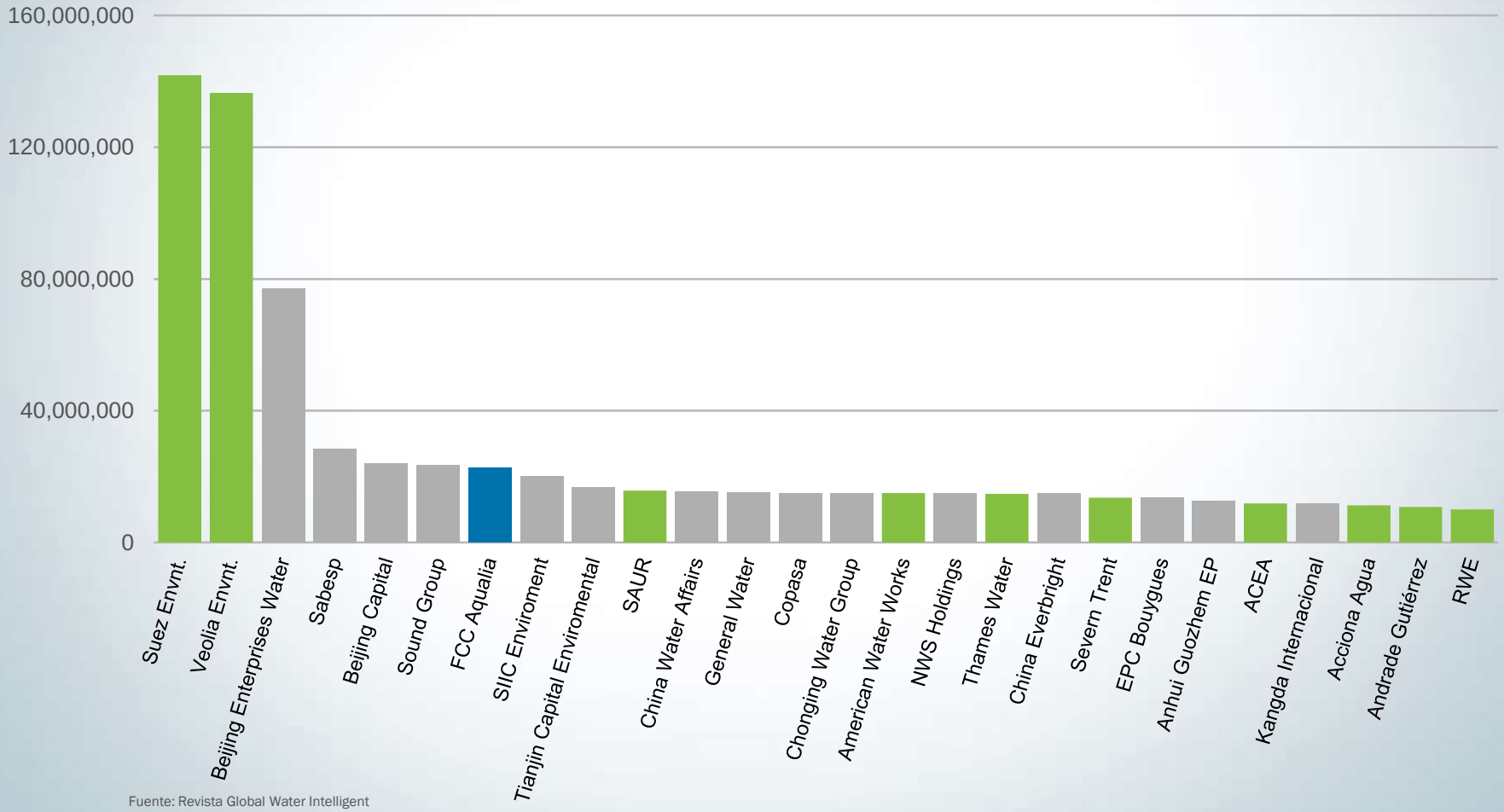


STEVEN SPIELBERG presents

BACK TO THE FUTURE

Global Water Companies (2016: Millions of Consumers)

FCC Aqualia
1000 M €/yr
8000 people



Fuente: Revista Global Water Intelligent

Wastewater Treatment

Directive 91/271/CEE // Directive 98/15/CE

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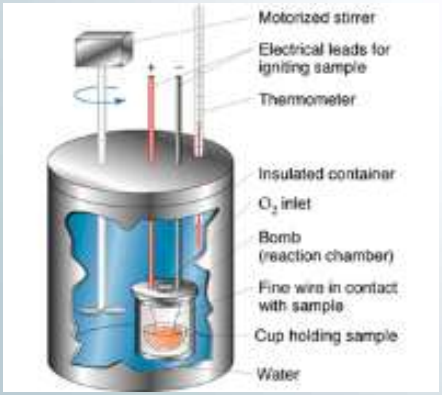
Biological Oxidation with Activated Sludge (Manchester, 1914) : 0,5 kwh /m3

To treat WW from 500 M people in Europe: 2000 MW

Aqualia: 500 000 000 m3/d (10 M people)
= 25 M € in Electricity



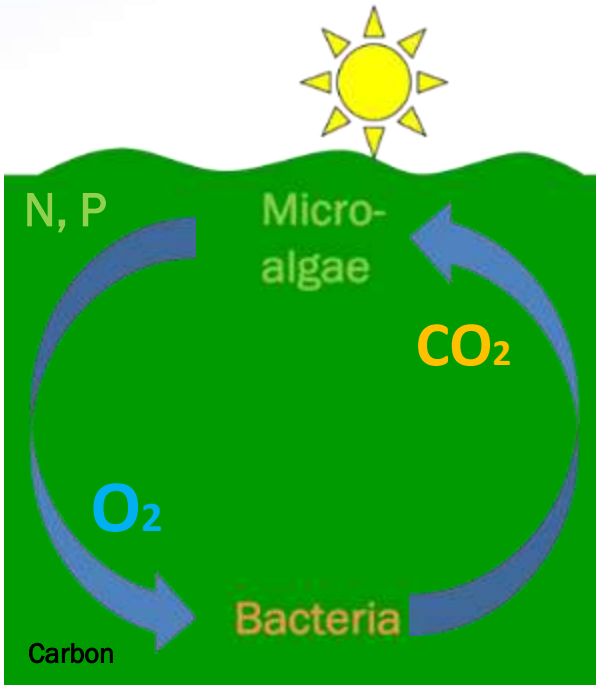
Potential energy content of urban WW is typically 500 mg COD/l x 4 Kwh/kg COD

~ 2 kWh_{th}/m^3 (0.7kW_{el}/m3)

N fixation Haber-Bosch Process 10 kWh/kg N

Free source of O2 and CO2: Symbiosis: Algae - Bacteria

Wastewater rich in fertilizer (C, N, P)



Biomethane

Water Re-use

Bio-fertilizers

Images: Shutterstock

FP7 All-gas

Symbiosis
Bacteria
CO2

ABAD ®

>65% CH_4

Biofertilizers
(high N and P)

CNG quality for
fleet vehicles

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Mean Temp (oC)	12	13	15	17	19	24	25	26	22	20	15	13	18.4
Precip (mm)	50	56	68	35	16	1	1	11	12	44	82	75	451

All-gas: From Dream to Design to Demo

Basic research

2010

Pilot plant

200 m2

2011

Prototype

2 x 500 m2

2014

Biomethane

2016

First kg of BIO-CH4 produced in June 2016

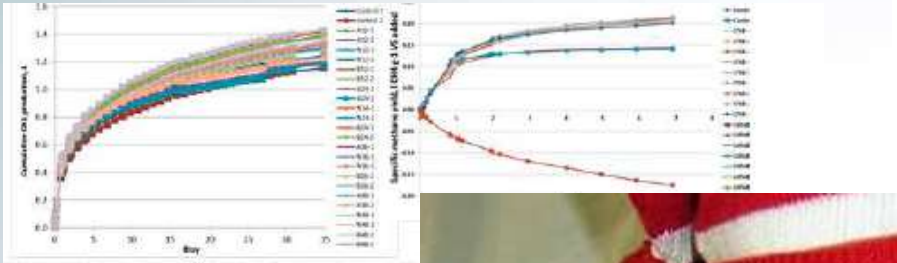
Full Scale

4 x 5200 m2

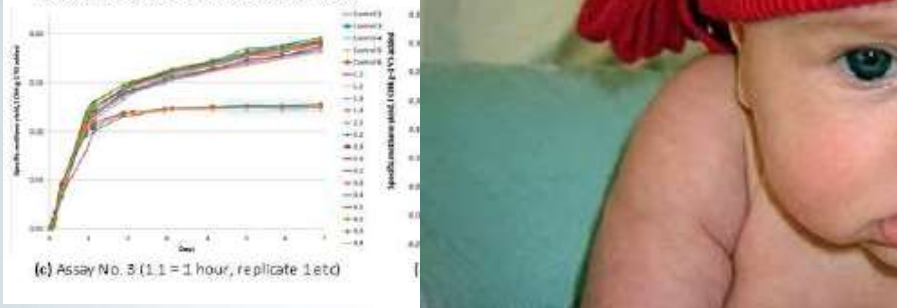
2017

Chiclana WWTP

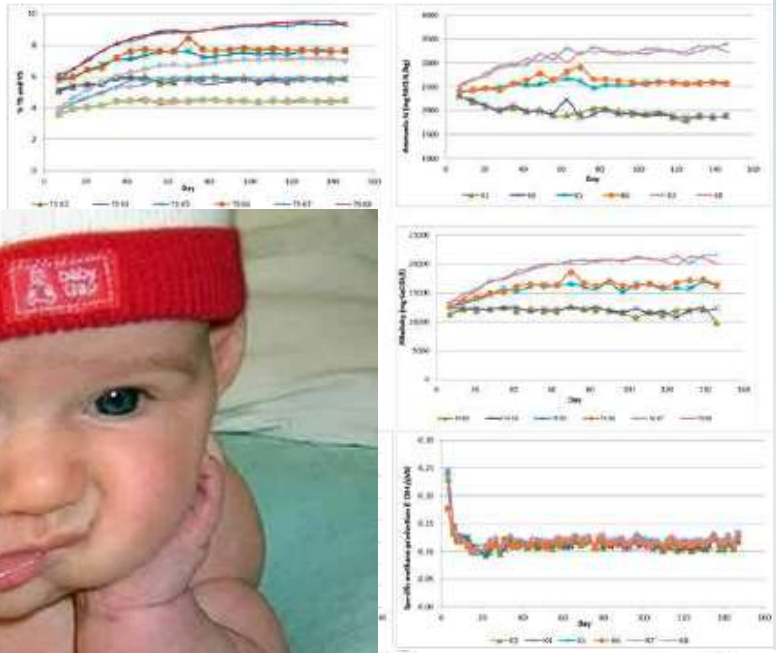
Results on many scales and years…. Species, productivity, water quality + disinfection… fuel upgrading

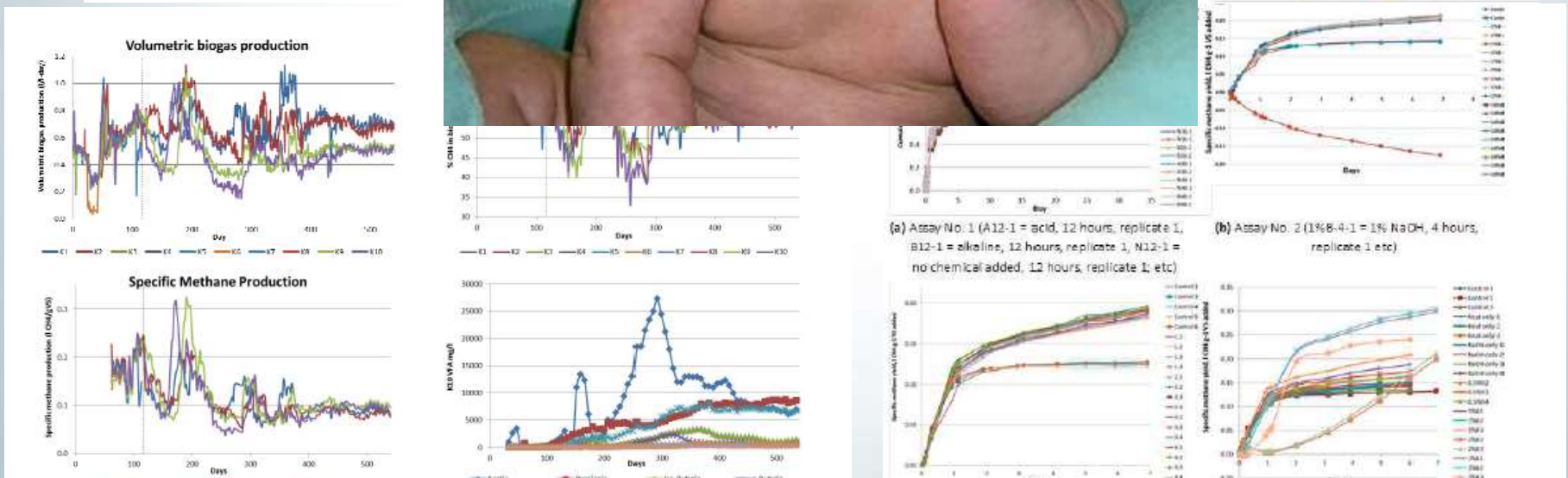


(a) Assay No. 1 (A12-1 = acid, 12 hours, replicate 1, B12-1 = alkaline, 12 hours, replicate 1, N12-1 = no chemical added, 12 hours, replicate 1; etc)



(c) Assay No. 3 (1.1 = 1 hour, replicate 1 etc)



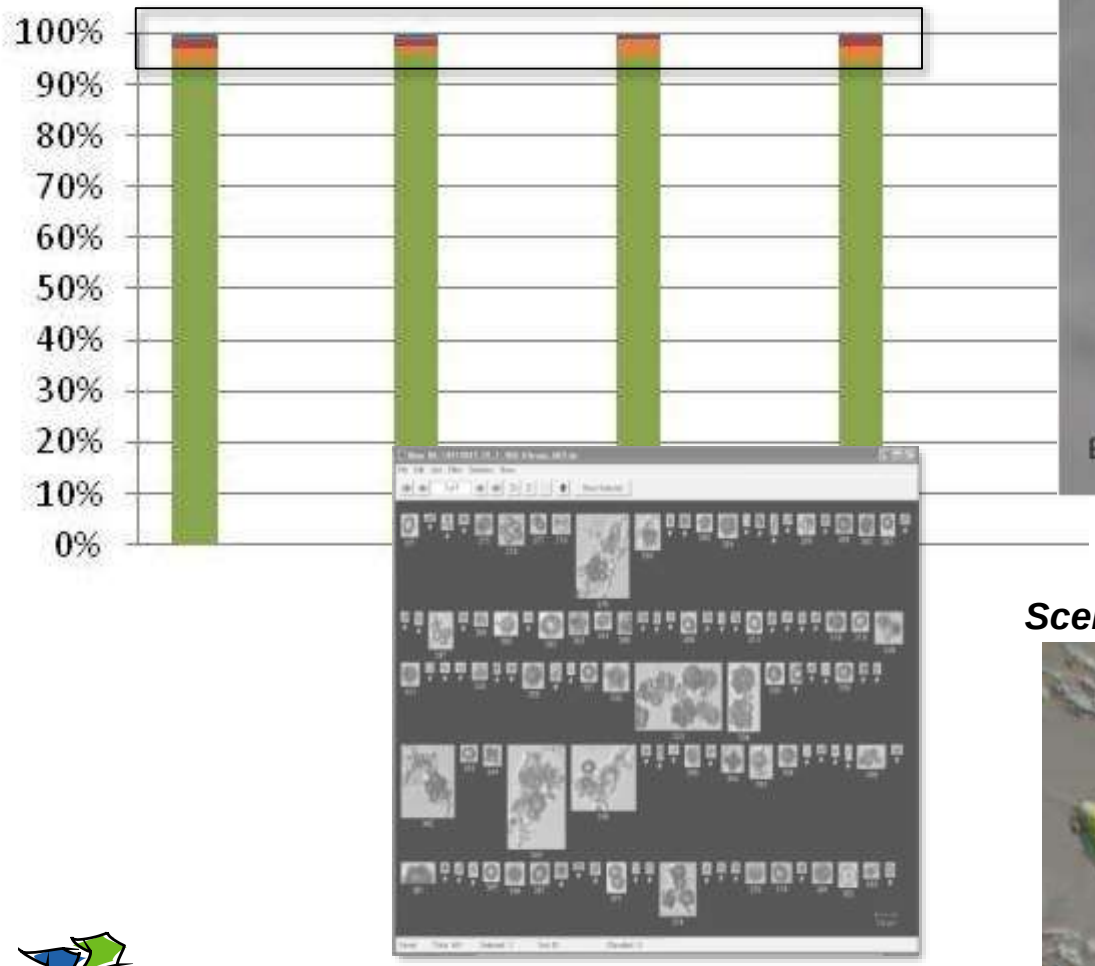


(a) Assay No. 1 (A12-1 = acid, 12 hours, replicate 1, B12-1 = alkaline, 12 hours, replicate 1, N12-1 = no chemical added, 12 hours, replicate 1; etc)

(b) Assay No. 2 (1%8-4-1 = 1% NaOH, 4 hours, replicate 1 etc)

Pilot plant: operation (18 mo)

Strain stability & control



Coelastrum

Navícula sp.

Scenedesmus ellipsoideus

Pond Mixing Options

PADDLE WHEEL

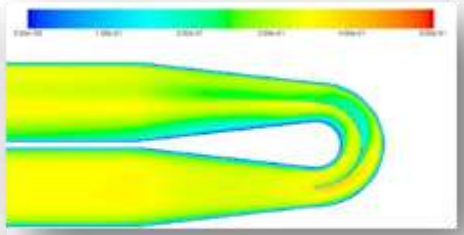
-Total **energy efficiency**:
~5% U. Florence
<17% Borowitza
~30% Weissmann
-**High head losses** (bends)
-**Dead zones**

SLOW SPEED SUBMERBILE BOOSTER

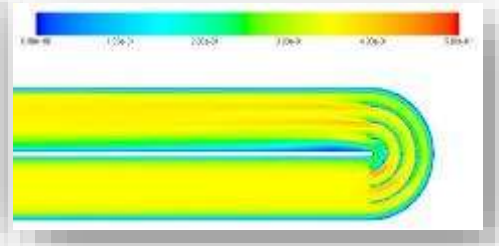
-Flow makers for many wastewater applications (carrousels)
-High propeller efficiency (mixing power/power consumption) ~ 80%
-Self cleaning properties
-Can be raised for inspection
-Gentle operation (<100 rpm)

Optimisation of Pond Mixing: Low Energy Algae Reactor

- **Energy consumption determination by CFD analysis and validation with 500 m2 raceways: Paddle wheel and LEAR in parallel.**



AQUALIA: LEAR

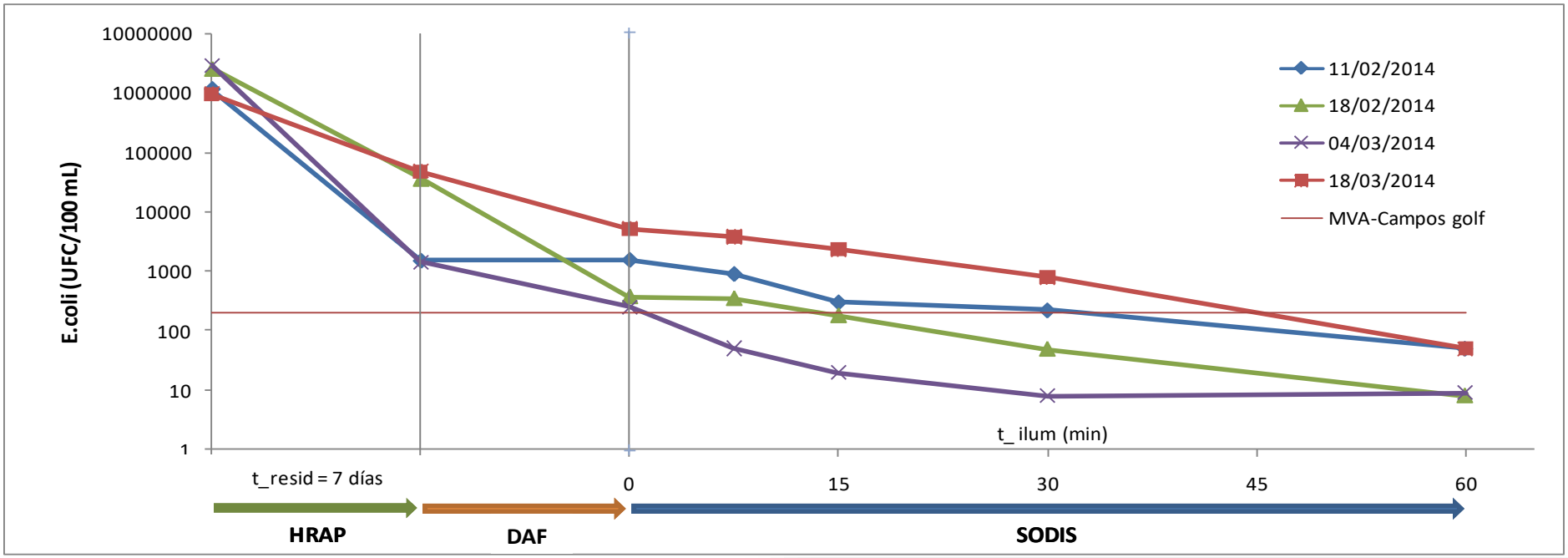


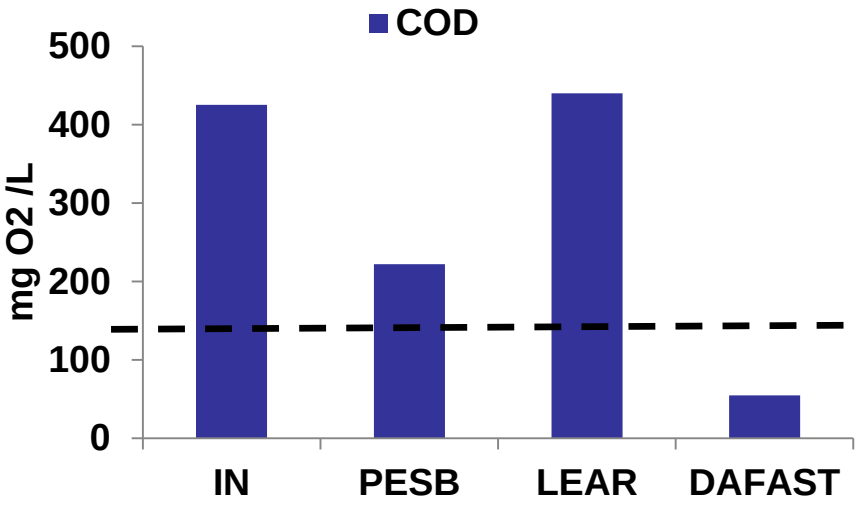
CONVENTIONAL PW RACEWAY

Energy use reduction:
80 % to paddle wheel
y 90 % to activated sludge

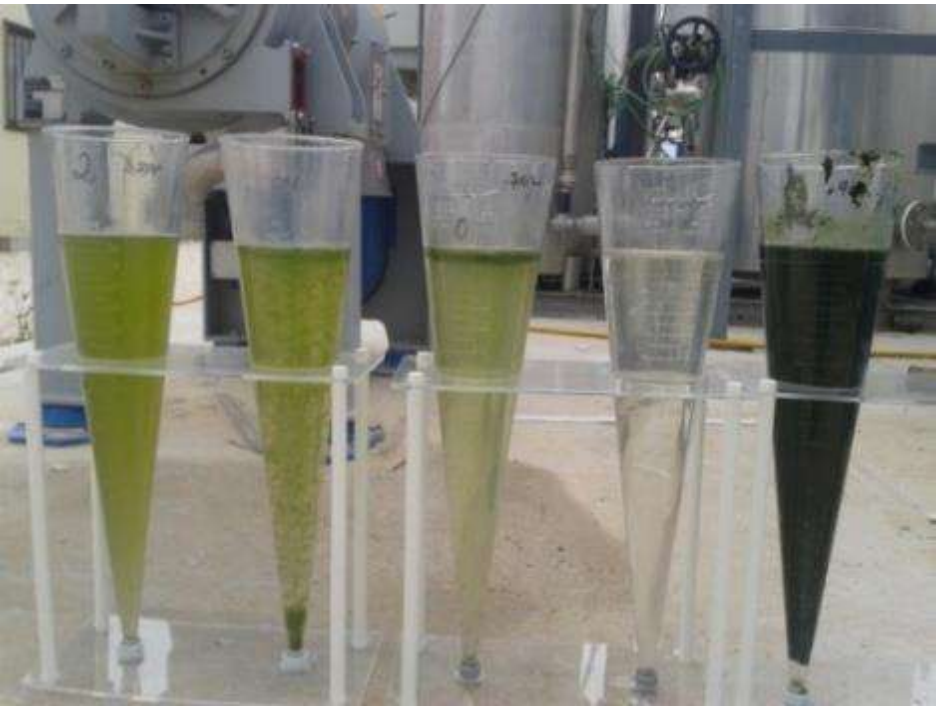
	Electricity Wh/m2	Electricity [kWh/m3]
Activated sludge (Aeration)		0.400
HRAP mixing PADDLE WHEEL	0.6	0.150
HRAP mixing SUBMERSIBLE BOOSTER	0.1	0.025

Algae cultivation : Water Quality Results





Algae Harvesting and Thickening with DAFAST

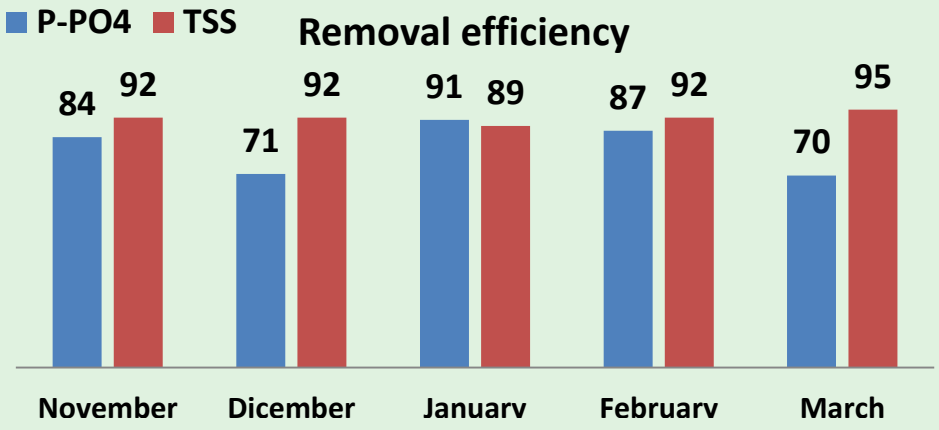


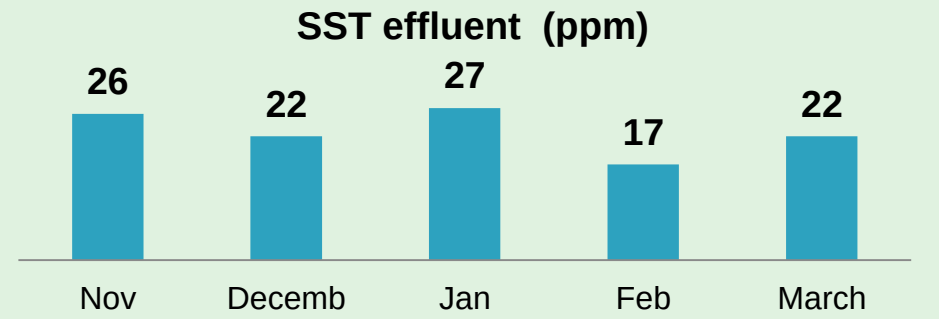
(*)

From algae culture of 400 ... 500 mg/l
To digestor feed
40 to 50 g/l

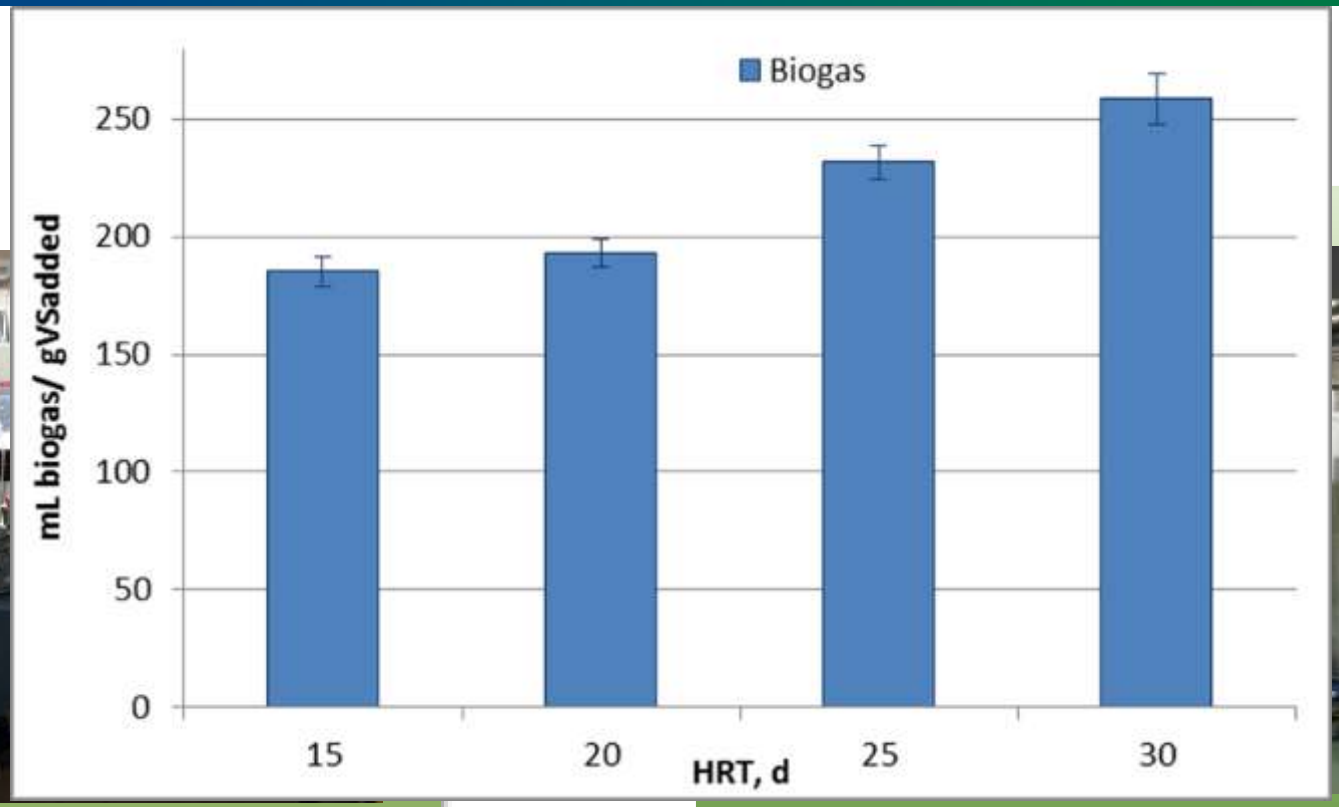
DAFAST Flotation Thickening

Chemical consumption	*Electricity consumption*
Coagulation 10ppm Al2O3	0.03 KWh/m3
+	
Floculation 1.5 ppm Polymer	
+	
DAFAST	





ALGAE-BACTERIA ANAEROBIC DIGESTION



LAB REACTORS
8X 5 L

- MESOPHILIC.
- THERMOPHILIC.
- CODIGESTION
- TPAD
- THERMAL HYDROLYSIS

PILOT PLANT
ALGAE DIGESTERS
2X600 L, 1 x 1500 L

- MESOPHILIC.
- THERMOPHILIC.
- THERMAL HYDROLYSIS

aqualia Southampton HYGEAR BDI Fraunhofer

	Methanol	Propan-2-ol	Diethyl ether	Petroleum ether	n-Hexane
Lipids [% w/w]	15,8	6,6	2,9	1,9	2,9
ε_r	32,63	18,30	4,34	2,00	1,89
Lipids in AFDW [%w/w]	19,7	8,2	3,6	2,4	3,7

Figure 100. IKAfex extration

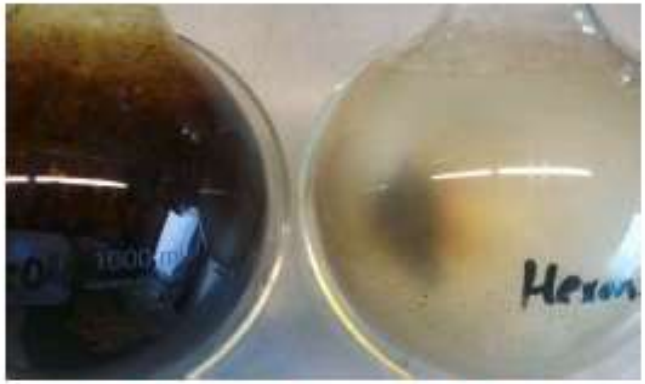


Figure 101. Fouling of methanol extract (left) and hexane extract (right)

Fatty acid	Acronym	Unit	Algae biomass
Dodecanoic acid	C12:0	%	1.2
Tetradecanoic acid	C14:0	%	3.6
Pentadecanoic acid	C15:0	%	4.4
Hexadecanoic acid	C16:0	%	29.9
Hexadecenoic acid	C16:1	%	15.8
Hexadecadienoic acid	C16:2	%	1.3
Hexadecatrienoic acid	C16:3	%	4.5
Octadecanoic acid	C18:0	%	3.4
Octadecenoic acid	C18:1	%	15.1
Octadecadienoic acid	C18:2	%	4.9
Octadecatrienoic acid	C18:3	%	13.6
Nonadecanoic acid	C19:0	%	2.2

Table 43. Fatty acid profile of algae biomass

The algae-FAME sample was measured according EN 14214.

Property		Unit	Limits	Test method
Visual inspection	clear and bright free from visible particulate matter			ASTM D 4176
Ester-content	97.1	% (m/m)	≥ 96.50	EN 14103
Density at 15°C	879.1	kg/m³	860 – 900	EN ISO 12185
Kinematic viscosity at 40°C	4.058	mm²/s	3.5 – 5.0	EN ISO 3104
Flash point	150.5	°C	≥ 101	EN ISO 2719
Sulphur content	97	mg/kg	≤ 10.0	EN ISO 20846
CFPP	+1	°C		EN 116
Cloud point	+3	°C		EN 23015
Derived Cetane number	49.6		≥ 51	EN 16715
Sulphated ash content	< 0.001	% (m/m)	≤ 0.02	ISO 3987
Water content	300	mg/kg	≤ 500	EN ISO 12937
Total contamination	5	mg/kg	≤ 24	EN 12662
Copper strip corrosion 3 h at 50°C	1a	rating	class 1	EN ISO 2160
Oxidation stability at 110°C	8.2	hours	≥ 8.0	EN 14112
Neutralization/Acid number	0.50	mg KOH/g	≤ 0.5	EN 14104
Iodine number	114	g/100g	≤ 120	EN 14111
Linolenic acid methyl ester	11.2	% (m/m)	≤ 12.0	EN 14103
Polyunsaturated (≥ 4 double bonds) methyl esters	0.06	% (m/m)	≤ 1	EN 15779
Methanol content	<0.01	% (m/m)	≤ 0.20	EN 14110

Fatty acid	Result	Unit
C 16:4	3.4	Area%
C 17:0	1.1	Area%
C 17:1	1.5	Area%
C 18:0	4.2	Area%
C 18:1 c & t	25.5	Area%
C 18:2 cis	5.1	Area%
C 18:2 trans	4.6	Area%
C 18:3 n9	0.3	Area%
C 18:3 n3	11.9	Area%
C 20:2 n6	0.5	Area%
C 15:1	0.1	Area%
C 16:0	19.1	Area%
C 16:1	6.9	Area%
C 16:2	1.1	Area%
C 16:3	1.8	Area%

All-gas Demo ponds – Fase 1: 2 ha

Cultivation Area: 4 X 5200 m2
WW Capacity: 2000 m3/d
Productión: 200 Ton /ha/ yr
Biogas yield: 30,000 kg/yr

All-gas Chiclana Demo

HYGEAR

All-gas

Potential:
1 hectare cultivation

5000 PE
Simultaneous TN, TP, COD and TSS
Below limits directive 91/271/EC

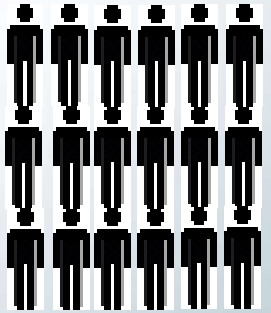
>1€/kg?¿

1000 m3/d WWT

950 m3/d reuse

0,3 kWh/m3 energy saving

106.800 kWh/year = 20 persons



100 Ton/ year

50-60% VS

13,000 kg CH4/yr

40-60 Ton/ year biomass

Do algae systems provide more usable energy than they consume?

- **EROI: Relation of primary energy supplied to primary energy used in process**

$$EROI_{BM} = \frac{EC_{BM} + EC_{CP}}{E_{BM}} = \frac{LHV_{BM} * \rho_{BM} + EC_{CP}}{E_{BM}} = 3{,}96$$

EC_{BM}: energy content of biomethane
EC_{CP}: is the primary energy of the co-products fertilizer and water purification
E_{BM}: direct and indirect energy required to produce biomethane

→ **The system produces four times more usable energy than it consumes**

Fraunhofer UMSICHT

From ~~Science fictión~~_ to REALITY

FP 7 All-gas (Chiclana)

Kilómeters covered:

2016: 30.000 km

2017: 150.000 km

2018: 250.000 km

2019: > 400.000 km

FLEET DEMO:
REAL DRIVING EMISSION TEST (RDE)

70% Rural
30% Motorway

Figure 2: SEAT LEON at the gas station

30% Urban
30% Rural
70% Motorway

Figure 3: SEAT IBIZA at the gas station

40% Urban
60% Rural

Figure 4: Volkswagen CADDY at the gas station

Comparison… Biofuels in 1 hectare

Biodiesel

5,000 liters
/Hectare per year
(5L/100km)
5 vehicles / ha

No arable land
No fresh water
No artificial fertilizers

13,000kg CH4
/Hectare per year
(4kg CH4/100km)
> 20 vehicles

Bioethanol

5,000 liters
/Hectare per year
(5L/100km)
5 vehicles / ha

Images: Shutterstock

Energy reduction directly related to wastewater treatment from 0,5 to 0,2 kWh/m3
→ 0,3 kWh/m3 X 1000 m3/d X 365d =
> 105, 000kWh/yr

EU Marginal Land
8.5 M ha =
850 000 000 km2
= 170 M vehicles

Spain
32 Million Vehicles
506 000 km2 (50 M ha)

Belgium
30 500 km2 (3 M ha)

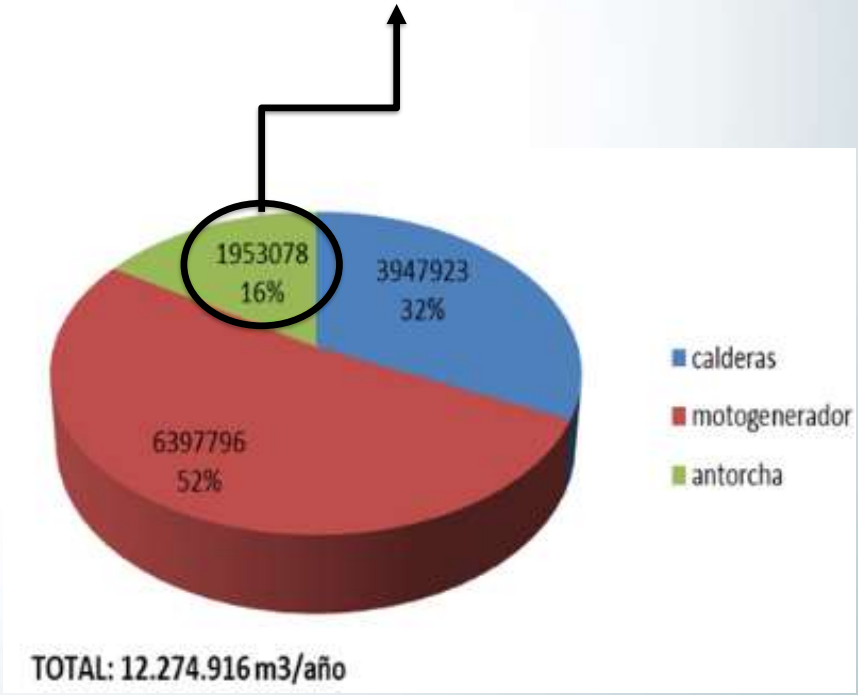
Andalucía
87 000 km2 (8,7 M ha)


GASINERA EDAR LA GAVIA
Biogás Vehicular
a partir de Agua Residual
ABAD Bioenergy
aqualia
All-gas
COLTRI
CNG
Canal de Isabel II
PEUGEOT
0848 KMT

Aqualia Digestion Units
> 20 WWTP plants

Potential
18 M Km/año =
2000 coches …

Reduce Waste of Energy in WWTP



ABAD Bioenergy®

Presently 15 vehícles of aqualia work exclusively with biomethane

EDAR La Gavia (Madrid). 2018
- Capacidad de 1 Nm³/h biometano

Demo 3 y 4

Demo 2

Demo 1

Industrial Prototype

First Test of concept

SCALIBUR
LEADING A REVOLUTION IN BIOWASTE RECYCLING

República Checa. 2020

Guijuelo (Salamanca) 2019

ADVISOR

Chiclana (Cádiz). 2018
- Capacidad de 10 Nm³/h biometano

EDAR Lleida. 2019
- Capacidad de 10 Nm³/h biometano

Jerez (Cádiz) Depuradora de Guadalete. 2016
- Biogas real. Capacidad: 4,5 Nm³/h biometano
- Validación con dos vehículos SEAT

SMART green gas

Chiclana (Cadiz) EDAR El Torno. 2014
- Capacidad de 1 Nm³/h biogas
- Unidad de afino experimental

All-gas

2020:
Valdebebas (CYII)
Almeria (Life)

NEW Challenges

INCOVER
Innovative Eco-Technologies for Resource Recovery from Wastewater

All-gas

SABANA

biosol
water recycling

All-gas

Southampton Fraunhofer HYGEAR BDI