Energy recovery through the anaerobic digestion of the residual **microalgae** biomass from a biodiesel production process

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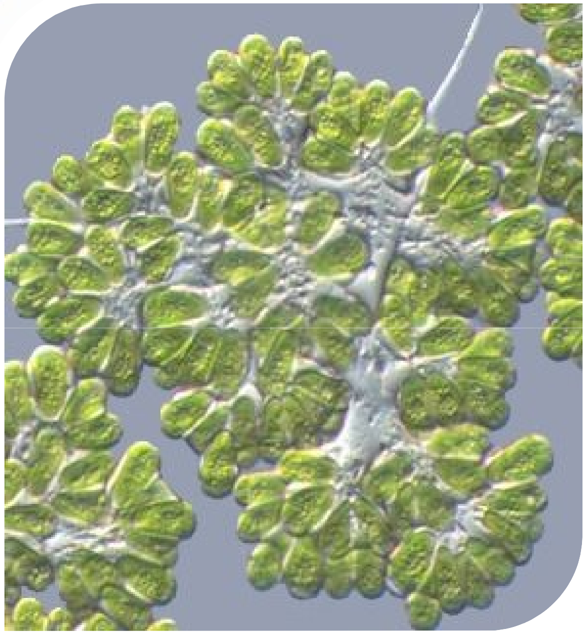
¿WHY MICROALGAE?

- Efficient solar conversion
- High biomass productivity
- High lipids accumulation
- No competition with lands for food production



PRODUCING BIODIESEL…

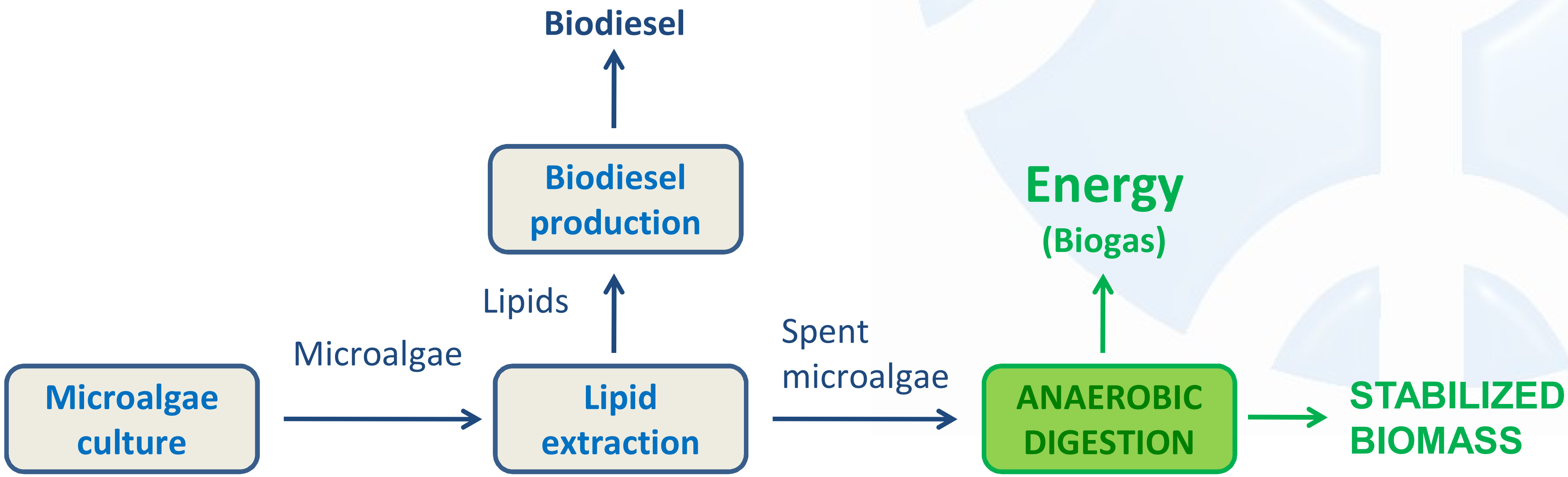
- High nutrients requirements
- High energy demands.
- Low energetic yield

PRODUCING BIOGAS…

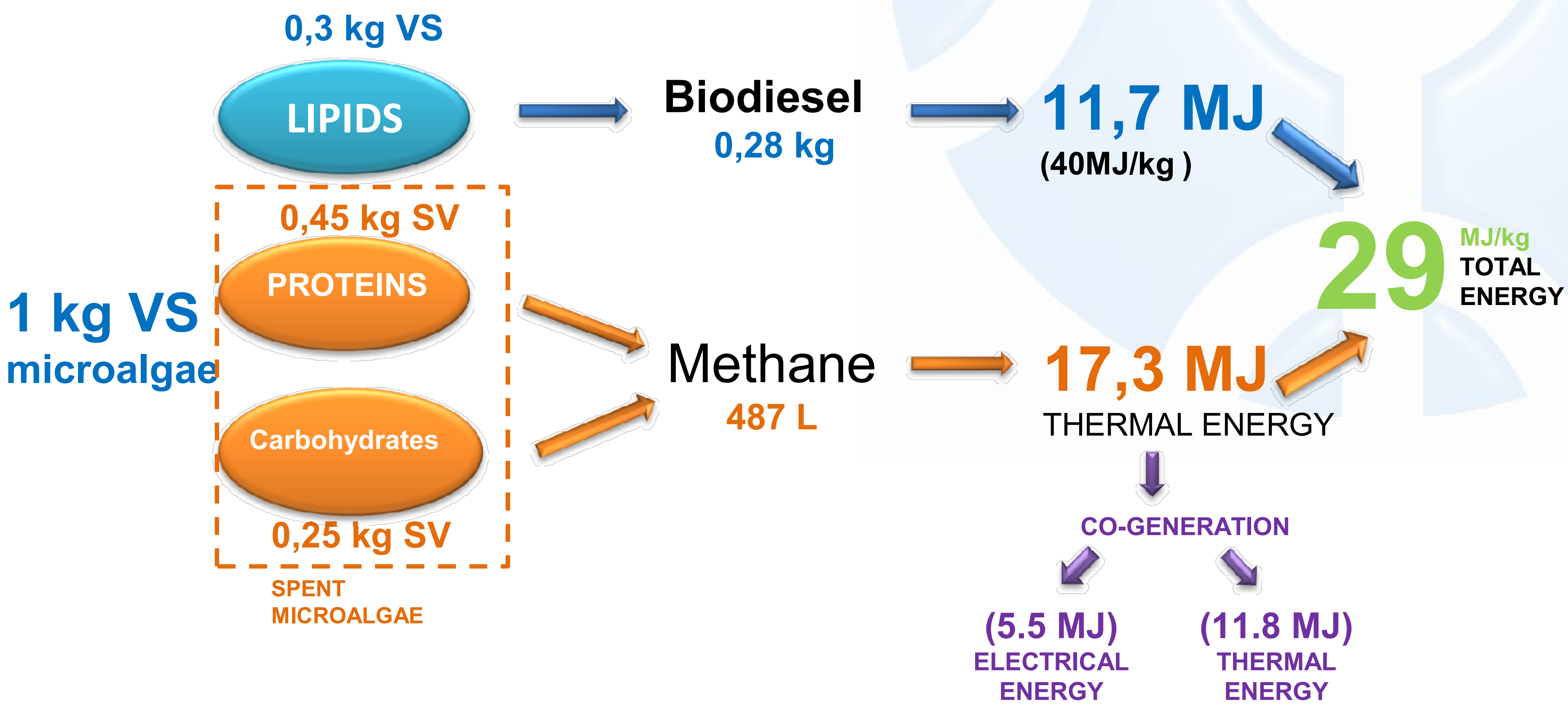
- Energy recovery from spent microalgae
- Tool for recovery and recicle nutrients
- Co-generation for eletrcial and thermal supply in others process

Considering

biodiesel and biogas production …



TAKE INTO ACCOUNT THE ENERGY...



1 How much **BIOGAS** Can be produced by **AD**?

2 How much **ENERGY** Can be recovered by **AD**?

3 can **BIOGAS** supply energy requirements of **Biodiesel**? Process

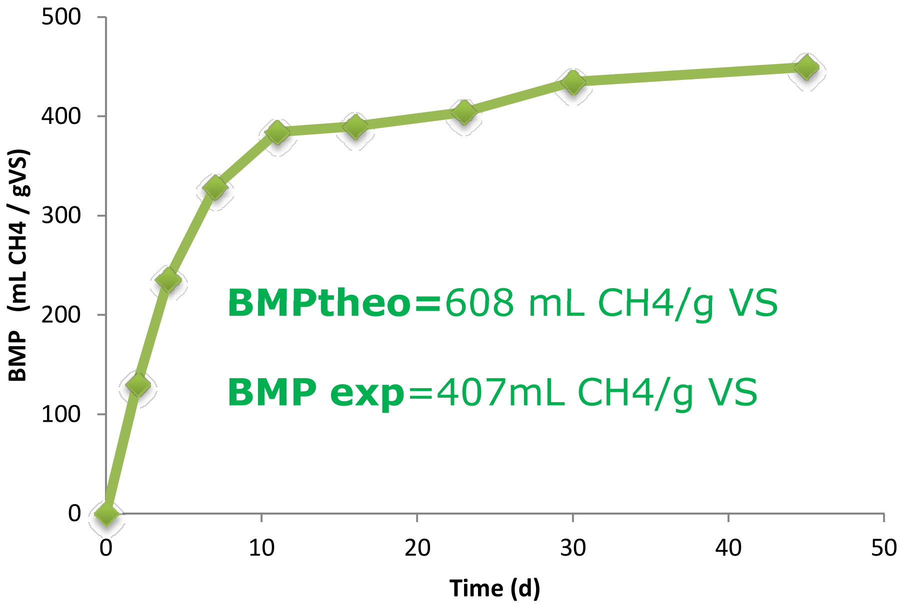
1 How much **BIOGAS** Can be produced by **AD**?

Table I. Spent microalgae characterization (*B. braunii* and *N. gaditana*).

	Spent *B. braunii*	Spent *N. gaditana*
Proteins (%)	46.0	47.7
Nitrogen (%)	7.4	7.6
Lipids (%)	2.7	2.9
Ash (%)	23.9	10.8
Crude fiber (%)	5.1	1.2
Carbohydrates (%)	22.3	37.5
Phosphorus (%)	0.8	1.2
SV/ST (g/g)	0.75	0.82
COD/SV (g/g)	1.60	1.63

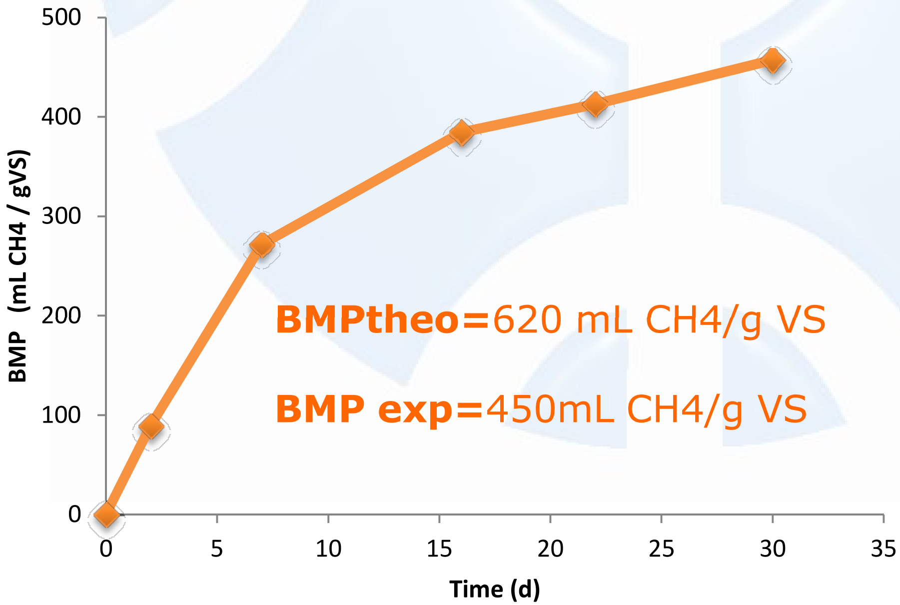
1 How much BIOGAS Can be produced by AD?

Botryococcus braunii



Biodegradability=
67%

Nanochloropsis gaditana



Biodegradability=
73%

2 How much ENERGY Can be recovered by AD?

Lipid content: 25%
Methyl-able fraction: 50%

Table III. Parameters to calculate energy distribution of microalgae *B. braunii* and *N. gaditana*.

Parameter	*B. braunii*	*N. gaditana*	Reference
	Biodiesel		
Lipid content in total microalgae (% of VS)	24.4	24.6	Proximate analysis
[1]Lipid extraction efficiency (%)	88.5	89.6	This research
Methyl-able fraction of neutral lipids (%)	50		[24]
Biodiesel yield (g biodiesel/g methyl-able lipids)	0.95		[34]
Lipid heat combustion lipids (kcal/g)	9		
Biodiesel heat combustion (MJ/kg biodiesel)	40		[35]
	Biogas		
[2]Fractivulgaris on of spent microalgae (%)	79.16	78.65	This research
BMP (mL CH_4/g VS) (From this research)	407	450	This research
Methane heat combustion (MJ/m^3 CH_4)	35.6		[6]

Notes: [1]Computed based on initial and final lipid content in microalgae; [2]Computed considering mass balance of total microalgae and extracted lipid.

2 How much ENERGY Can be recovered by AD?

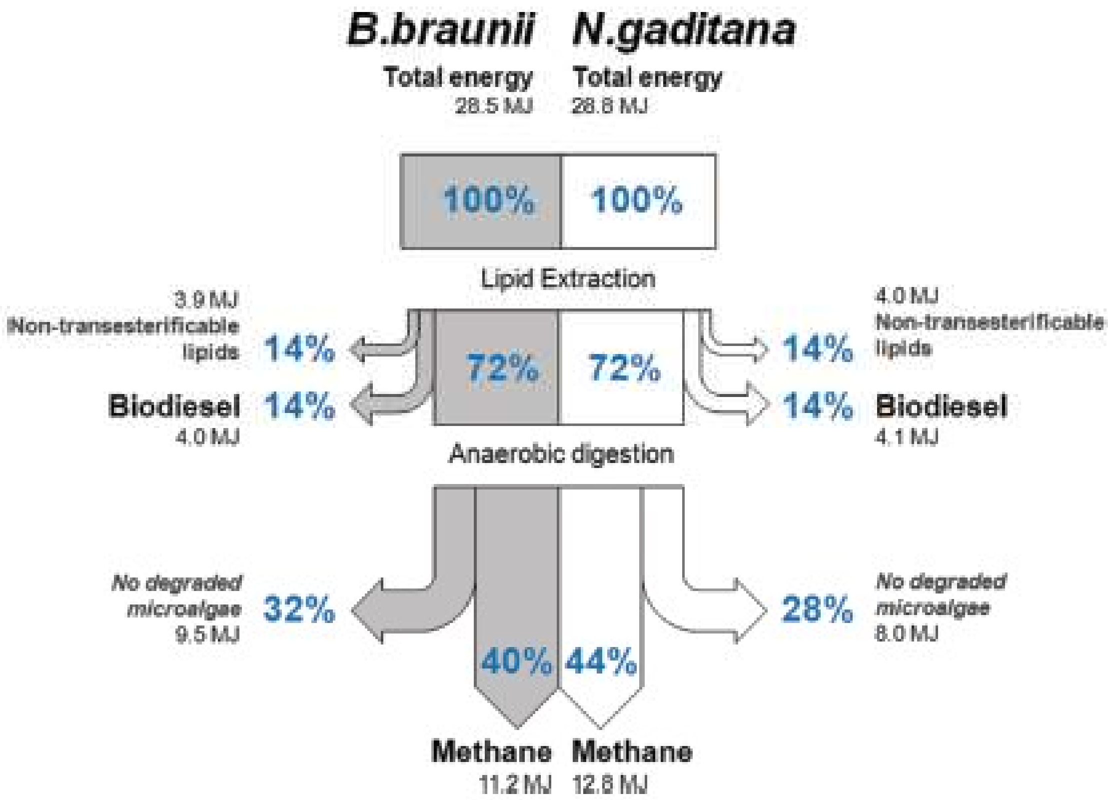


Fig. 4. Energetic distribution of *B. braunii* and *N. gaditana* through biodiesel and anaerobic digestion processes. Results were calculated considering 1 kg VS calculation basis.

3

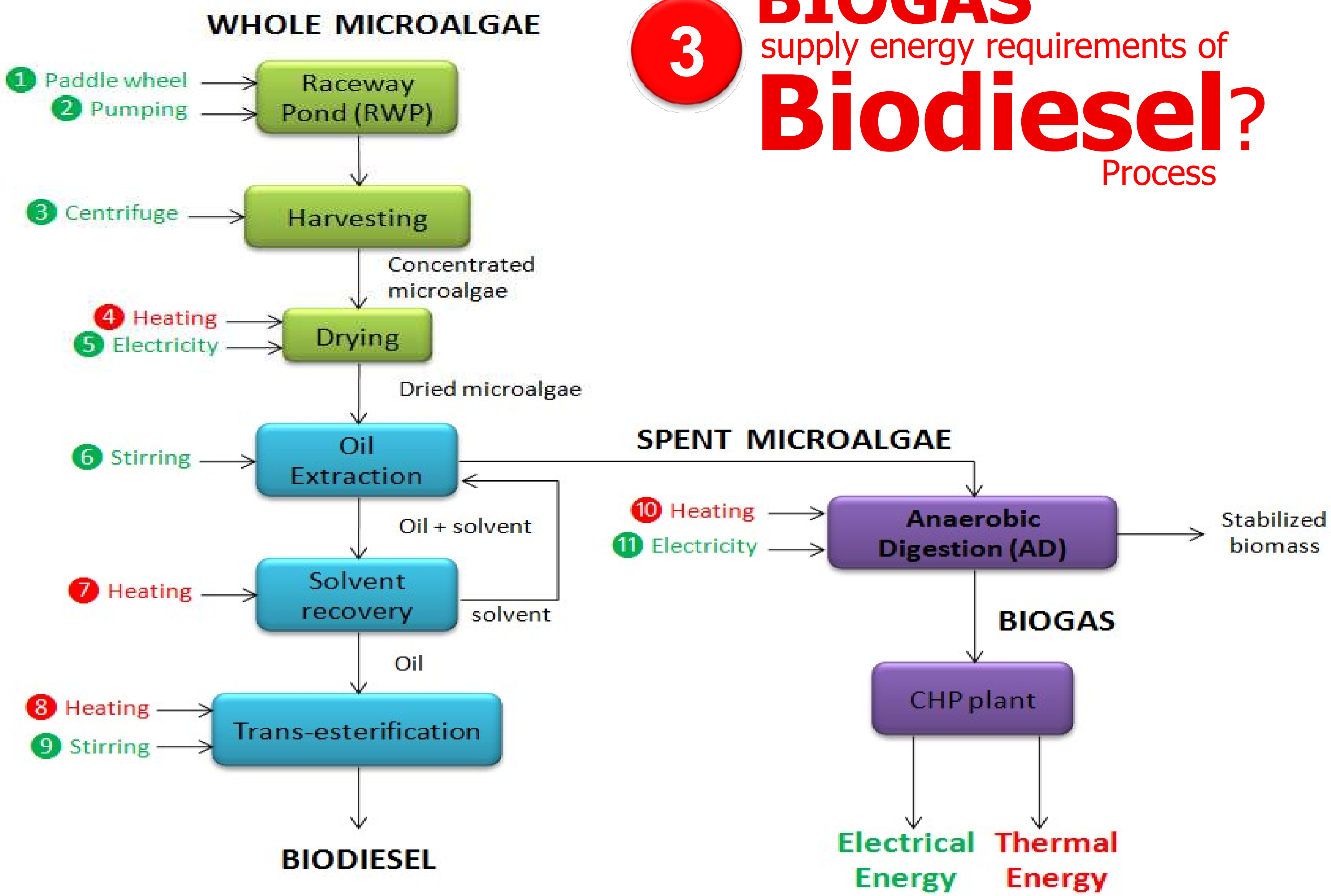
can
BIOGAS
supply energy requirements of
Biodiesel?
Process

Volume: 200m3
Px= 0.1kg/m3-d

Table IV. Parameters to calculate energy demands and energy production of microalgae *B. braunii* and *N. gaditana* growth in raceway pond.

Raceway pond	*B. braunii*	*N. gaditana*	Reference
Volume (m^3)	200	200	
Biomass productivity ($kg/m^3 \cdot d$)	0.10	0.13	[4, 36–38]
Flow rate (m^3/d)	40	52	Mass balance
Biomass concentration (g TS/L)	0.5	0.5	
Operation time (d/year)	365	365	
Power consumption:			
[1]paddle wheel (W/m^3)	1	1	[39]
[2]H20 pump (kW_eh/m^3)	0.077	0.077	[40]
Harvesting			
Concentration factor	150	150	[41]
Final concentration (g TS/L)	75	75	Mass balance
Centrifuged flow (m^3/d)	0.27	0.35	Mass balance
Power consumption:			
[3]centrifuge (Decanter) (kW_eh/m^3)	1	1	[41]
Drying			
Final humidity (%)	4%	4%	
Flow dried (kg/d)	20	26	Mass balance
Power consumption:			
[4]Drying (kW_th/m^3)	92.98	92.98	Calculated
Oil extraction			
Oil flow (kg/d)	2.53	5.42	Calculated
Power consumption:			
[5]Heating ($kW_{th}h$/kg biodiesel)	6.22	6.22	[7]
[6]Stirring (kW_eh/kg biodiesel)	2.3	2.3	[7]
Trans-esterification			
Biodiesel flow (kg/d)	1.20	2.57	Calculated
Power consumption:			
[7]Heating ($kW_{th}h$/kg oil)	0.72	0.72	[11]
[8]Stirring (kW_eh/kg oil)	0.0297	0.0297	[11]
Anaerobic digestion			
Spent microalgae flow (kg/d)	17.47	20.58	Calculated
BMP (mL CH_4/g VS)	407	450	This research
HRT (d)	30	30	
OLR (kg/m^3-d)	2	2	
Volume reactor (m^3)	10.43	13.75	Calculated
Cp microalgae (MJ/kg-°C)	4.2		
Heat losses (%)	10		
ΔT° (°C)	15		
Power consumption:			
[9]Heating ($kW_{th}h/m^3$)	–	–	Heat and mass balance
CHP plant			
Electrical efficiency (%)	40	40	[42]
Thermal efficiency (%)	45	45	[42]

3 can BIOGAS supply energy requirements of Biodiesel? Process



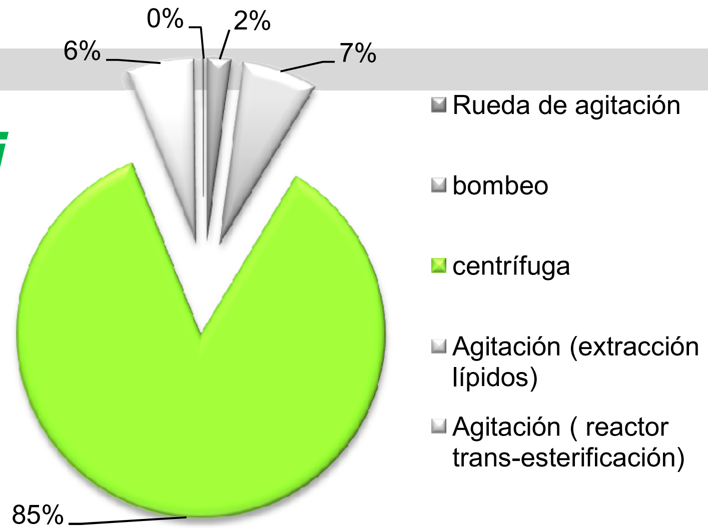
Energy balance

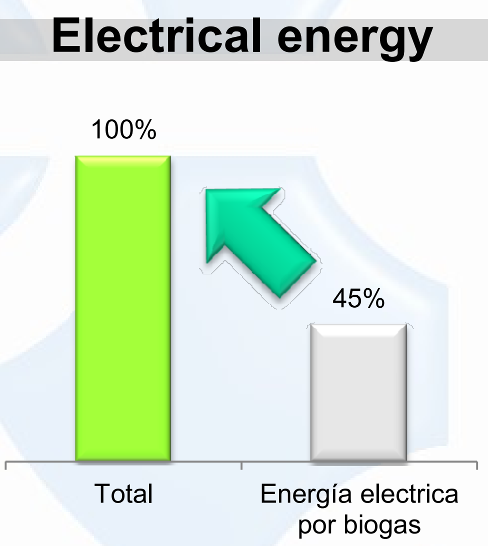
Table V. Onsite energy production and demands in raceway growth for microalgae *B. braunii* and *N. gaditana*.

Electrical energy	*B. braunii* kW_eh/year		*N. gaditana* kW_eh/year	
Produced (co-generation)	+7, 659		+10, 964	
[1]Paddle wheel	−350		−456	
[2]Pumping (harvesting)	−1, 124		−1, 461	
[3]Centrifuge	−14, 600	**85%**	−18, 980	**82%**
[5]Stirring (lipid extraction)	−1, 008		−2, 162	
[8]Stirring (trans-esterification)	−27		−59	
Balance	−9, 451		−12, 154	
Thermal energy	kW_{th}h/year		kW_{th}h/year	
Produced (co-generation)	+8, 616		+12, 334	
[4]Drying	−8, 343	**70%**	−10, 846	**60%**
[6]Heating (lipid extraction)	−2, 726		−5, 846	
[7]Heating (trans-esterification)	−664		−1, 425	
[9]Heating (Anaerobic digestion)	−123		−145	
Balance	−3, 240		−5, 926	

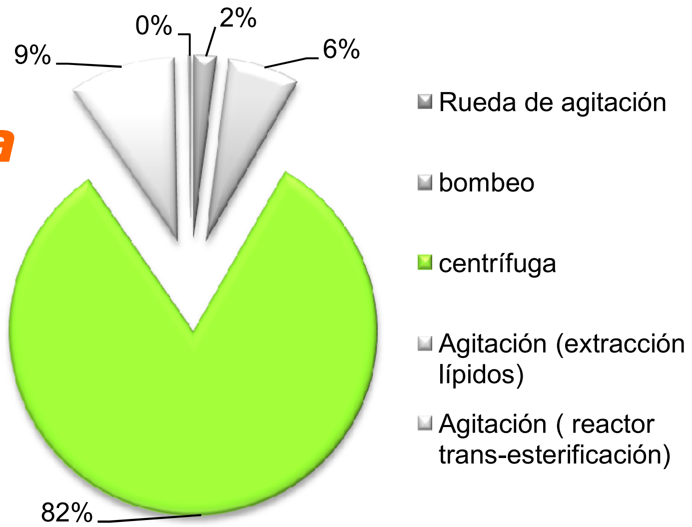
Electrical demands

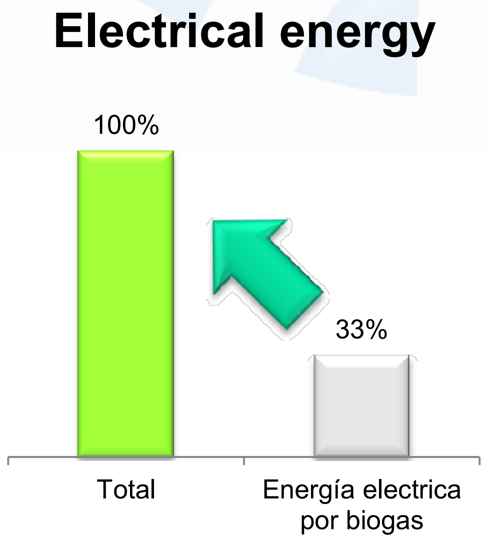
B.braunii





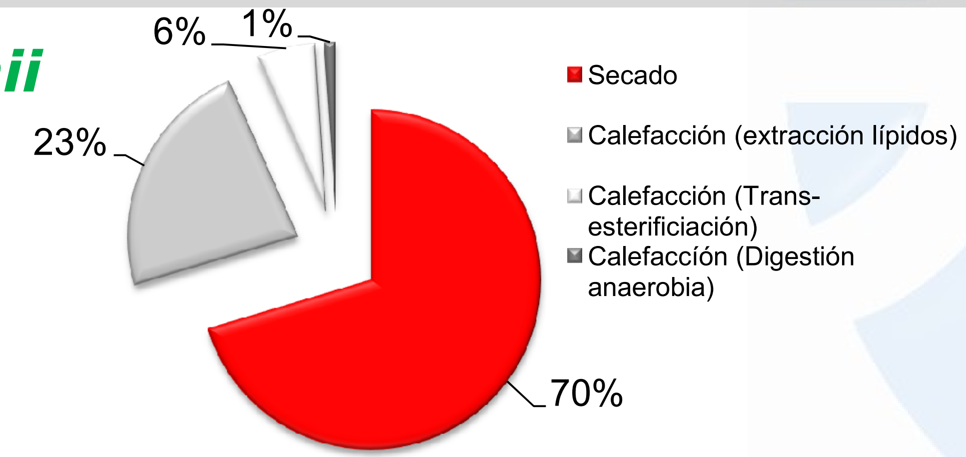
N.gaditana

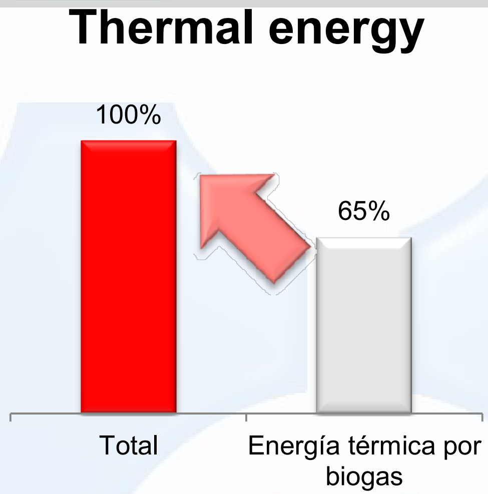




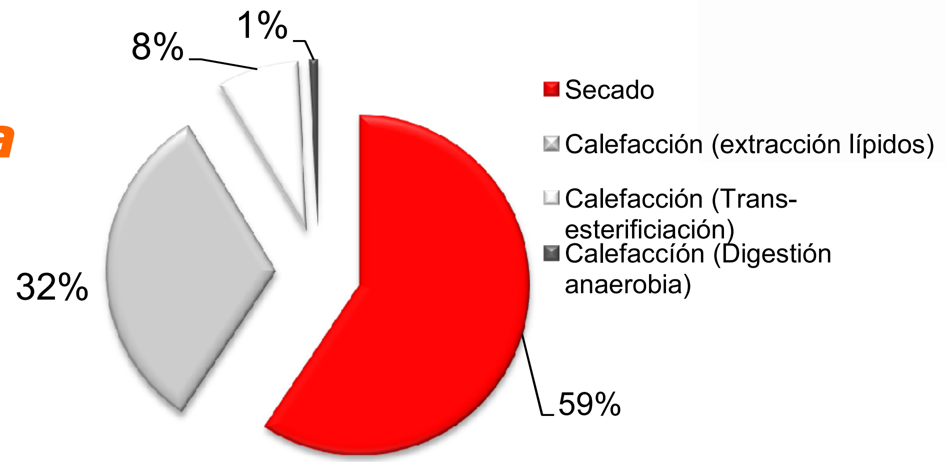
Thermal demands

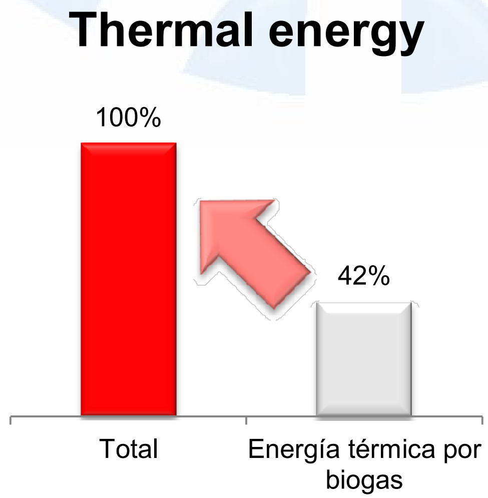
B.braunii





N.gaditana





CONCLUSIONS

°AD IS A USEFUL PROCESS FOR RECOVERING ENERGY FROM SPENT MICROALGAE

°BIOGAS CAN SUPPLY ENERGY TO GLOBAL PROCESS IN ORDER TO IMPROVE NEGATIVE ENERGETIC YIELD

Next steps…

°Biogas production to continuous AD system

° Evaluation of nutrient recovery process for recycling to microalgae culture

Agradecimientos

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THANK YOU!

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