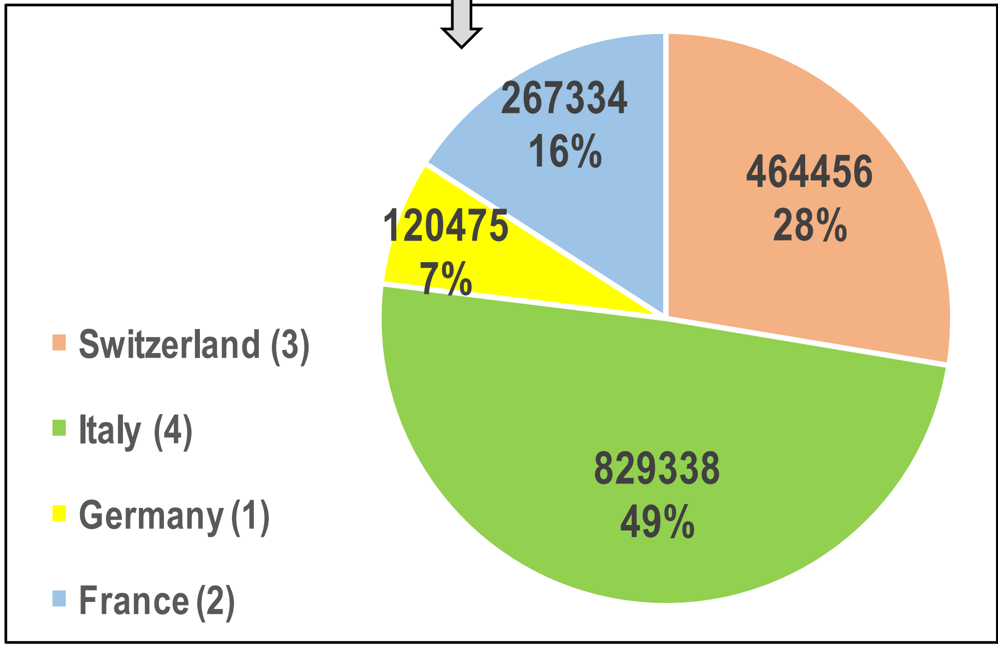
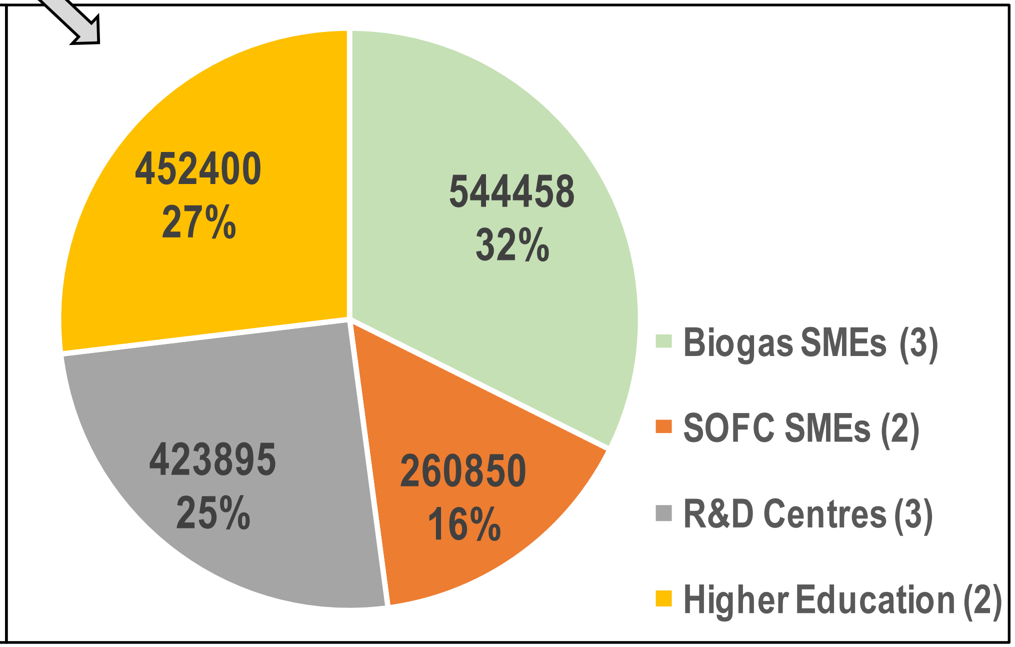
Waste2Watts
FCH-JU Project 826234

W2W facts

- 2019-Jan-01 to 2020-Dec-31 / **2 year** project
- **<u>low cost</u> biogas cleaning** for coupling with **<u>low cost</u> SOFC** to prepare biogas market entry for SOFCs.
- **1.68 M€** funding





W2W Partners

Coordination – WP6
System Design – WP4

SOFC supply-WP3

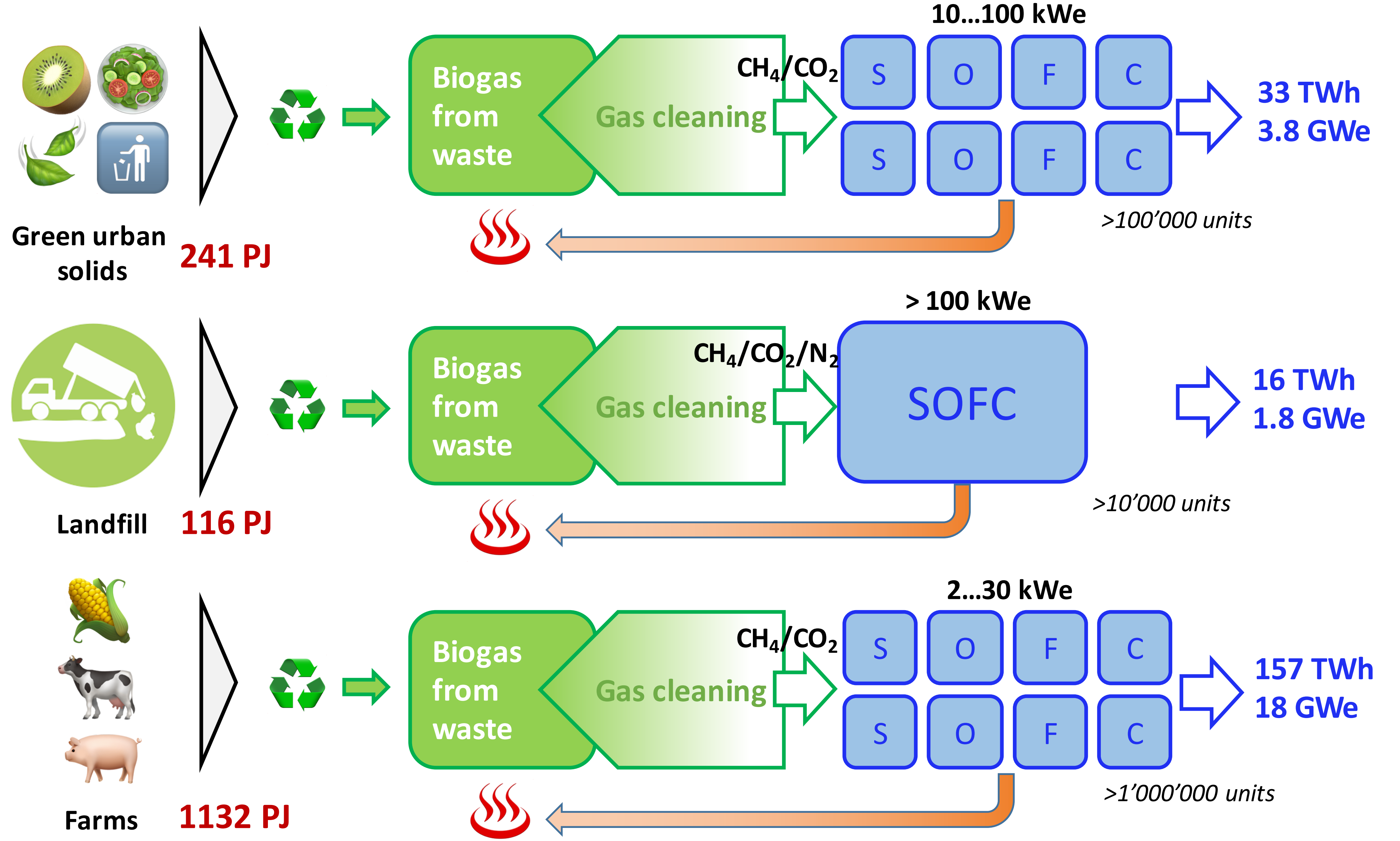
Biogas resource – WP1

ADVISORY BOARD of
biogas experts
+ biogas SMEs

Biogas cleaning – WP2

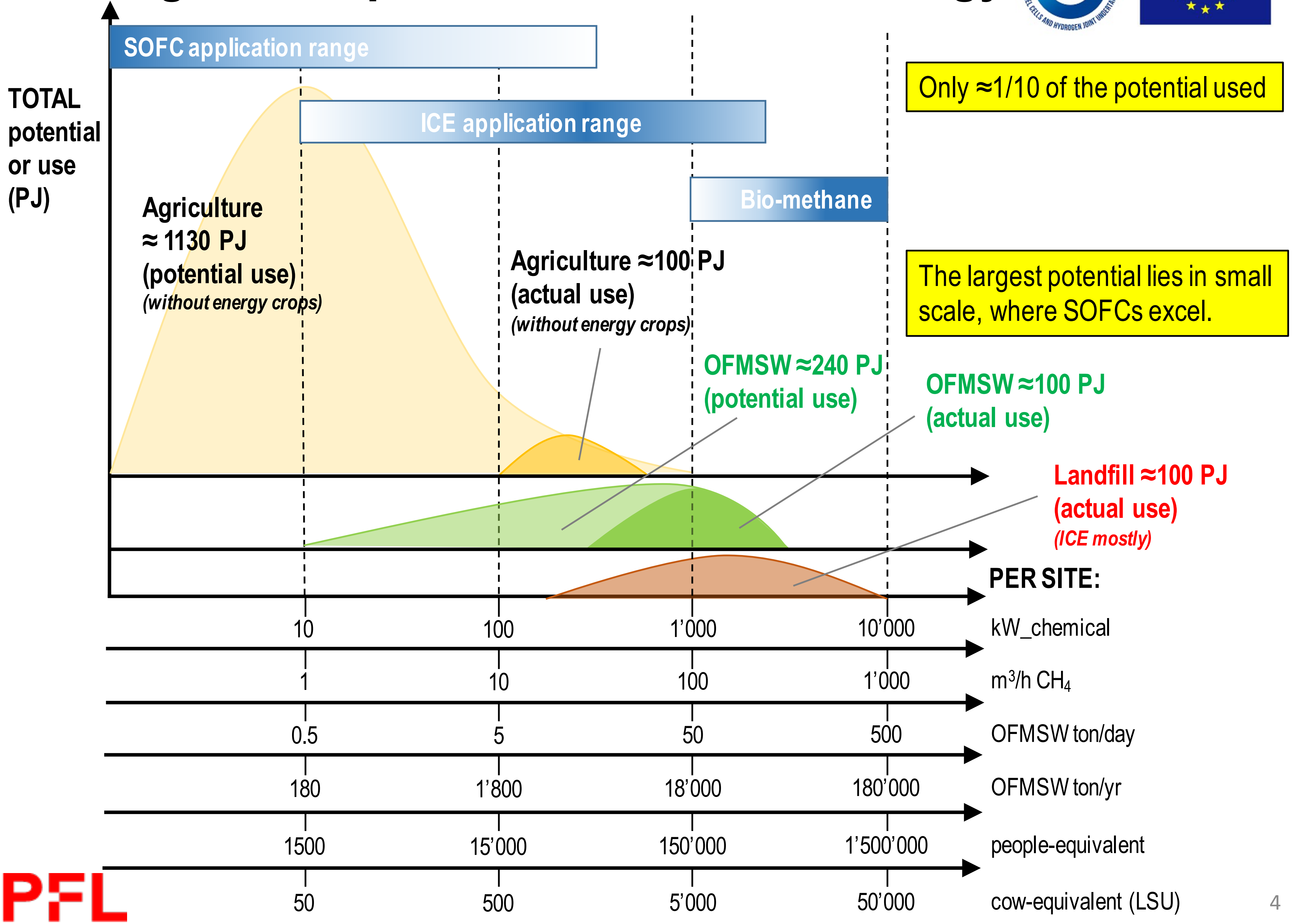
Testing – WP3

EU POTENTIAL BIOGAS RESOURCES

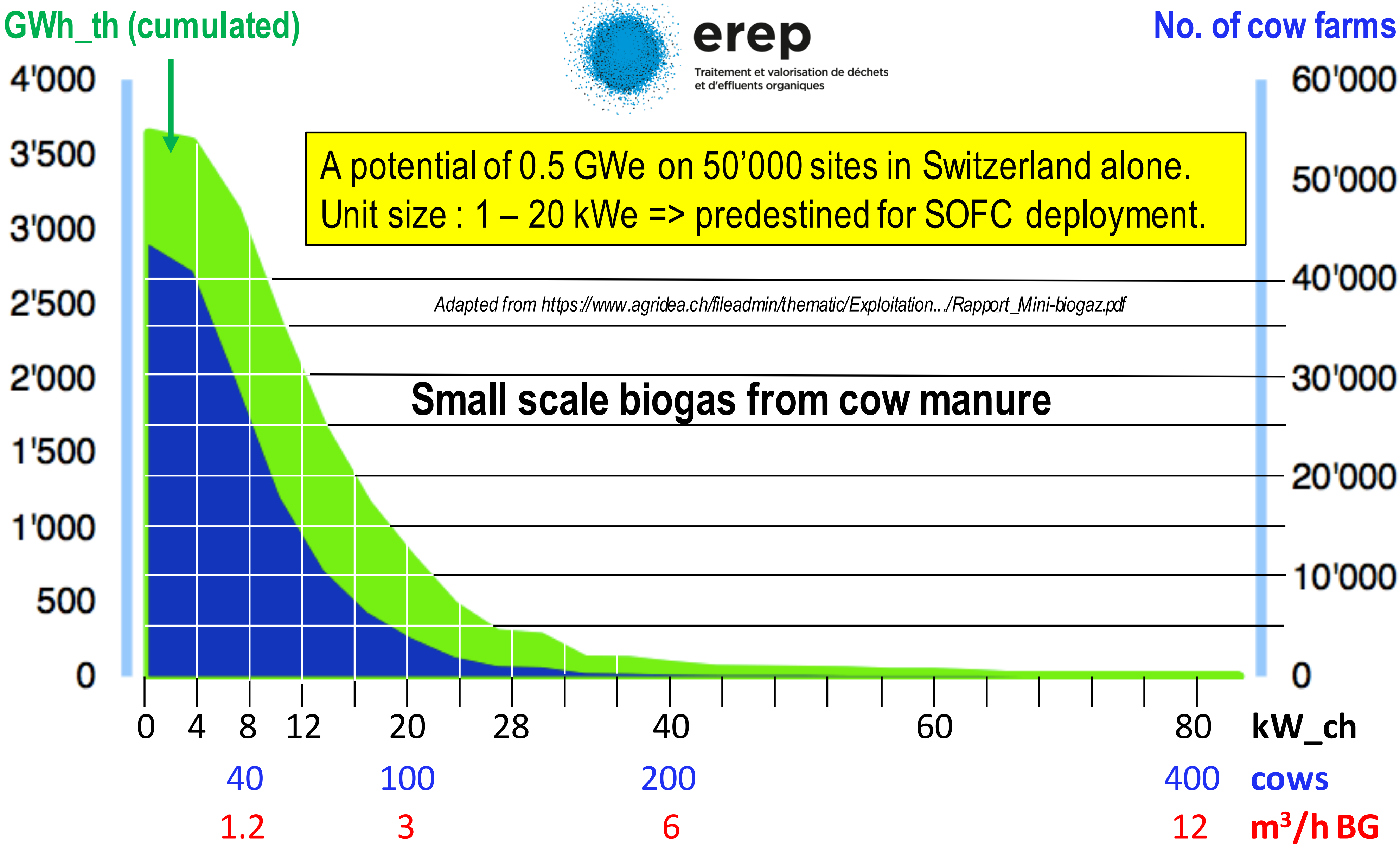


EPFL

EU biogas use, potential, scale, technology



Example: biogas from manure (CH)



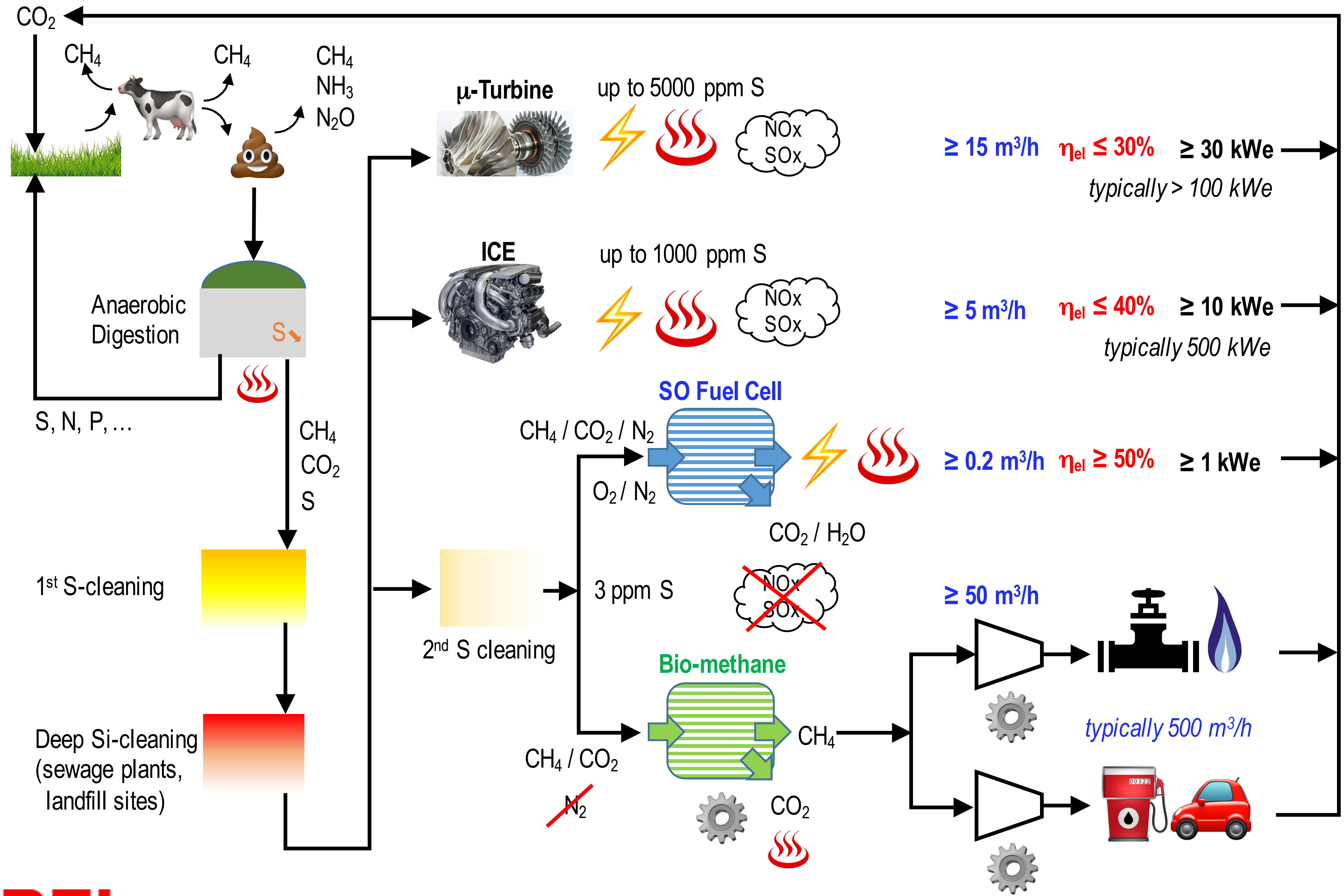
A potential of 0.5 GWe on 50'000 sites in Switzerland alone.
Unit size : 1 – 20 kWe => predestined for SOFC deployment.

=> The situation is similar for the whole European agriculture

Messages

- Biogas = underused resource
- often small scale, especially farms
- small scale digesters now offered as ‘containers’ (6 m long, 33 m^3, 1 ton/day waste, ≈10 kWe)
- millions of potential sites
- world market ≈ 15 x the EU market
- there is a strong push and competition from bio-methane separation and grid injection; but this is presently limited to >100 m^3/h and rather >500 m^3/h production

Biogas cleaning / conversion comparison



Messages

- Biogas cleaning is a requirement for all downstream conversion
- Engines (ICE) are robust but emit high SOx, NOx
- SOFC : most efficient and cleanest
- need for low cost cleaning (essentially for **sulfur**) and low cost SOFC (by high volume production)
- **W2W** addresses this

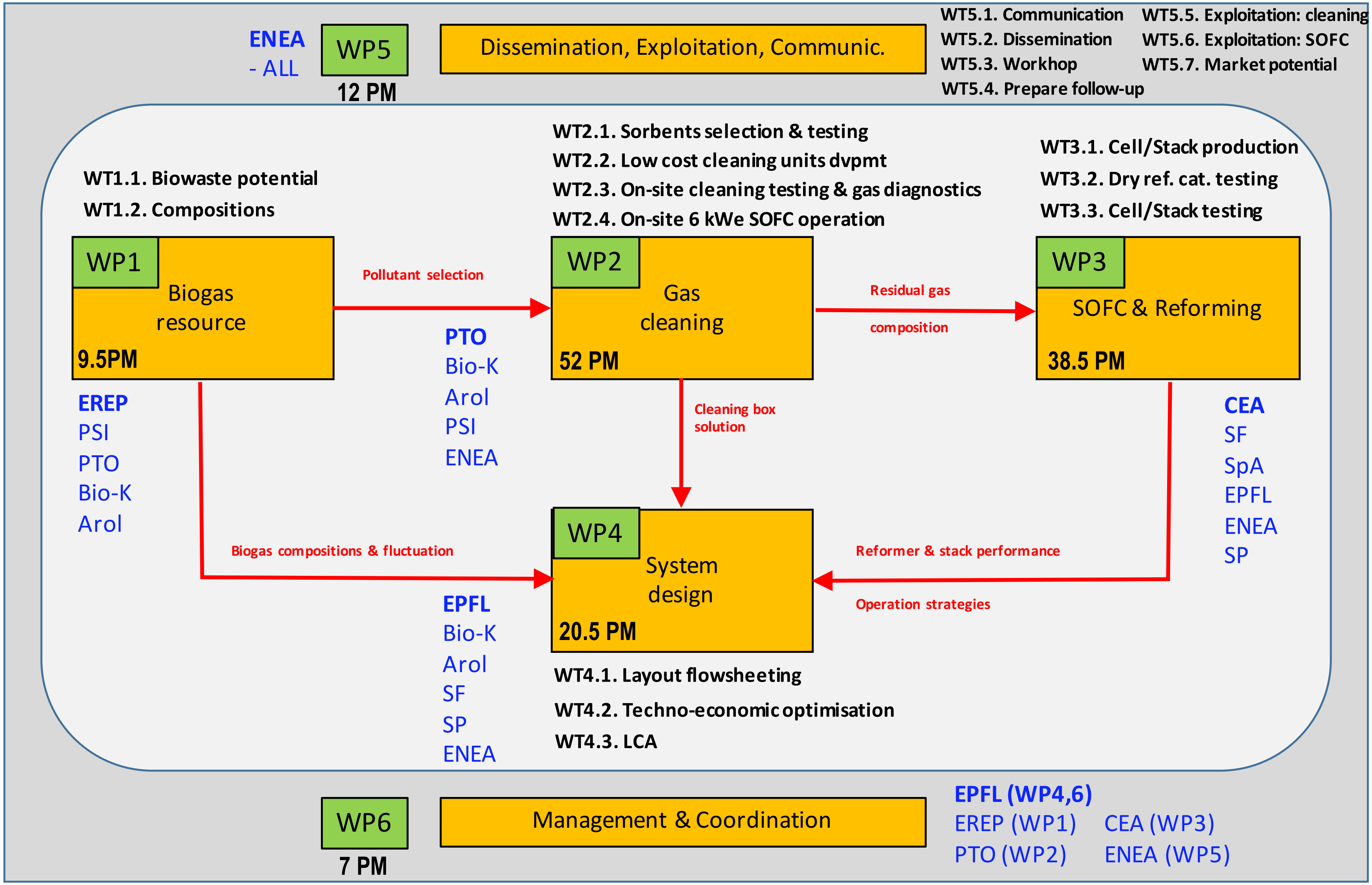
Objectives

- Design and engineer a biogas-SOFC CHP system with minimal gas pre-processing, low-cost pollutant removal and optimal thermal integration.
- 2 cleaning approaches and hardware development:

Site size (kWe)	Bio-source	Cleaning requirement	How	PoC in W2W	Where
few kWe to tens kWe	farms; local OFMSW	H_2S, org. S (1000 ppm)	solid sorbents	6 kWe SOFC (BlueGen-II)	CH
>hundreds kWe	large OFMSW; landfill	H_2S, org. S (100 ppm) Si (10 ppm)	e.g. cooling, other methods	Cleaning installed on MSW/LF site	IT

- validate cleaning with gas analytics
- Cost projections for high volume production for both the cleaning and SOFC systems.
- Detailed full system model
  - considering feedstock, composition fluctuations, gas dilution and pollutant signatures
  - optimizing thermal integration with bio-CO_2 (**dry-dominant reforming**) and digester heating, to maximise net electrical efficiency and minimise cost
- Post-project multiplication of developed solutions (with Advisory Board)

Work plan



ENEA
- ALL
WP5
12 PM
Dissemination, Exploitation, Communic.
WT5.1. Communication
WT5.2. Dissemination
WT5.3. Workhop
WT5.4. Prepare follow-up
WT5.5. Exploitation: cleaning
WT5.6. Exploitation: SOFC
WT5.7. Market potential
WT1.1. Biowaste potential
WT1.2. Compositions
WP1
Biogas resource
9.5PM
EREP
PSI
PTO
Bio-K
Arol
Pollutant selection
PTO
Bio-K
Arol
PSI
ENEA
WT2.1. Sorbents selection & testing
WT2.2. Low cost cleaning units dvpmt
WT2.3. On-site cleaning testing & gas diagnostics
WT2.4. On-site 6 kWe SOFC operation
WP2
Gas cleaning
52 PM
Residual gas composition
WT3.1. Cell/Stack production
WT3.2. Dry ref. cat. testing
WT3.3. Cell/Stack testing
WP3
SOFC & Reforming
38.5 PM
CEA
SF
SpA
EPFL
ENEA
SP
Cleaning box solution
Biogas compositions & fluctuation
Reformer & stack performance
Operation strategies
WP4
System design
20.5 PM
EPFL
Bio-K
Arol
SF
SP
ENEA
WT4.1. Layout flowsheeting
WT4.2. Techno-economic optimisation
WT4.3. LCA
WP6
7 PM
Management & Coordination
EPFL (WP4,6)
EREP (WP1)
PTO (WP2)
CEA (WP3)
ENEA (WP5)

Gas cleaning starting point

	Pollutant to remove	Agro-waste	OFMSW	LFG	S-o-A cleaning	SOFC/ reformer tolerance
1	H_2S org. sulfur (COS, CS_2, mercaptans)	H_2S: **1000s ppm** org. sulfur: several **ppm**	H_2S: **100s ppm** org. sulfur: several **ppm**	H_2S: **100s ppm**	in-situ biological/ chemical + chem. wet/oxidative sorption + deep dry solid sorption	1 ppm
2	Siloxanes D4, D5,…	undetected	up to 0.1 ppm	0.4 – 23 ppm Si	Dry cold solid sorption	0.01 ppm
3	Halogens (X)	0.2-1.4 ppm HCl 0.1 ppm halo-C	0.2-1.6 ppm HCl 1 ppm halocarbons	11-20 ppm HCl 6-14 ppm halo-C	(no strict SOFC limit; co-adsorbed with S, (Si))	20 ppm
4	Other VOC (linear HC, aromatics)	1-3 ppm	1-50 ppm	100s ppm	(no strict SOFC limit; co-adsorbed with S, (Si))	1000s ppm

Key questions: *Can S be removed cheap enough down to **1 ppm** or better?*

*How important is **organic sulphur**?*

*What can be the **impact of X / VOC on S(Si)-cleaning** efficiency (matrix, roll-up)*

*Can **Si** be removed completely?*

*Effect on the **reformer**?*

Cleaning thresholds: other technologies

Trace compound	Grid injection quality	Gas vehicle quality	ICE	µ-Turb.	SOFC (SP)
H_2S	5 mg/m³ (=3.3 ppm)	5 mg/m³ (=3.3 ppm)	<150 ppm <2000 capable	<10000 ppm	1 ppm
Organic S					1 ppm
Siloxanes (total Si)	1 mg/m³ (=800 ppb) (boiler limit: 0.1 mg/m³)	0.1 mg/m³ (=80 ppb)	30 ppb 10-20 mg/m³	<10 ppb	10 ppb
Cl/F	1 mg/m³ Cl (0.6 ppm) 10 mg/m³ F (12 ppm)		60-490 ppm	200 ppm	10 ppm
Linear HC		-2°C HC dewpoint			0.5%
Aromatics					0.5%
H_2 content	2 mol%	2 mol% (limit=steel tank)	10%	>5%	high
O_2 content	0.001 to 1 mol%	1			<15% POX
CO	0.1 mol%				high
NH_3, amine	3-10 mg/m³ (4-13 ppm)	10 mg/m³	50-100 mg/m³		no limit

Key questions: *Could the SOFC (and reformer) tolerate **3 ppm S** ?*

*Could the reformer tolerate **80 ppb Si** ?*

Bioresourcing results (WP1)

- **Agricultural bio-waste**, particularly crops residues, represent the most important unexploited bio-waste resource. **0.925 PWh/y at EU level, ~0.2 PWh/y in France, ~0.1 PWh/y in Germany, ~0.05 PWh/y in Italy.**

- **OFMSW currently treated by composting** processes would be suitable for biogas production and valorisation in SOFC. **6.3 TWh/y** in CH + D + F + IT .

- The **potential of bio-waste able to run very small scale SOFC (5 kWe) is low** compared to other scales (37 TWh, CH/D/F/IT). The **deployment potential for 20-30 kWe scale SOFC** is more important (153 TWh, CH/D/F/IT). **These two scales presently lack a biogas valorisation technology** adapted to their size.

- The potential of bio-waste able to run **larger scale SOFC (>50 kWe incl. multi-100 kWe) is also significant** (160 TWh, CH/D/F/IT); however this **competes with other valorisation technologies** currently available and largely implemented (ICE).

Gas cleaning recommendations–WP2

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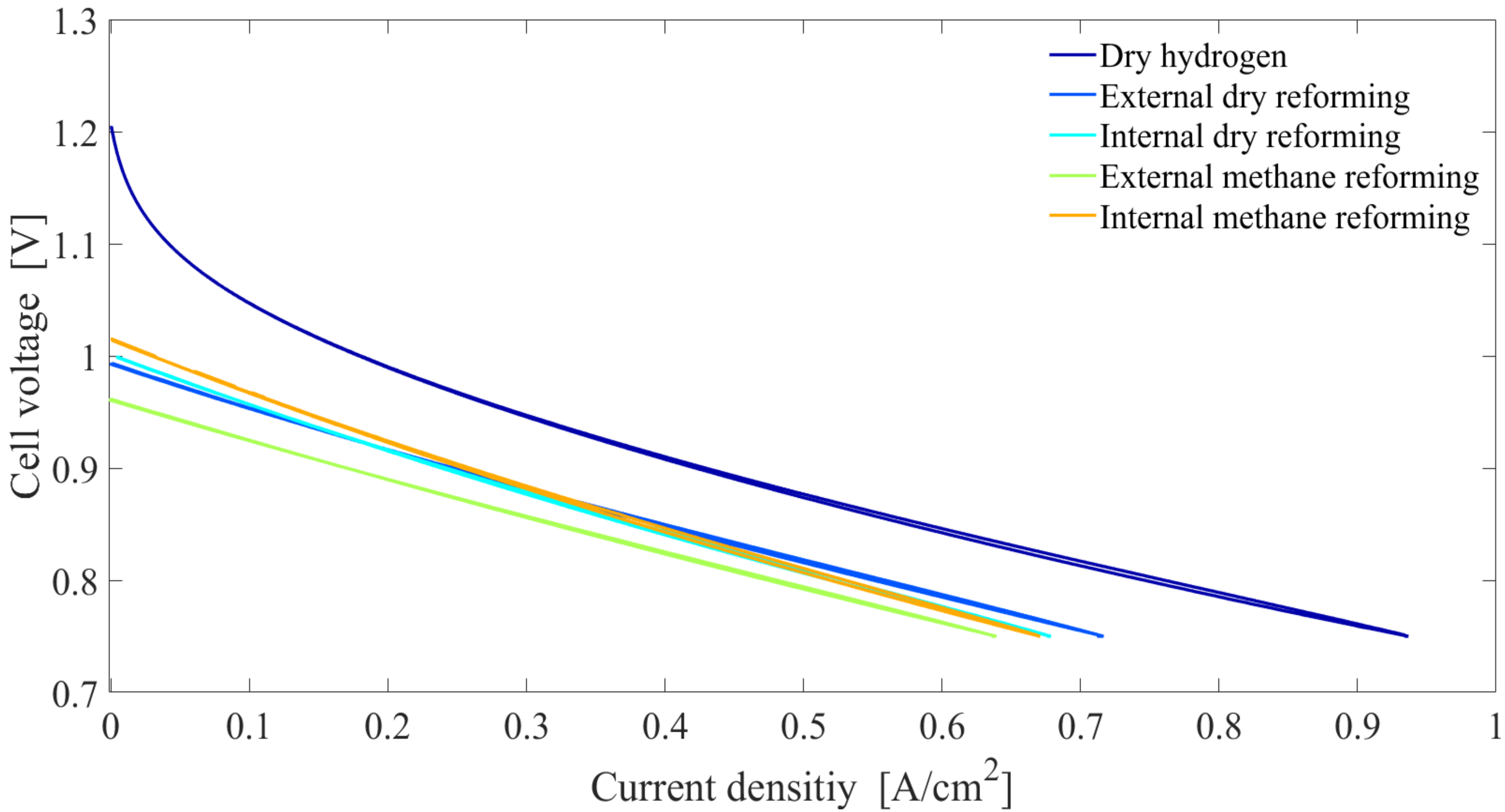
- High site-to-site variability → sampling campaign(s) should be on-site before SOFC installation
- High temporal variability per site → gas cleaning should be oversized for SOFC protection
- The more difficult compounds are not the most abundant.
  – 300 ppm_v H_2S is removed quite easily; 1 ppm_v DMS is not.
  – if SOFC can tolerate ~5 ppm_v sulfur, the gas cleaning would be much easier/cheaper
- H_2S is often measured online and available.
  – Sizing cleaning units for H_2S should look at a 1-year average H_2S concentration.
- To come up with a standardized cleaning solution, sorbent tests focus on the worst case: difficult compounds (H_2S, DMS, COS, CH_3S) in difficult matrix conditions (+VOC, Si).
- 6 commercial sorbents have been selected and are under test campaigns

Cell test results (WP3)



%vol	H_2	CH_4	CO	CO_2	H_2O
Dry ref. internal	0	25	0	75	0
Dry ref. external	23	0	43.5	23	10.5
Methane ref. int.	0	33	0	22	45
Methane ref. ext.	53	0	26	8	13

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