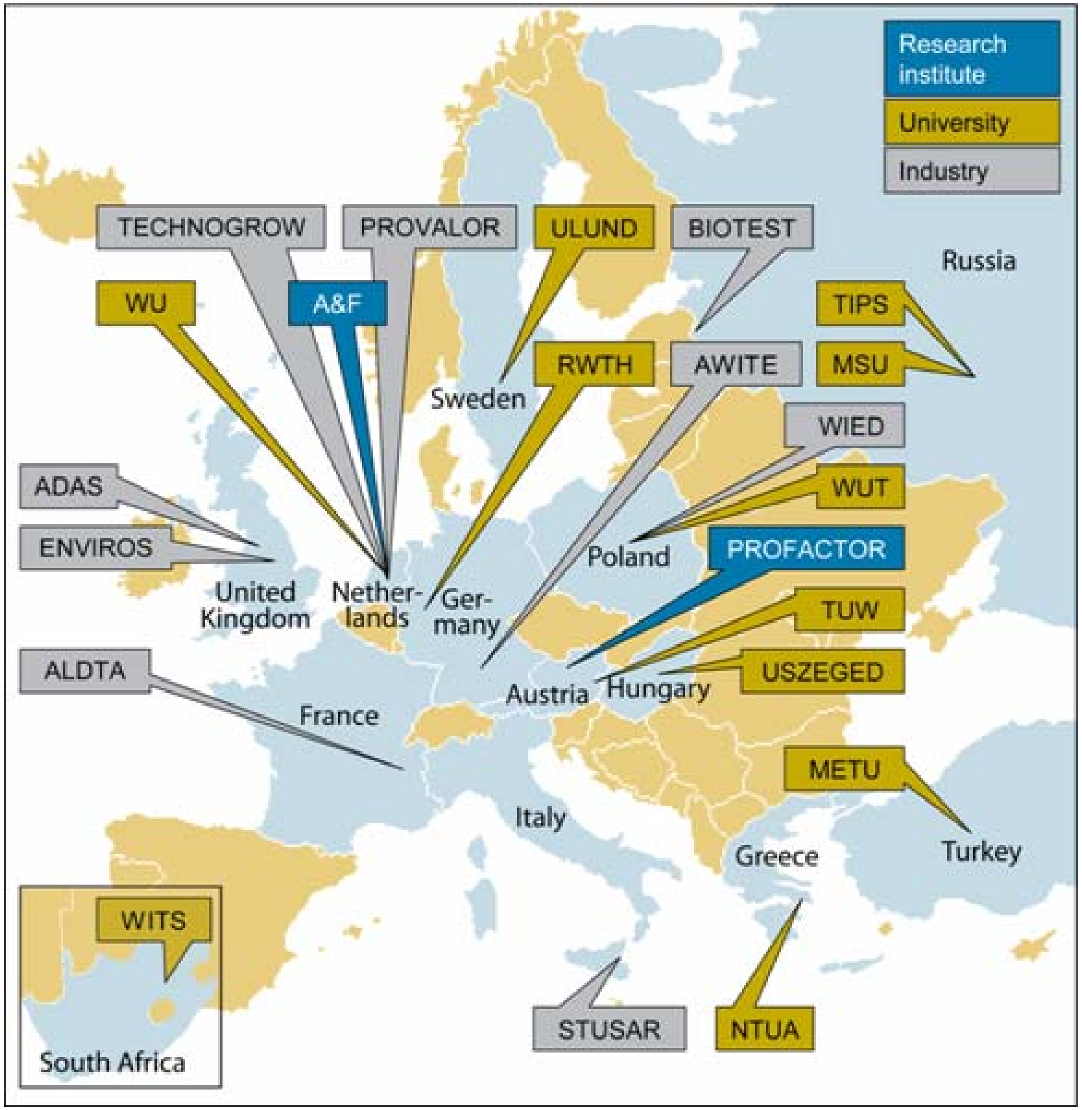
Non-thermal production of pure hydrogen from biomass

EU FP6-SES Integrated Project

HYVOLUTION

Pieternel Claassen on behalf of partners in HYVOLUTION: www.hyvolution.nl

Partners in HYVOLUTION

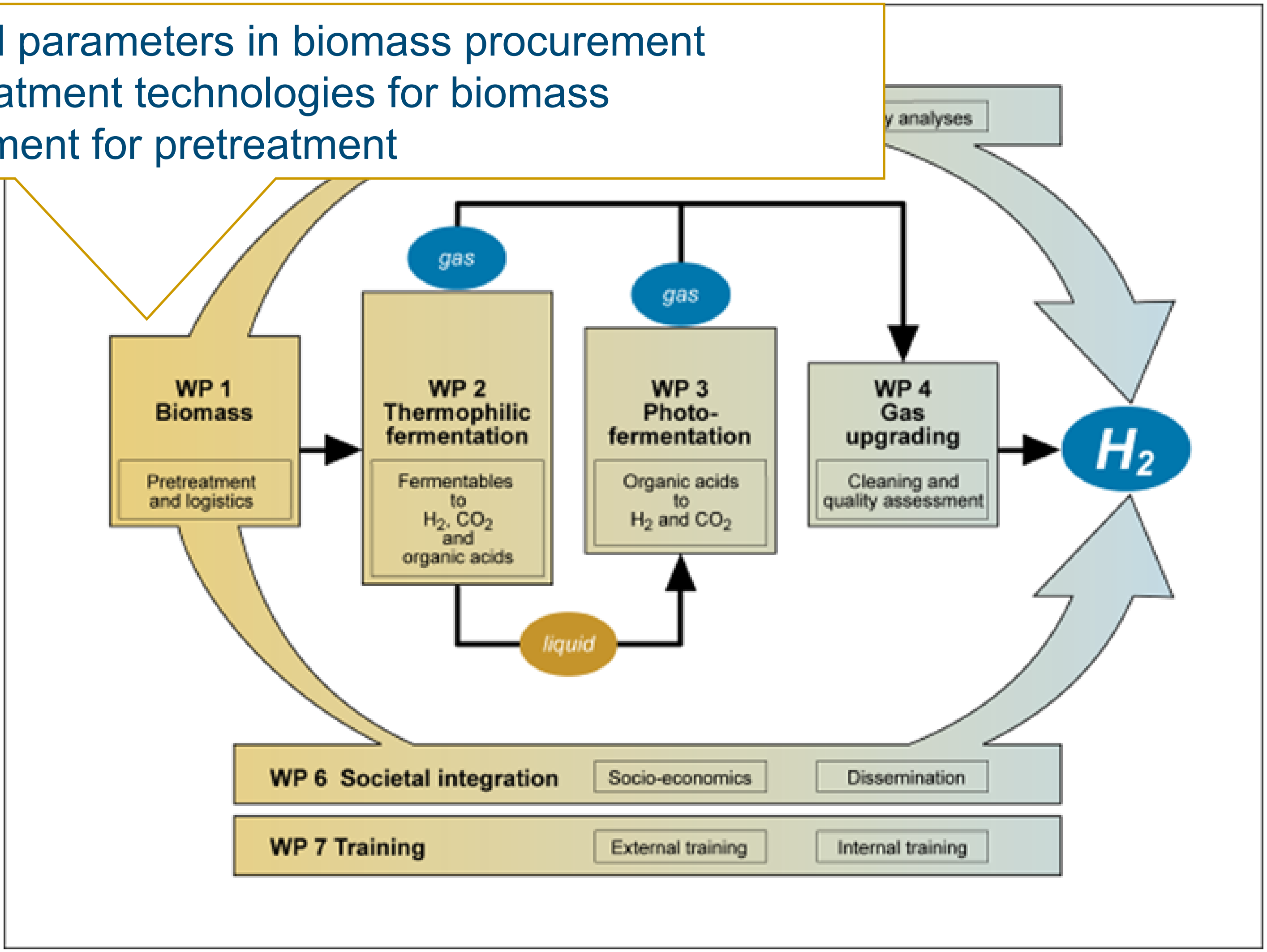


Aim:
Blue print for a bioprocess for decentral hydrogen production from biomass

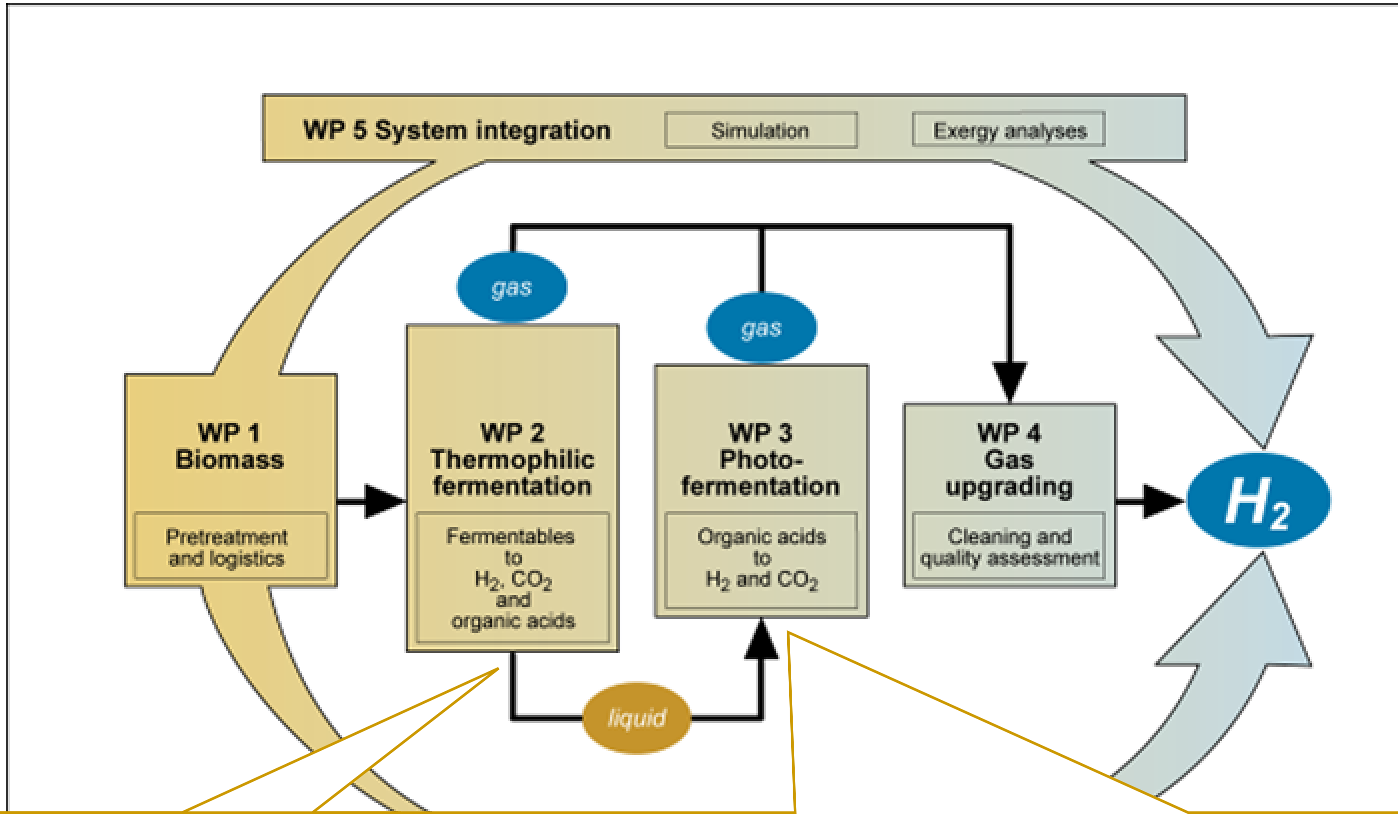
22 partners
13 countries
Jan 2006 – Dec 2010
14 M€ budget; 574 M TWD
10 M€ EC grant: 410 M TWD
www.hyvolution.nl

Objectives in workpackages

-Critical parameters in biomass procurement
-Pretreatment technologies for biomass
-Equipment for pretreatment



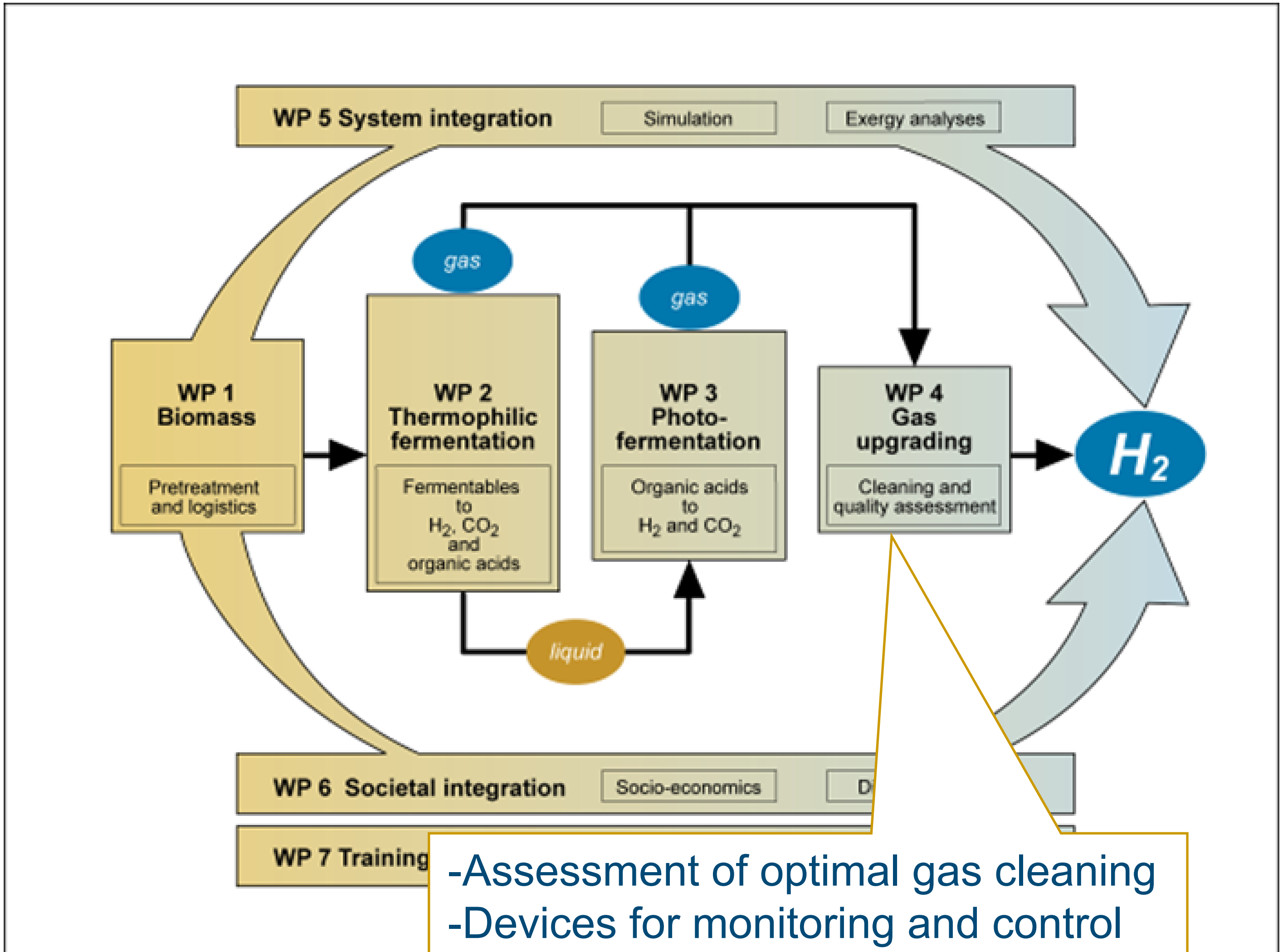
Objectives in workpackages



-Maximum conversion of biomass to hydrogen

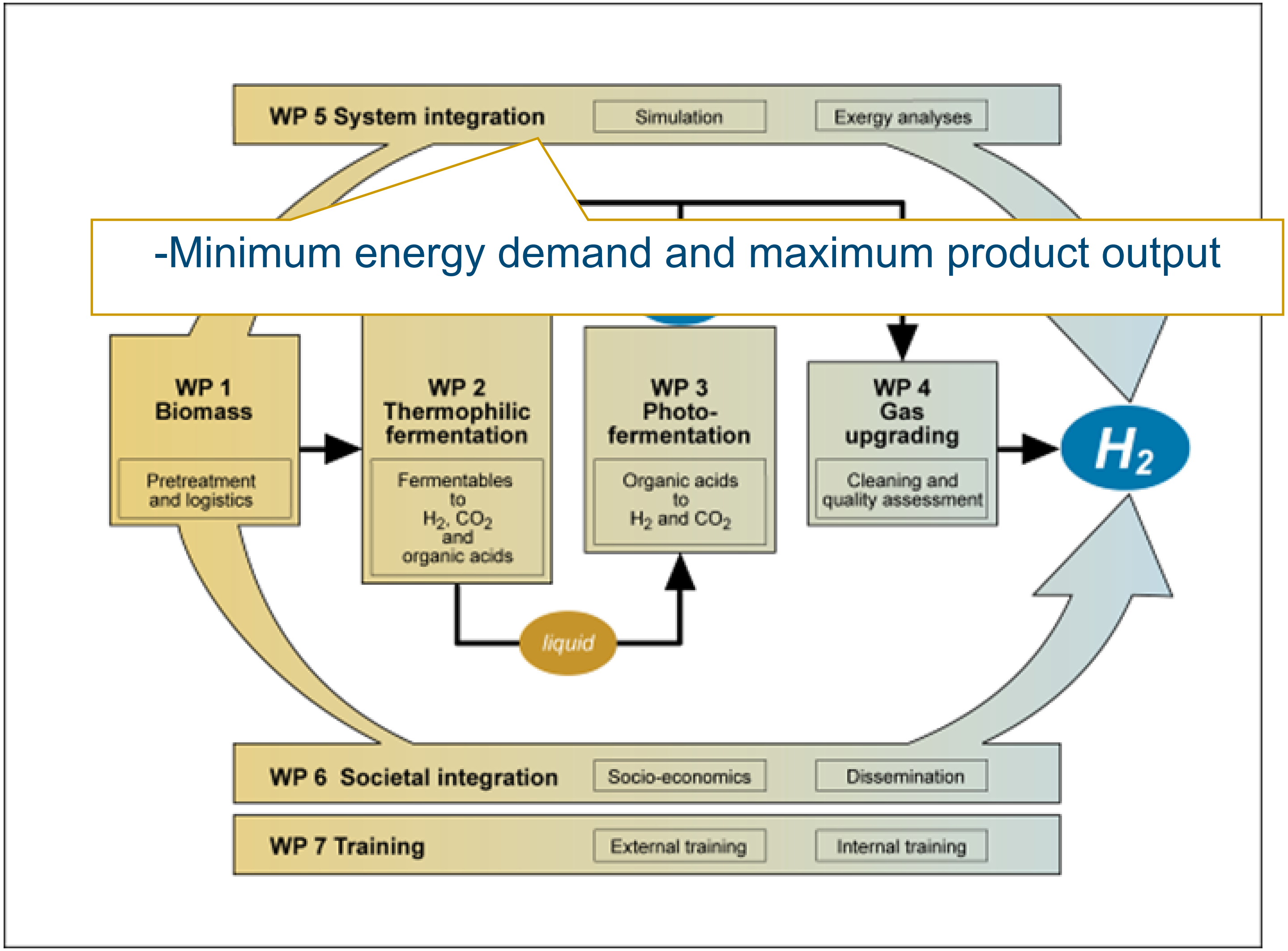
-Reactors for thermophilic and photo-heterotrophic hydrogen production

Objectives in workpackages



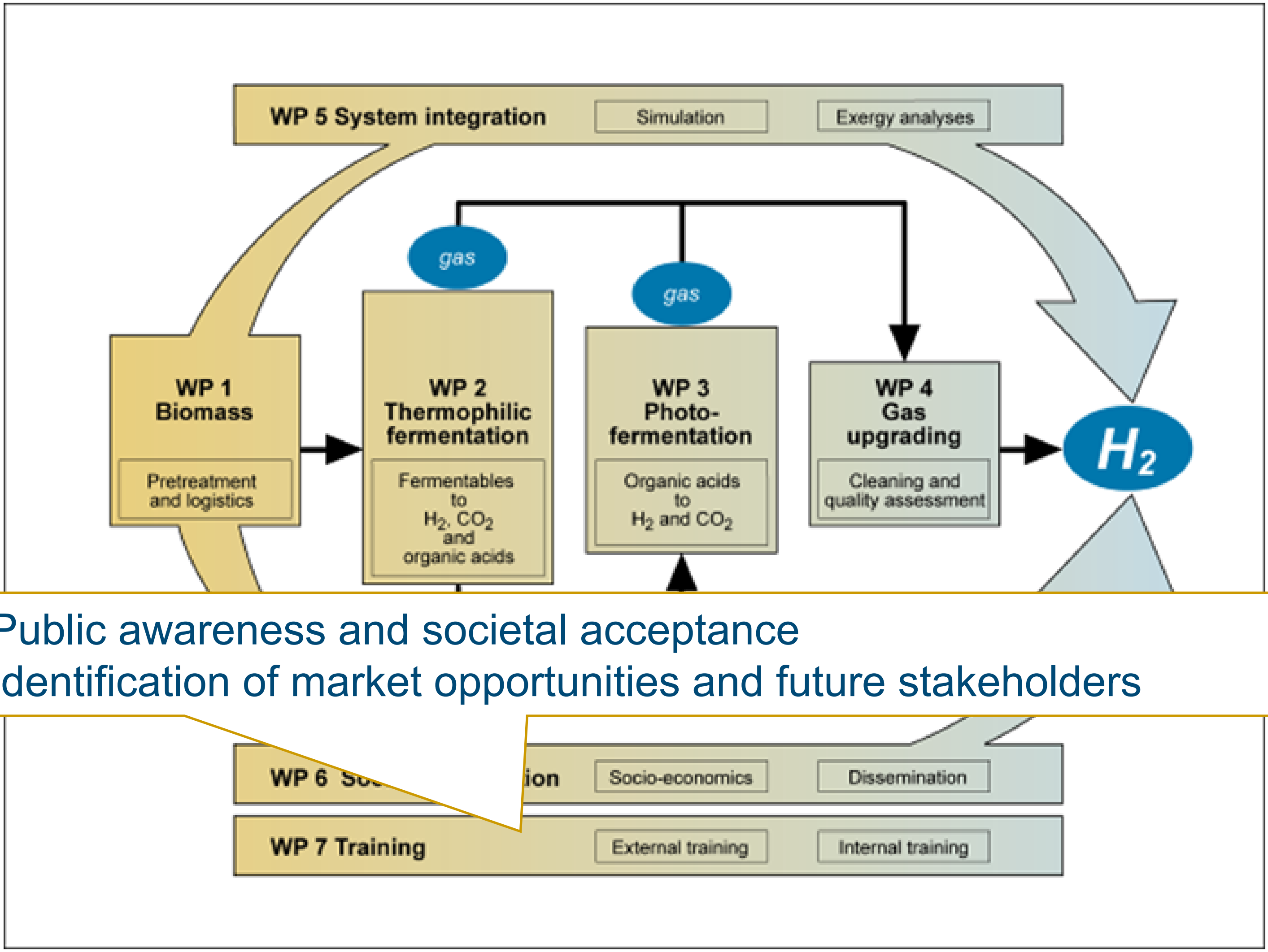
-Assessment of optimal gas cleaning
-Devices for monitoring and control
-Equipment for gas upgrading

Objectives in workpackages



-Minimum energy demand and maximum product output

Objectives in workpackages



-Public awareness and societal acceptance
-Identification of market opportunities and future stakeholders

The core of HYVOLUTION

$C_6H_{12}O_6 + 6\ H_2O \rightarrow 6\ CO_2 + 12\ H_2$ *$\Delta G_o' = +3$ kJ*

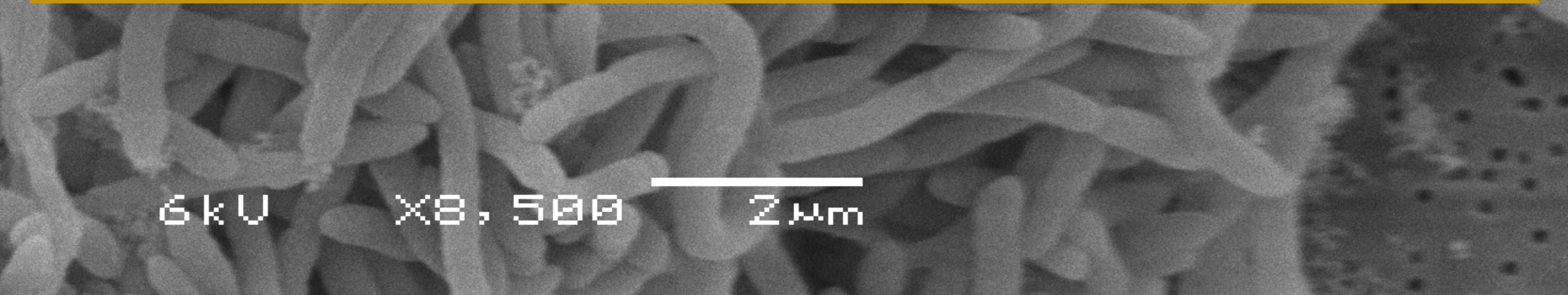
$C_6H_{12}O_6 + 2H_2O \longrightarrow 2CO_2 + 2CH_3COOH + 4H_2$ **$\Delta G_o' = -206$ kJ**

(hyper)thermophilic bacteria

photons

$CH_3COOH + 2H_2O \longrightarrow 2CO_2 + 4H_2$ **$\Delta G_o' = 0$ kJ**

photosynthetic bacteria



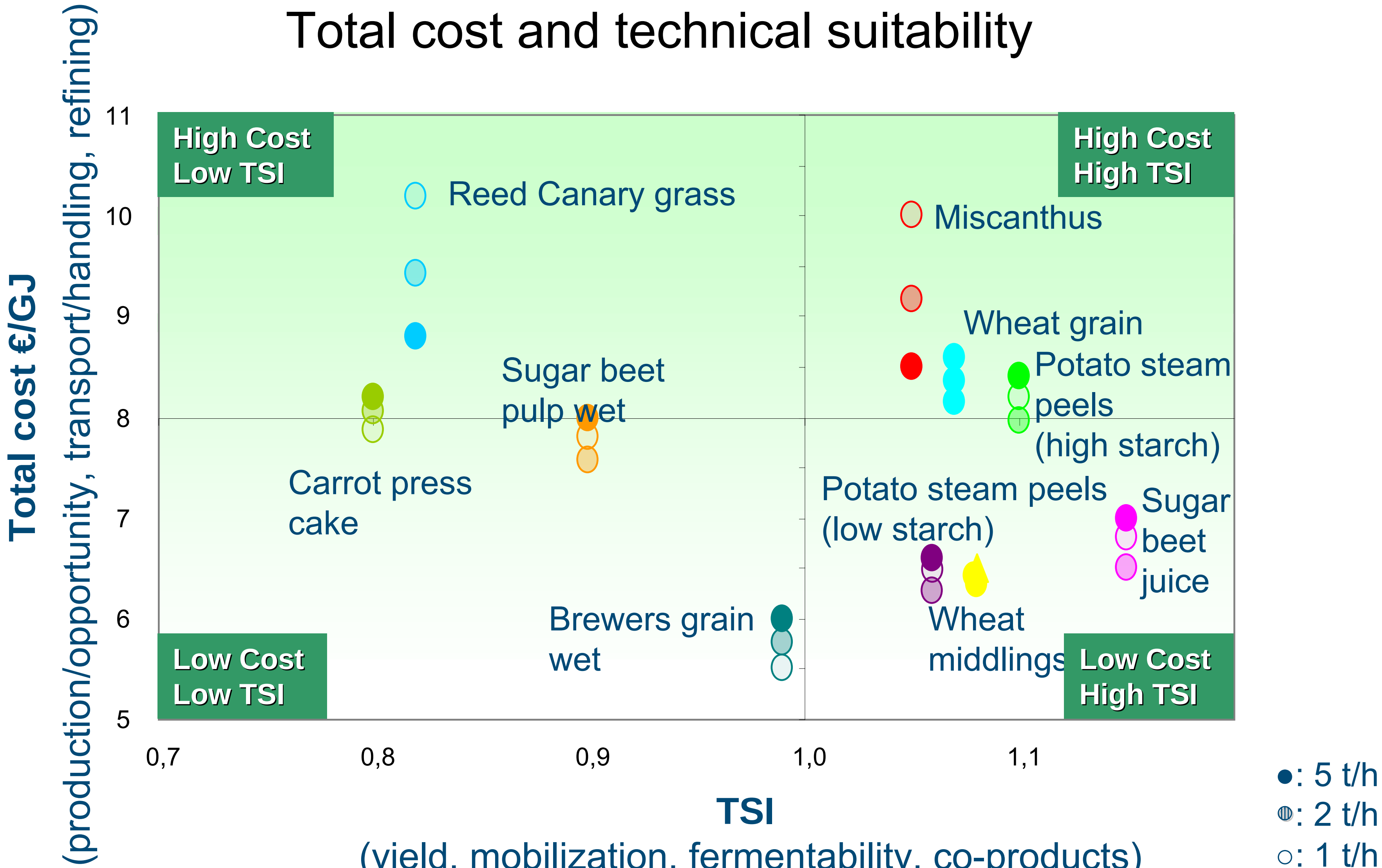
Primary by-products from agriculture

	Crop Category	Crop	Main product	Primary by-products	
				Leafy	Stems
			Million ton dry matter		
Crops already cultivated for nutritional needs	Sugar Crops	Sugar beet	18.1	7.3	-
	Starch Crops	Potato	12.9	8.8	-
		Wheat	97.5	-	82.6
		Barley	48.2	-	40.8
		Maize	43.8	-	74.5
		Other cereals	25.7	-	18.3
		Rice	2.3	-	1.7
	Other Food Crops	Grapes	12.7	-	10.9
		Apples	1.7	-	2.0
		Other fruits	3.6	-	15.1
		Vegetables	5.4	7.3	-
		Oil seeds	9.4	-	40.3
Energy crops	Sugar Crops	Sweet sorghum	19.5	4.9	7.8
	Lignocellulosic crops	Miscanthus	21.6	5.6	-

Total production:
322 Mton
Total by-products:
328 Mton

Potential H_2:
13 Mton annually

Total cost and suitability of biomass



Biomass selection

- Selected biomass for HYVOLUTION:




Sugar beet
sucrose

Potato steam peels
starch

Wheat bran
starch and
lignocellulose

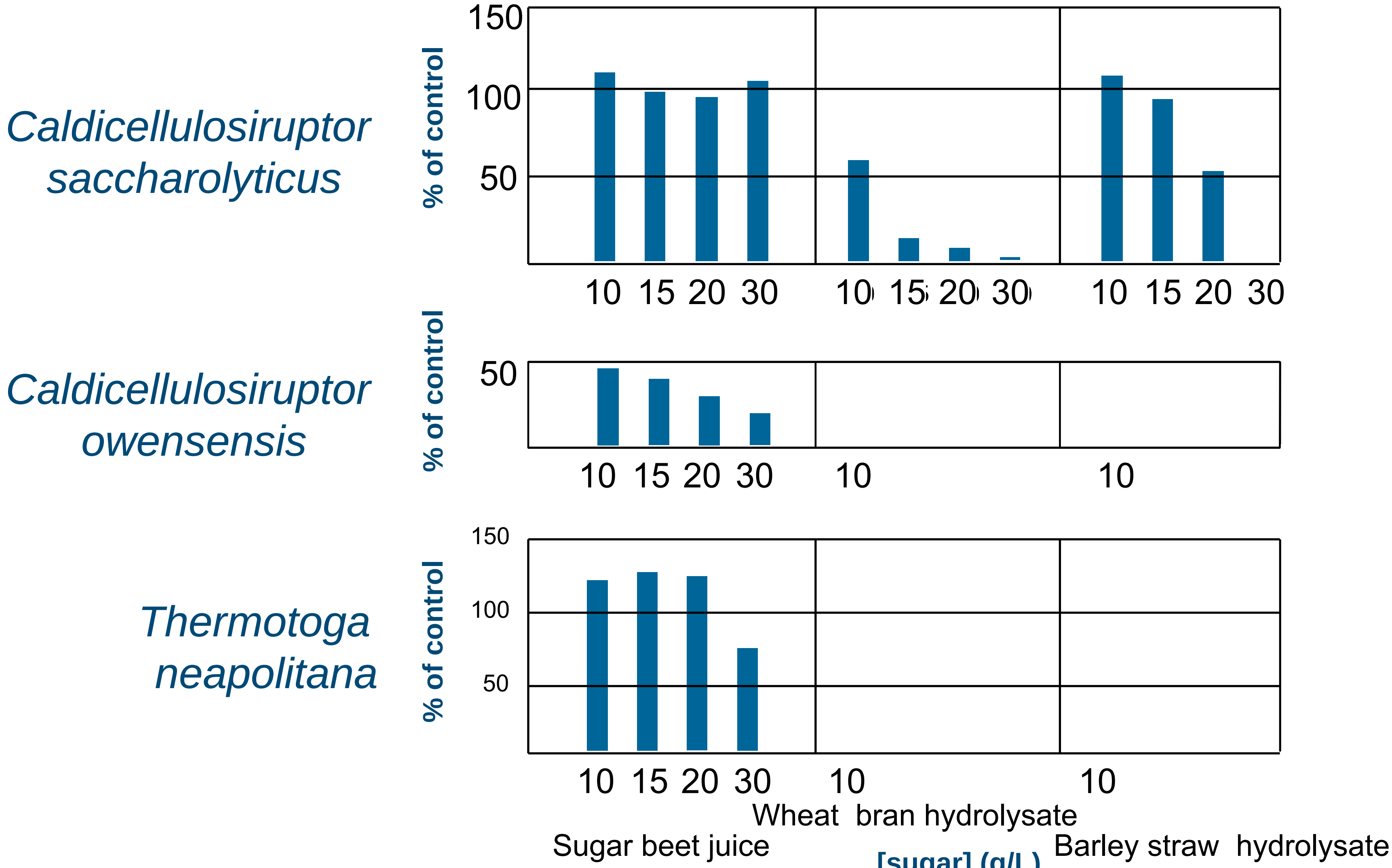
Barley straw
lignocellulose

Biomass pretreatment

High solids, conical screw reactor

Experimental parameters:
-acid/ alkaline
-temperature(s)
-duration
-enzymes

Fermentability test: production of acids



WP 2 THERMOPHILIC FERMENTATION

AIM

- Maximum efficiency in conversion of biomass feedstocks to H_2 through cost-effective, stable, optimized thermophilic fermentation

P_{H2}

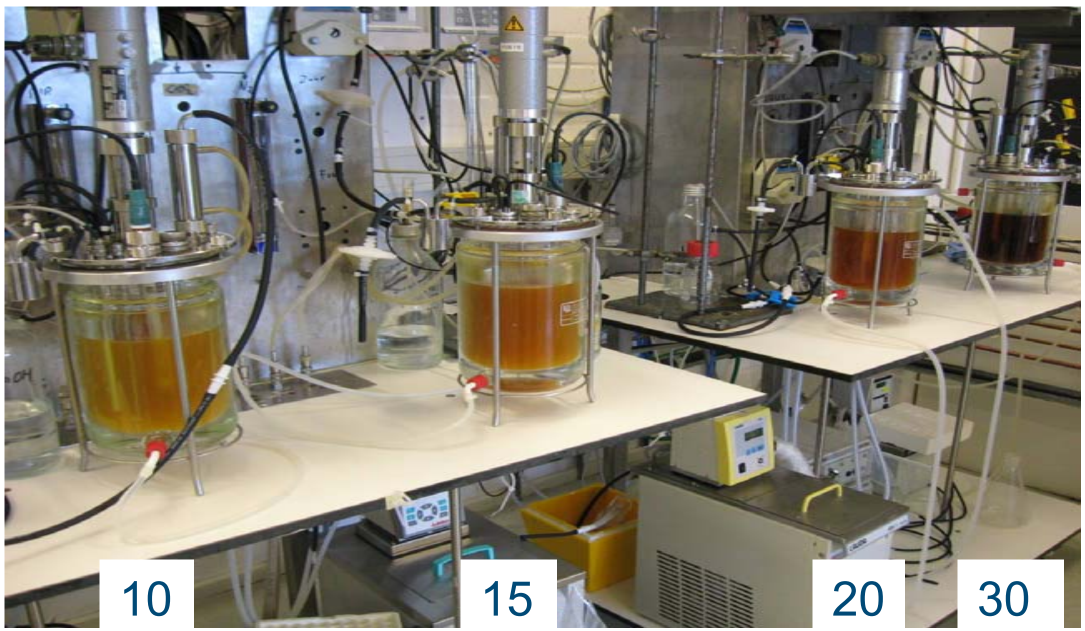
CO_2

π

Sugar type

[Sugar]

Nutrients



Yield

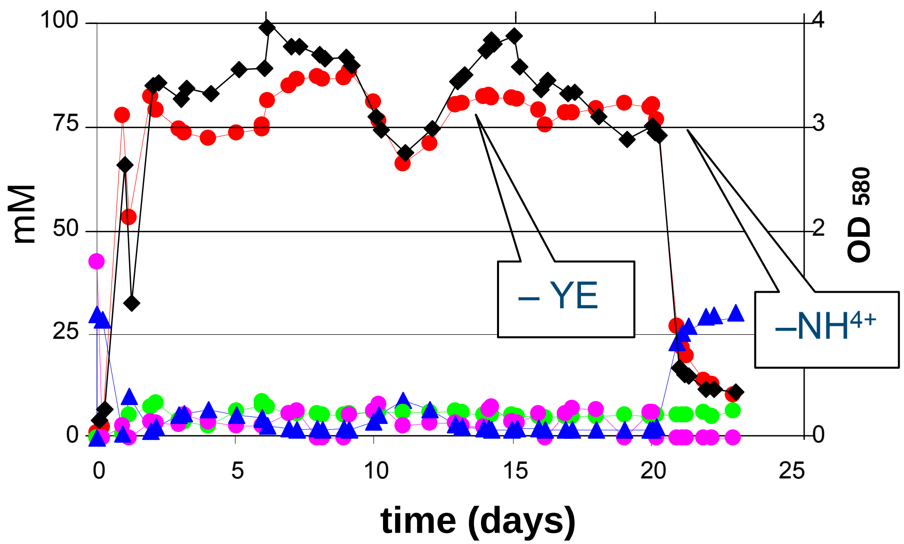
Productivity

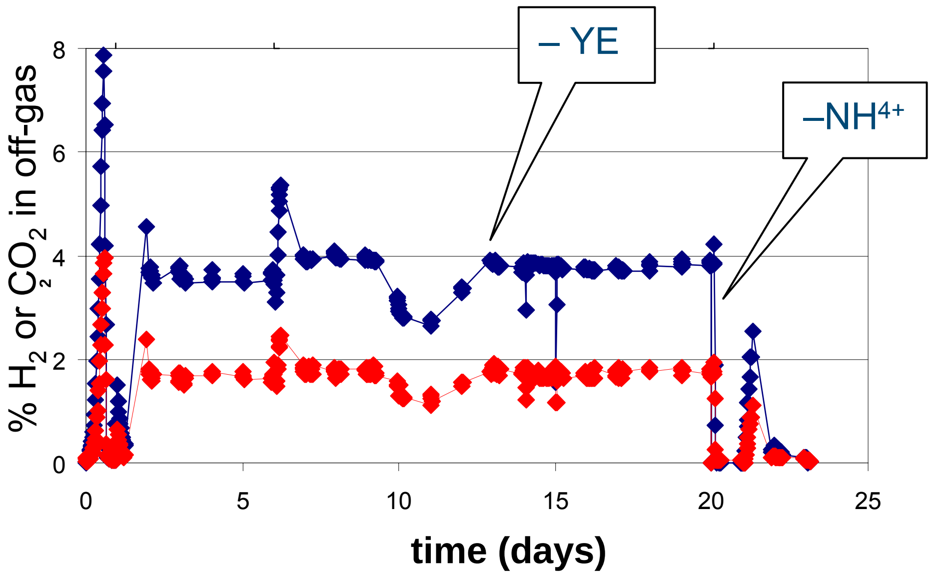
Molasse g/L

HYvolution

A&F, Ulund

C. saccharolyticus on molasses

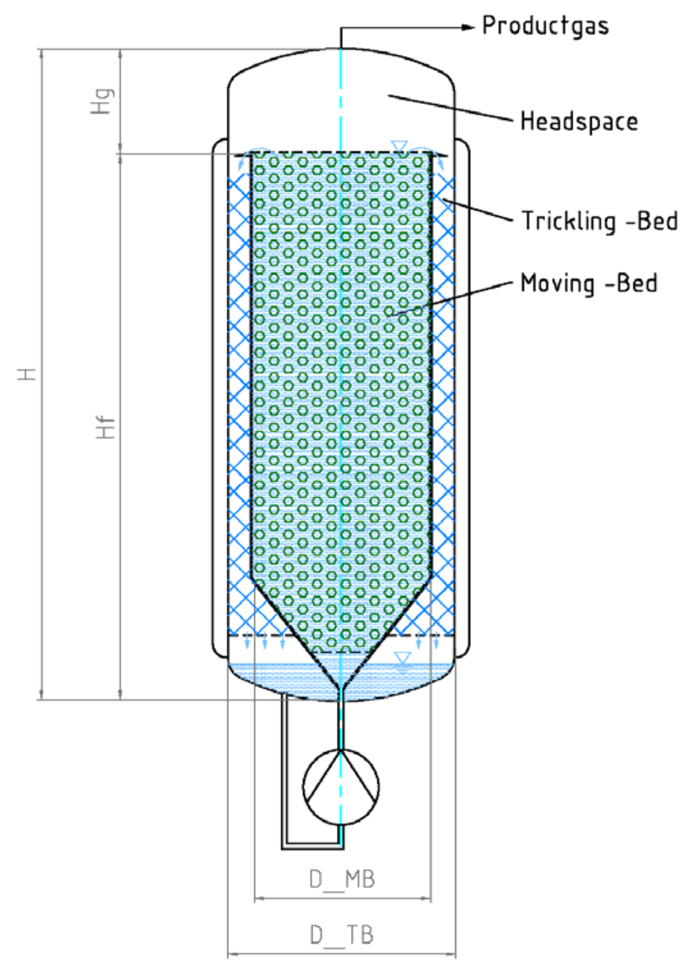




● acetate ● lactate ● ethanol ▲ sucrose ◆ OD 580 ◆ H_2 ◆ CO_2

Q_{H_2} = 0.032 g L^{-1} h^{-1}
Y_{H_2} = 2.8
Substrate conversion efficiency = 70%
C-balance = 0.83
Sucrose consumption = 94%

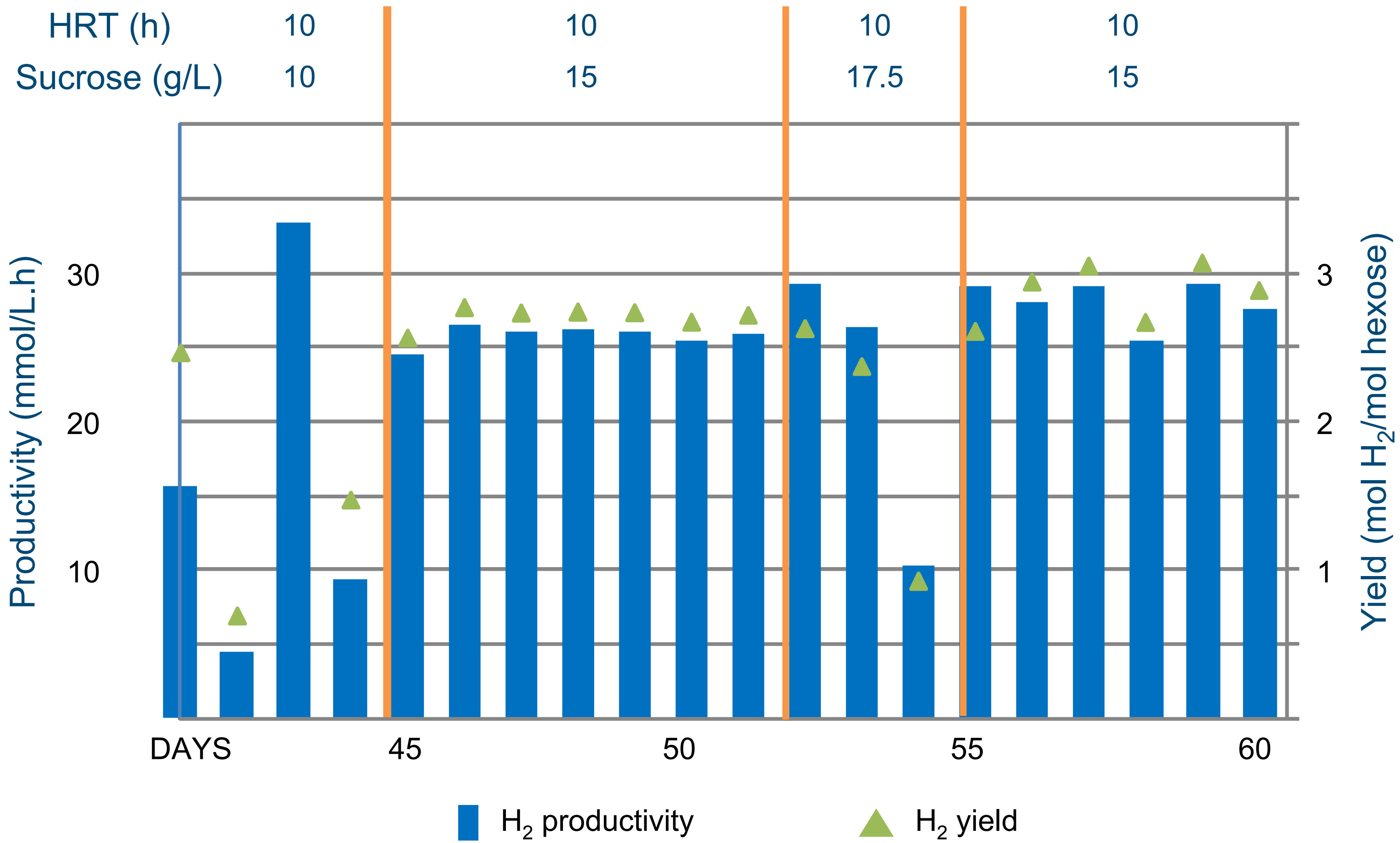
Bioreactor development



30 L CFTB

600 L CFTB

Continuous H_2 fermentation using thick juice



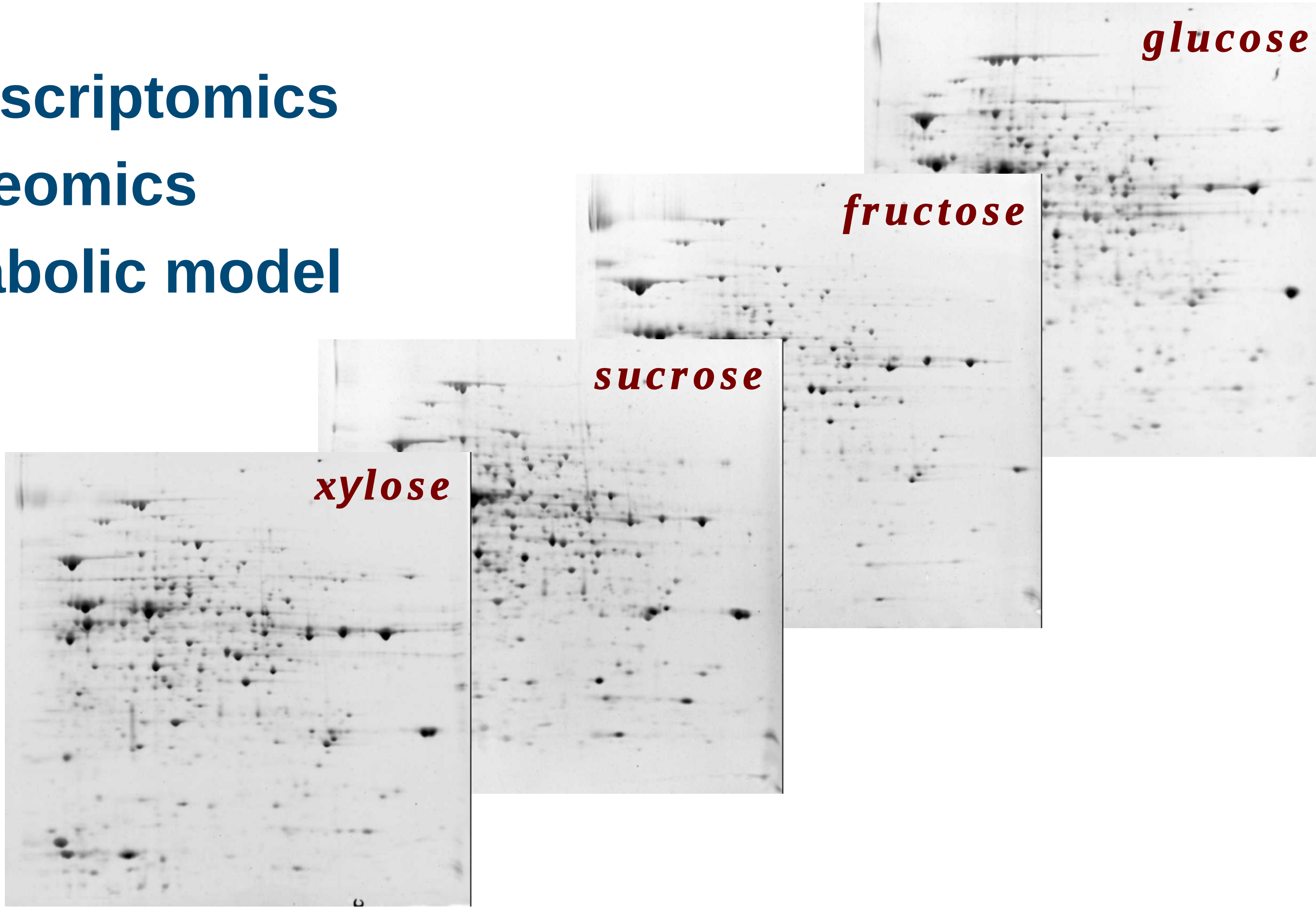
Fluidized bed bioreactor from WITS at FBR

Physiology of *C. saccharolyticus*

Transcriptomics

Proteomics

Metabolic model

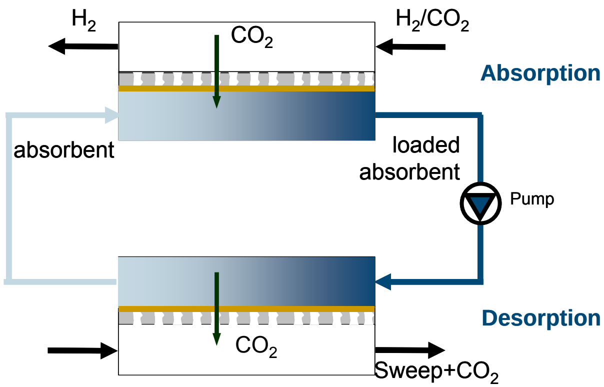


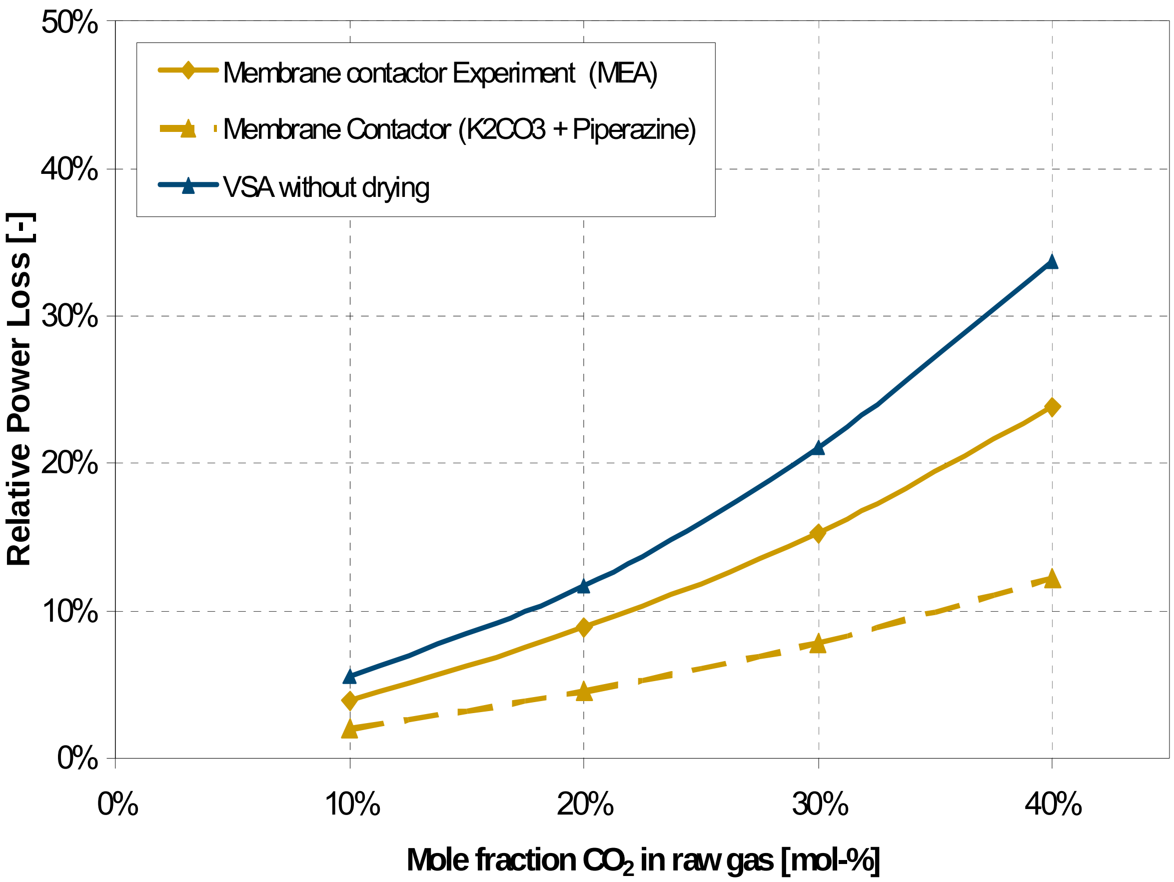
Outdoor continuous photofermentation

Aachen

Ankara

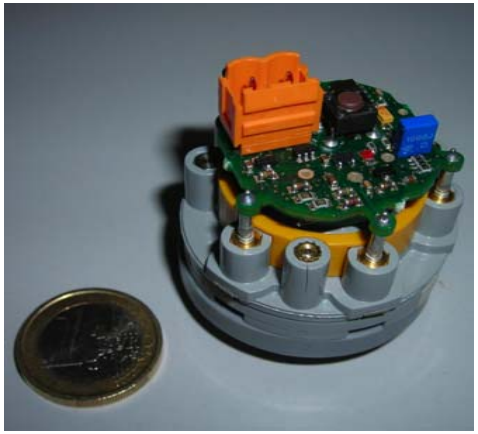
Energy demand for gas upgrading



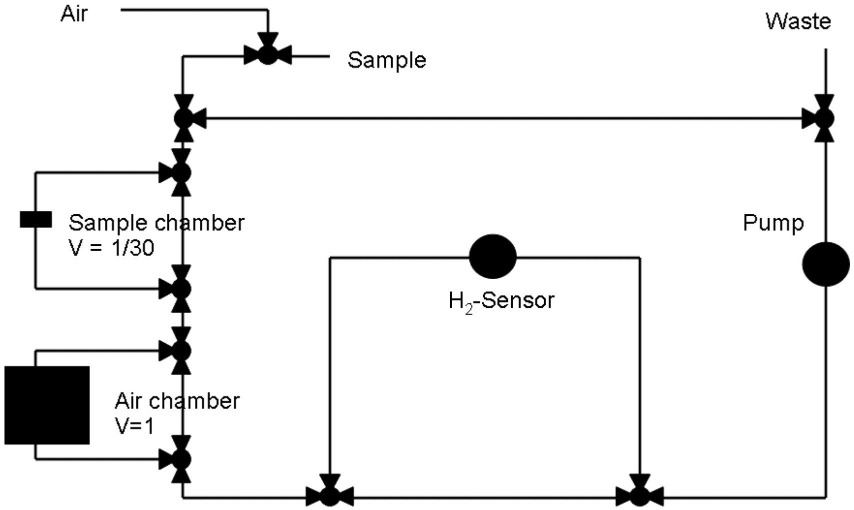


Gas analysis

- Use of electrochemical H_2-sensors (measuring range: 0-5%; ~ € 500 / sensor);
- Inclusion of state-of-the-art sensors (CO$_2$, CH$_4$, O$_2$, H$_2$S) in separate channels
- Development and construction of dilution device

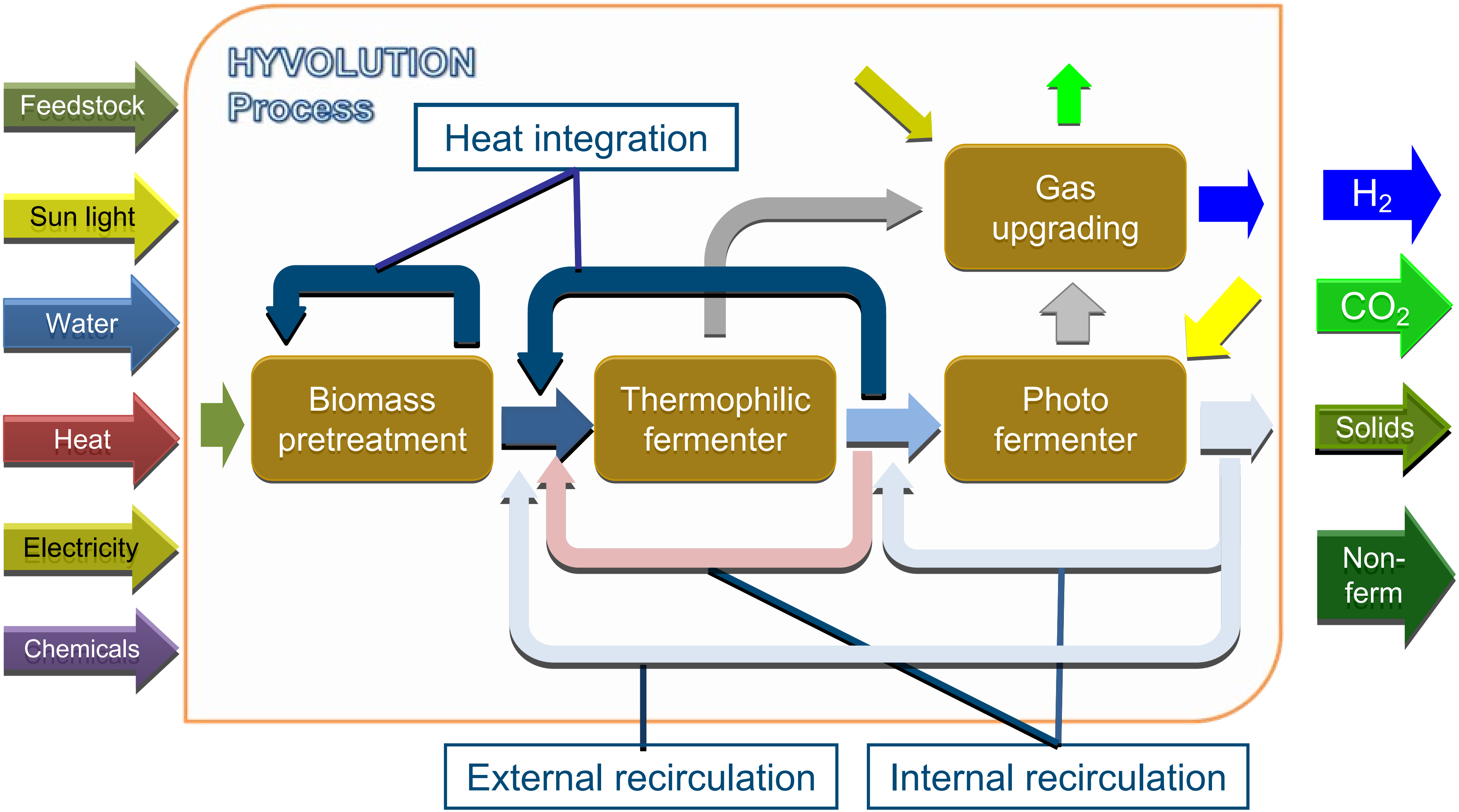


Hydrogen sensor

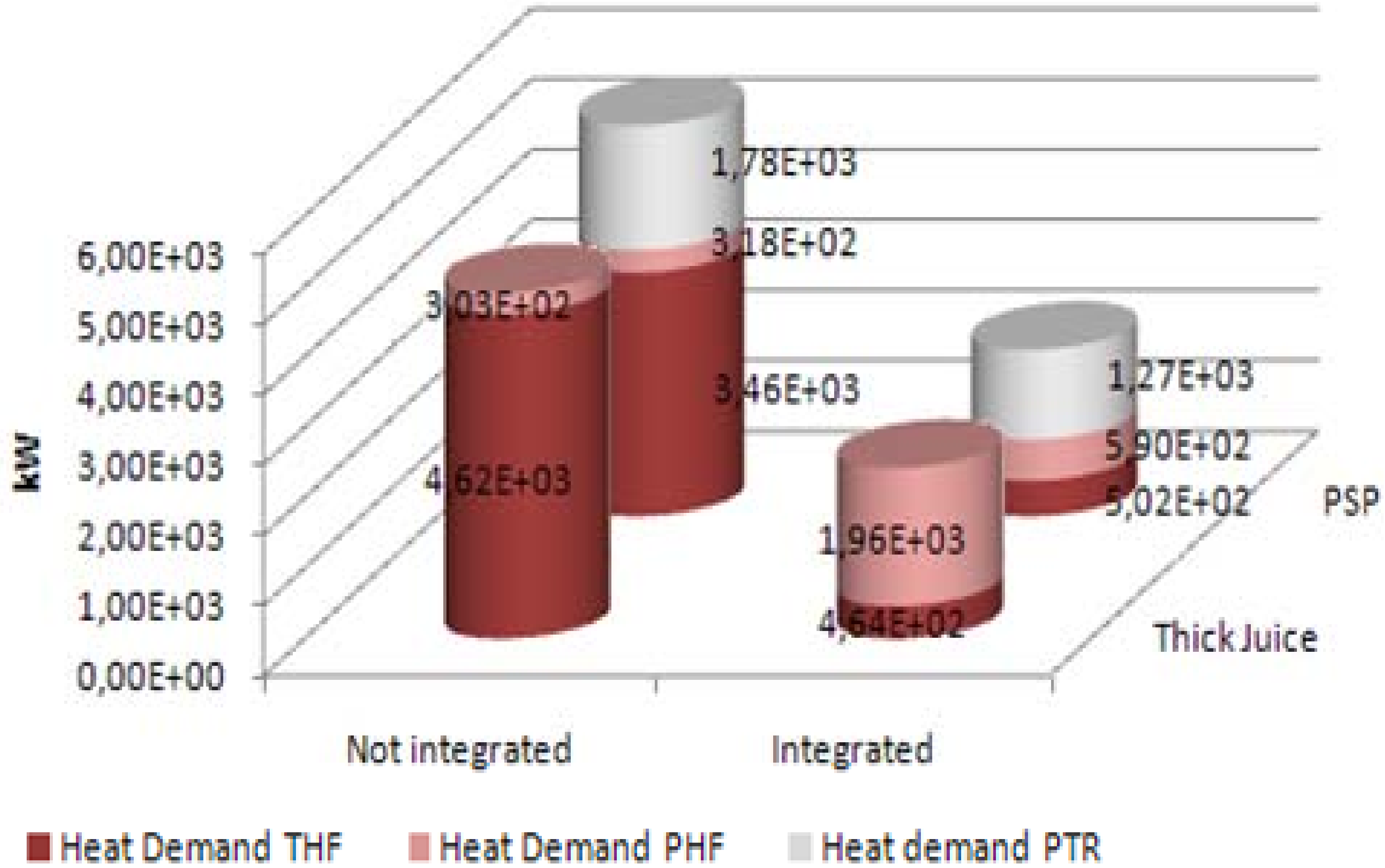


Automated dilution device

Integration options

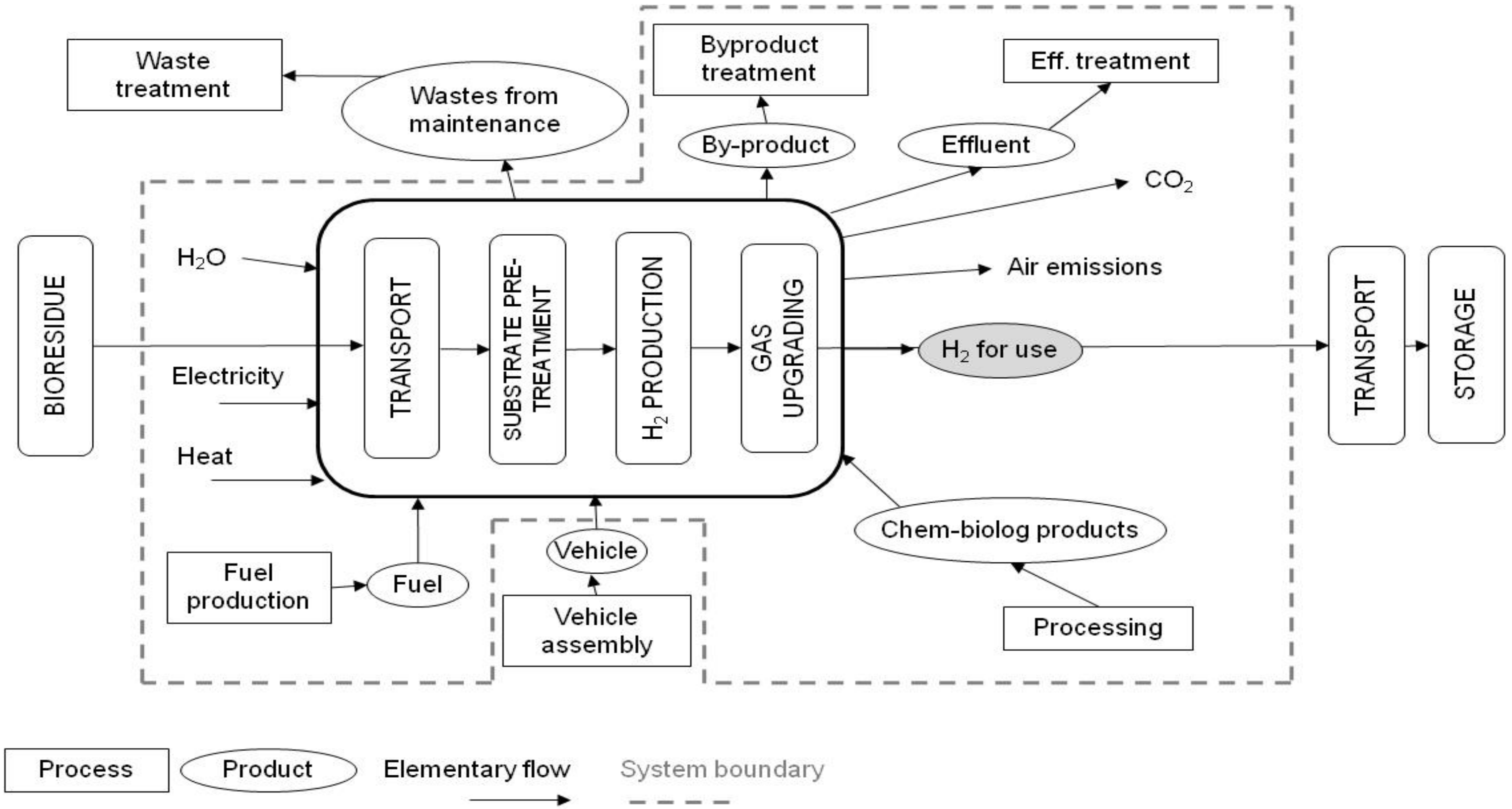


Heat integration



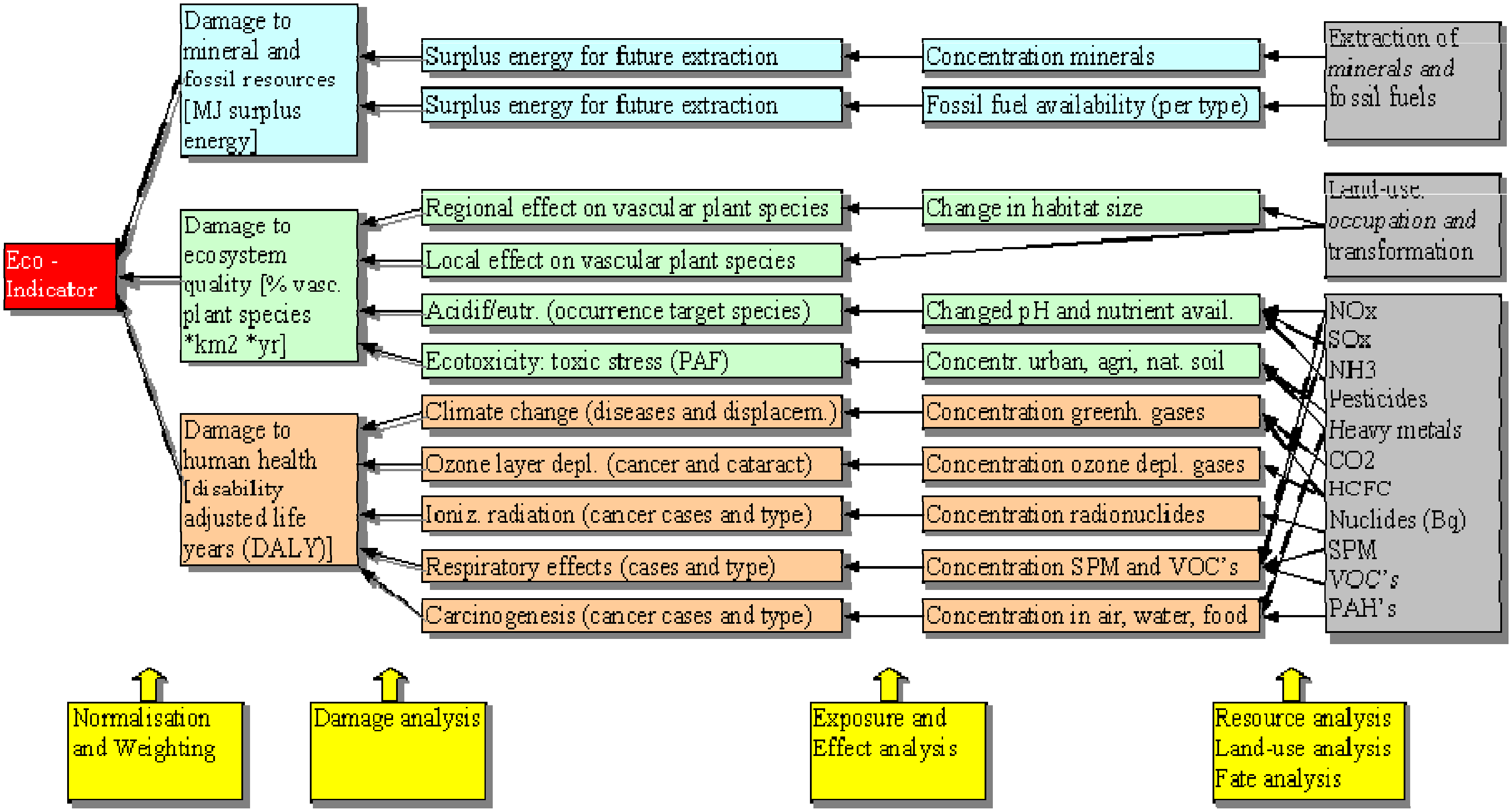
One of the AIMS

- Identification of environmental impacts



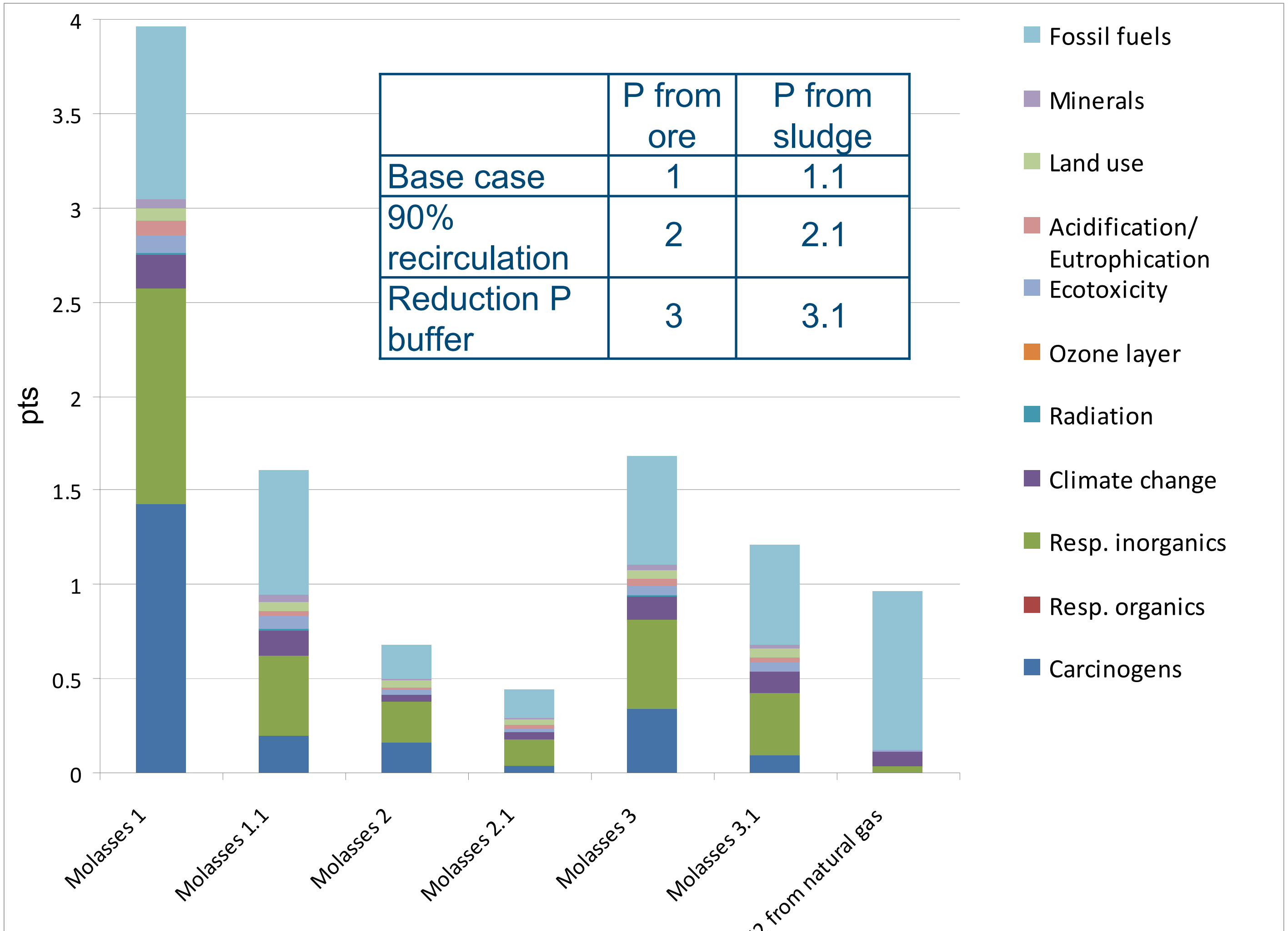
Methodology

Eco-indicator 99



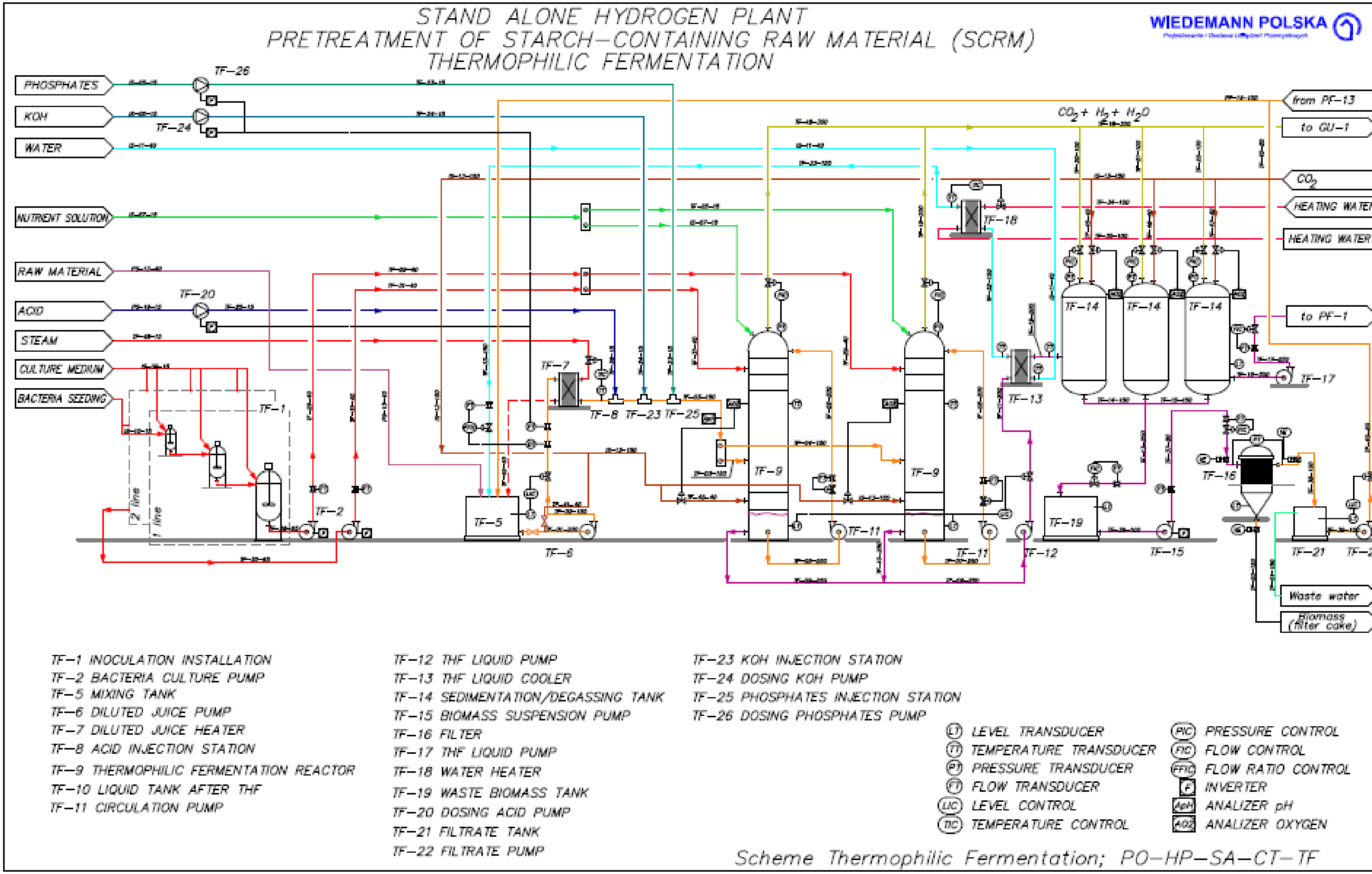
LCA of molasses as feedstock

Environmental impact



	P from ore	P from sludge
Base case	1	1.1
90% recirculation	2	2.1
Reduction P buffer	3	3.1

Blue print for a 2 MW HYVOLUTION plant



Hyvolution

Current state of the art and outlook

	Scenario's			
	Base case	Longterm case: >2030	Current HYVOLUTION data	
Thermophilic fermentation	Glucose	Biomass	Thick juice [1]	Molasses [2]
Substrate (g glucose /L)	13	40	7.5	10
Yield (% of maximum)	67	85	88	60
Productivity (mmol H_2/L.h)	5.4	53	29	17
Stripping	CO_2	-	~N_2	N_2

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Stripping	CO_2	-	~N_2	N_2
Photofermentation	Acetate	DFE	DFE[3]	DFE[4]
Substrate (mM acetate)	40	120	±40	±40
Yield (% of maximum)	50	85	67	91
Productivity (mmol H_2/L.h)	0.33	3.3	1.5	1.1

[1]: CFTB; [2]: CSTR; [3]: Hup^- mutant; [4]: Wild type

Future hydrogen production costs

Cost breakdown into process steps.

	Base case Cost (€/kg)	Long term case >2030 Cost(€/kg)
Raw material (PSP)	1.19	0.70
Pretreatment	1.74	1.23
Thermophilic fermentation	6.07	1.47
Photofermentation	8.78	1.37
Gas up-grading	2.15	1.37
Total production cost	**19.93**	**6.14**

Critical parameters from cost-point of view:

-thermophilic fermentation	productivity and hydrogen removal
-photofermentation	productivity and bioreactor design

Thank you for your attention

Join us in greening the HyWay!