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Selection and sustainability assessment of NETPs

WP1 leader: Gonzalo Guillén-Gosálbez
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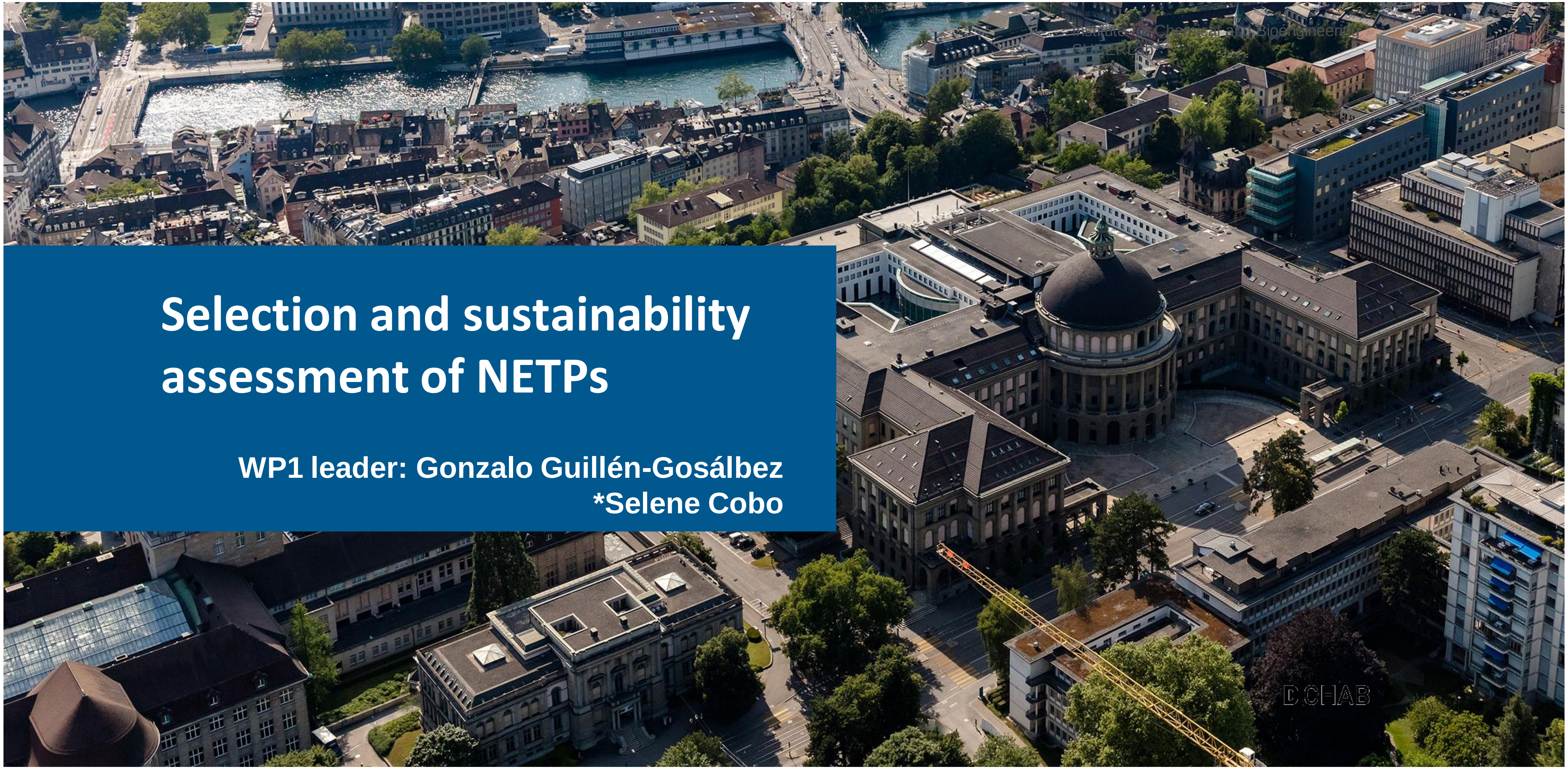
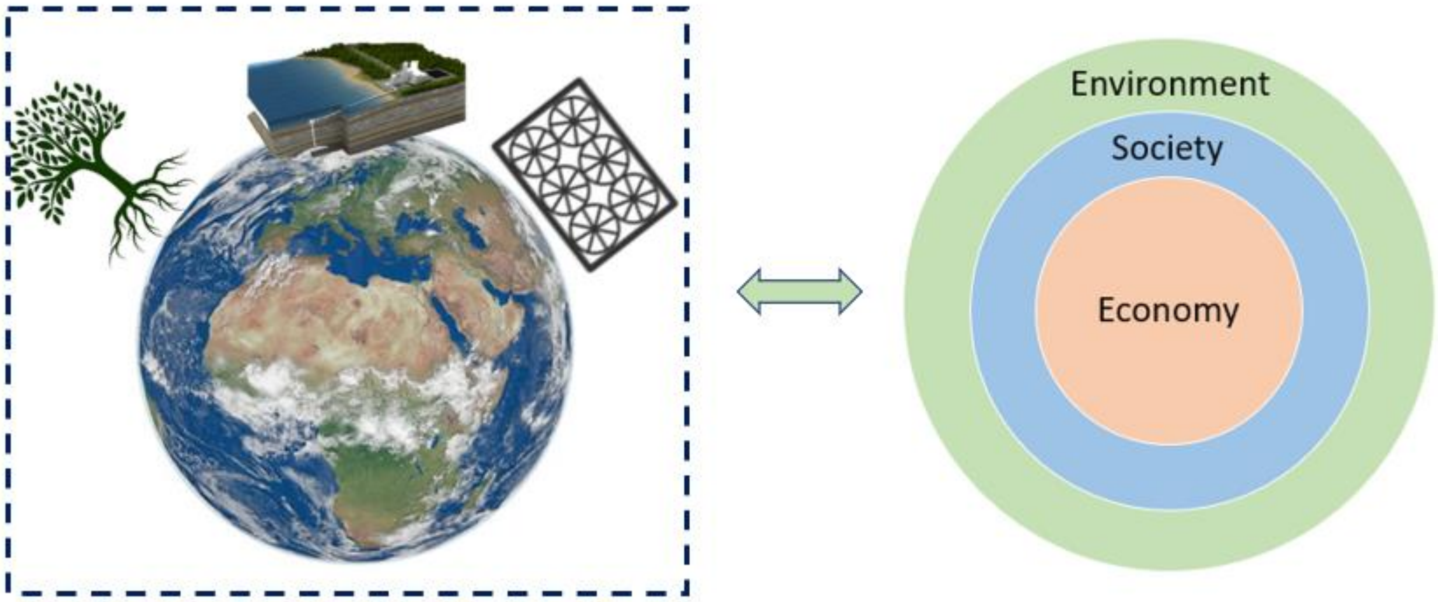


WP1 Objectives

To quantify the sustainability performance of NETPs

- To review current and emerging NETPs and select those that will be studied in the course of the project. ✓
- To identify sustainability KPIs. ✓
- To identify indicators and trade-offs within all sustainability dimensions for the selected NETPs.
- To provide a performance evaluation and benchmark for the selected NETPs.

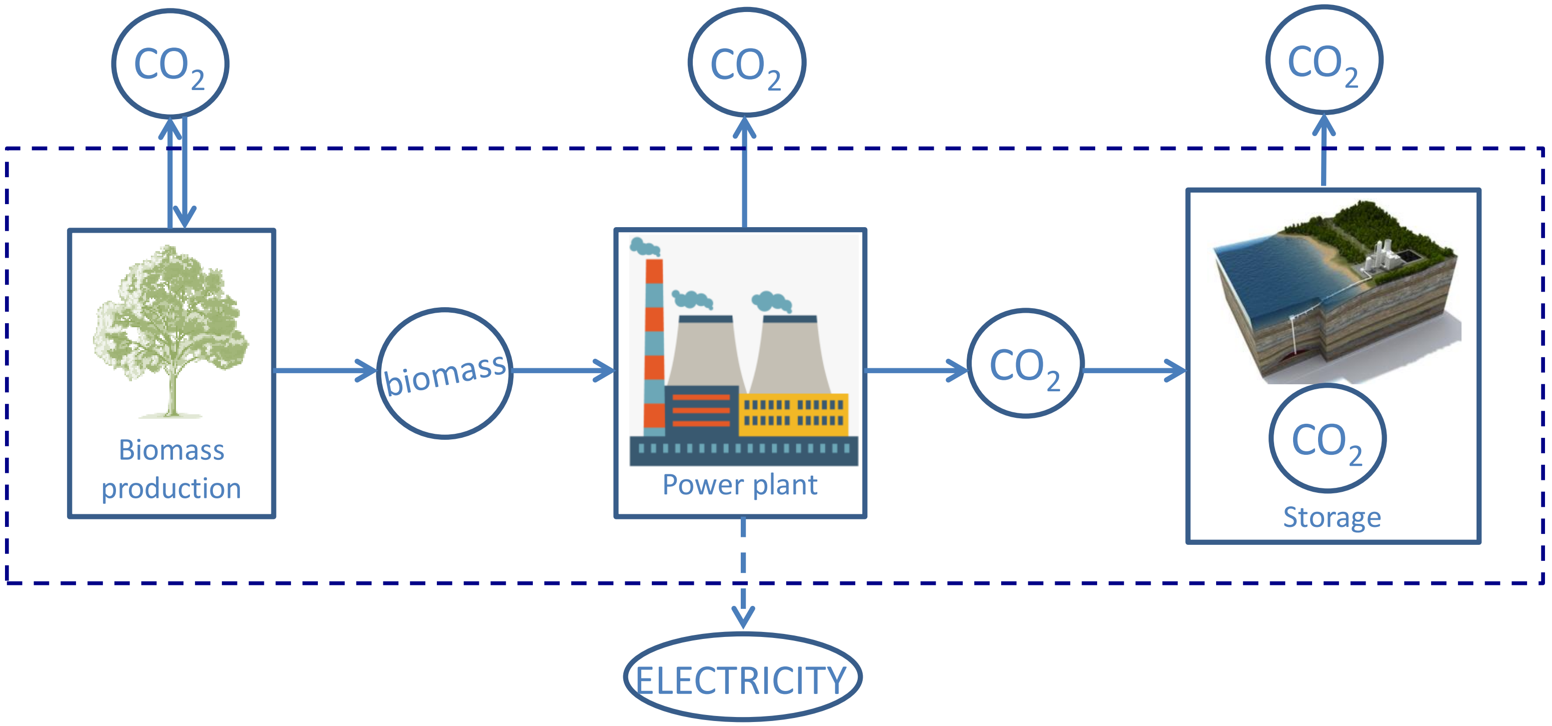


Definition of NETPs

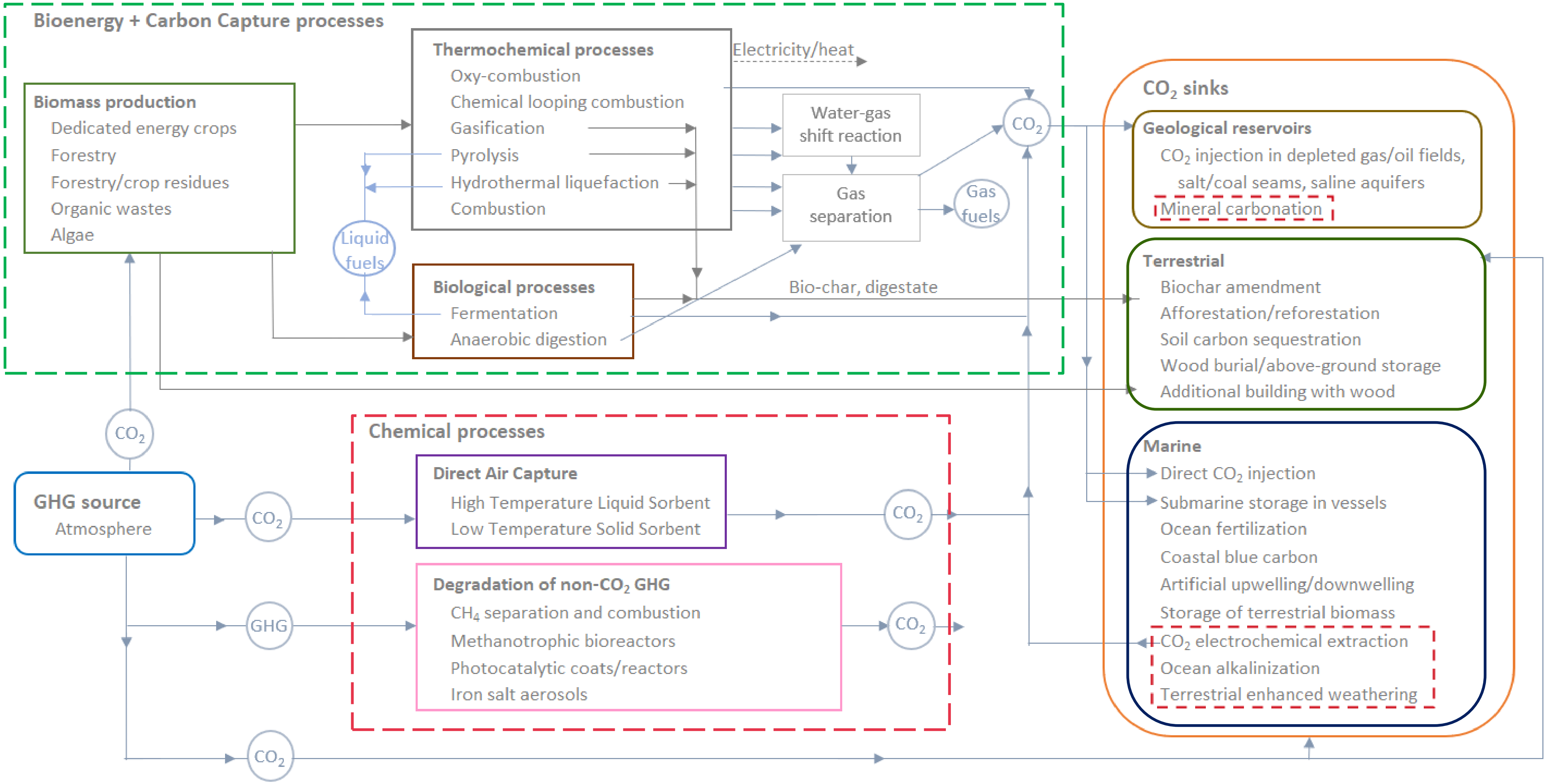
Negative emission system

i. Its life cycle GHG emissions cannot exceed the amount of GHGs withdrawn from the atmosphere and subsequently stored.

ii. The GHGs must be sequestered “in a manner intended to be permanent”.



Overview of potential NETPs



Net negative GHG balance still not confirmed for some of these technologies/processes

Enhancement of natural carbon sinks. State-of-the-art

Terrestrial NETPs

- Easy-to-implement practices
- NGOs/Trillion Tree Campaign

Marine NETPs

- Low TRLs
- Few experimental results

BECCS. State-of-the-art

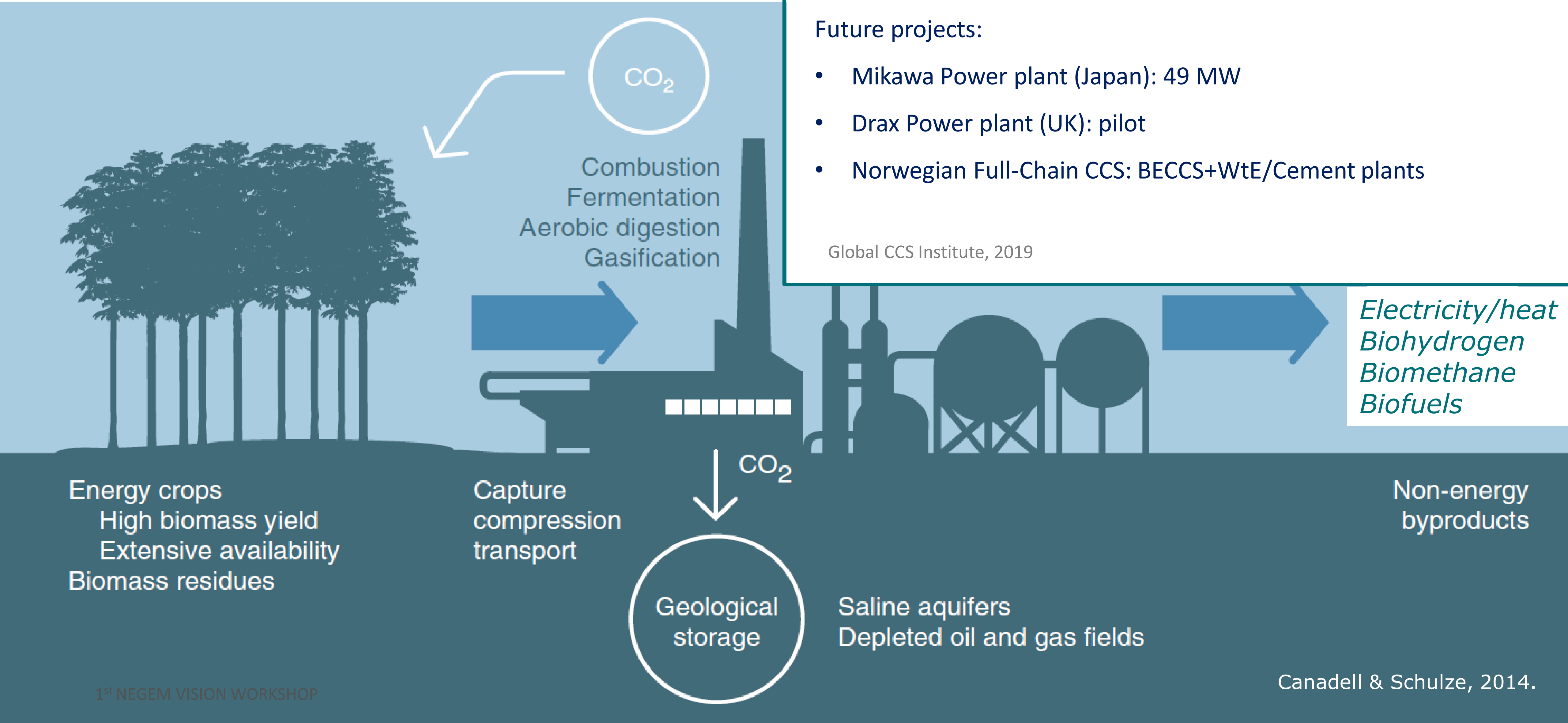
Total BECCS, 2019: 1.5 Mton CO_2

Illinois plant (ethanol production): 1 Mton CO_2/yr

Future projects:

- Mikawa Power plant (Japan): 49 MW
- Drax Power plant (UK): pilot
- Norwegian Full-Chain CCS: BECCS+WtE/Cement plants

Global CCS Institute, 2019



Canadell & Schulze, 2014.

Direct Air Capture. State-of-the-art

Table 1. Reported DAC plants

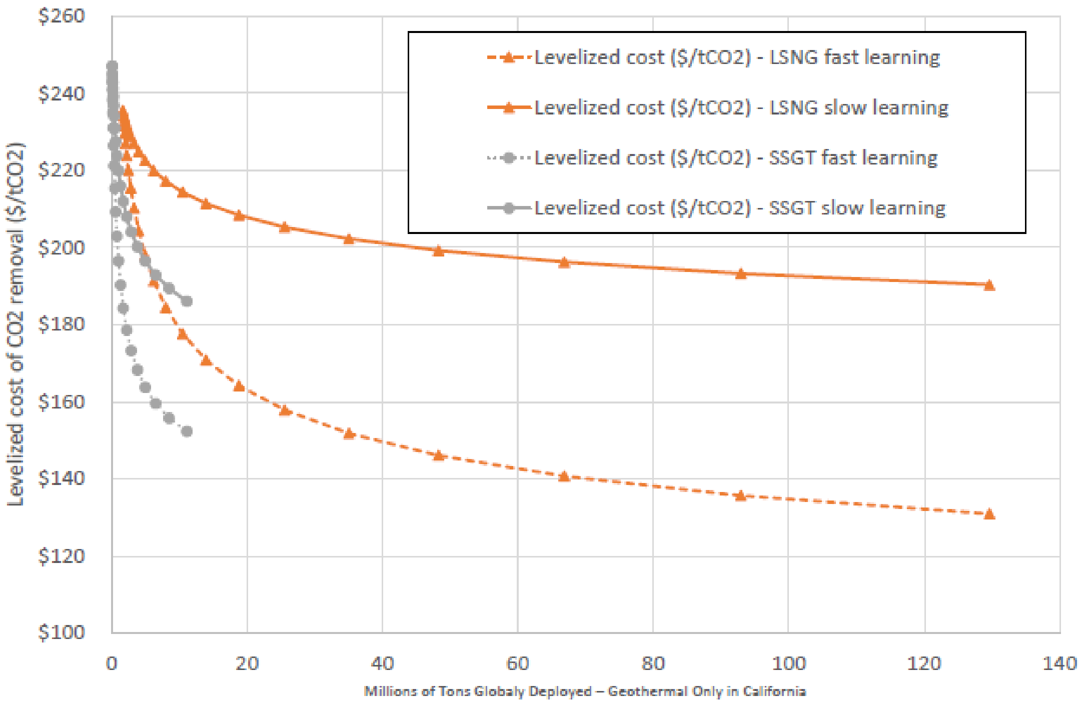
Company	Location	Technology	Year	Capacity (tons CO_2/y)
Global Thermostat	Menlo Park, CA, USA	LTSS	2010	?
Global Thermostat	Menlo Park, CA, USA	LTSS	2013	?
Climeworks	Dresden, Germany	LTSS	2014	?
Carbon Engineering	Squamish, BC, Canada	HTLS	2015	365
Climeworks	Hinwil, Switzerland	LTSS	2017	900
Climeworks	Hellisheidi, Iceland	LTSS	2017	50
Oy Hydro-cell	VTT Jyvaskyla, Finland	LTSS	2017	1.4
Climeworks	Troia, Apulia, Italy	LTSS	2018	150
Global Thermostat	Huntsville, AL, USA	LTSS	2018	4000
TOTAL				5466.4

Lawrence Livermore National Laboratory, 2020

New plants under construction:

Climeworks: 4 kton/yr

Carbon Engineering: 0.5 Mton/yr



Lawrence Livermore National Laboratory, 2020

Limited by resource use and scale-up rates

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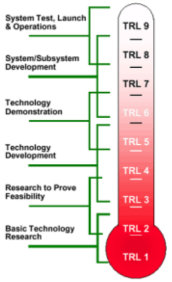
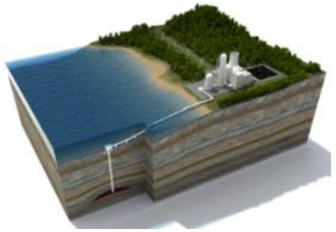
Selection of NETPs





TRL Max CDR Costs

Single score

Cut-off criteria:

- ***Low potential**: TRL≤3, CDR≤0.5 Gtonne·yr^{-1}, costs>200 €·ton^{-1}, score≤-2*
- ***Intermediate potential**: 3<TRL≤6, 0.5<CDR≤ 7 Gtonne·yr^{-1}, 50 <costs≤200 €·ton^{-1}, -1≤score≤1.*
- ***High potential**: TRL>6, CDR>7 Gtonne·yr^{-1}, costs≤50 €·ton^{-1}, score≥2.*

CDR cut-off: mean CDR projected across 1.5 ºC scenarios for 2030, 2050 and 2100 (IPCC)

Table 2. Ranking of NETPs from lower to higher deployment potential

	NETPs	TRL	Max CDR Gtonne·yr^{-1}	Cost (2019€) €·tonne^{-1} CO_2	Score [-3, 3]
TERRESTRIAL	Wood burial or storage	1-2	1-3	7-51	0
	Biochar amendment	4-6	0.5-2	28-112	0
	Afforestation/reforestation	8-9	0.5-3.6	5-47	2
	Soil carbon sequestration	6-7	2-5	0-93	2
	Building with wood	8-9	0.5-1	Negligible	2
MARINE	Downwelling	1-2	0.035	228-5142	-3
	Upwelling	1-3	0.059	n/a	-2
	Ocean fertilization (Fe)	1-4	3.6	459	-2
	CO_2 extraction from seawater	2-3	[a]	347-562	-1
	Ocean storage of terrestrial biomass	1-2	6.75	104	-1
	Ocean alkalinization	2-3	8.43-12.15	3-160	0
	Coastal blue carbon	5-6	0.13-0.80	9	0
	Ocean fertilization (N and P)	2-3	5.5	21	1
	Direct injection[1]*	*1-2*	*12.5*	*14-19*	*1*
	Submarine storage in vessels[1]*	*1-2*	*[a]*	*16*	*1*
BECCS	Hydrothermal liquefaction	5	0.5-5	210-294	-1
	Algal BECCS	1-2	53	n/a	0
	Anaerobic digestion	8	2.8	139-313	0
	Chemical looping combustion	4	0.5-5	n/a	0
	Oxy-combustion	5	0.5-5	136	0
	Combustion	4-6	0.5-5	116	0
	Pyrolysis	7	0.5-5	136-387	0
	Gasification	3-5	0.5-5	160-182	0
	Ethanol fermentation	7	0.5-5	19-163[j]	1
CHEMICAL	Degradation of non-CO_2 GHG	1-3	n/a	n/a	-1
	Terrestrial enhanced weathering	3-5	4.9-95	25-591	0
	Ex situ mineral carbonation[1*]	*3-4*	*[a]*	*60*	*1*
	Direct air capture (LTSS, MSA)[2]*	*3-4*	*[a]*	*97*	*1*
	Direct air capture (LTSS, TSA)[2*]	*7*	*[a]*	*≈ 600*	*1*
	Direct air capture (HTLS)[2*]	*7*	*[a]*	*88-216*	*2*
	In situ mineral carbonation[1*]	*7*	*[a]*	*17*	*3*

[1*] Storage technology, integration with atmospheric CO_2 capture required to achieve negative emissions.
[2*] CO_2 capture technology, storage required to achieve negative emissions.
[a] Limited by resource use and scale-up rates.

Selection of NETPs

Table 3. Potential unintended impacts of NETPs
(positive impacts: green cells, either positive or negative impacts: yellow cells, negative impacts: red cells)

	NETPs	Release of stored C	Lag between action & CDR	Land-use change	Crop productivity	Albedo change	Biodiversity impacts	Ocean acidification	High water demand	High energy demand	GHG emissions	Pollutant emissions
TERRESTRIAL	Wood burial or storage										LUC	
	Biochar amendment										LUC; N_2O, CH_4	
	Afforestation/reforestation											
	Soil carbon sequestration										N_2O	N, P
	Building with wood										LUC	
MARINE	Downwelling										CO_2	
	Upwelling										CO_2	
	Ocean fertilization										N_2O, CH_4, DMS	Mining/grinding
	CO_2 extraction from seawater											
	Ocean storage of terrestrial biomass											
	Ocean alkalinization											Particles/metals
	Coastal blue carbon											
	Direct injection [1*]											
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BECCS	Hydrothermal liquefaction										LUC	Fertilizers
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	Pyrolysis										LUC	Fertilizers
	Gasification										LUC	Fertilizers
	Ethanol fermentation										LUC	Fertilizers
CHEMICAL	Degradation of non-CO_2 GHGs										Degraded products	
	Terrestrial enhanced weathering										N_2O	Particles/metals
	Ex situ mineral carbonation [1*]											Mining/grinding
	Direct air capture (LTSS, MSA) [2*]											Sorbent production
	Direct air capture (LTSS, TSA) [2*]											Sorbent production
	Direct air capture (HTLS) [2*]											Sorbent production
	In situ mineral carbonation [1*]											

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Selection of NETPs for the sustainability assessment

TERRESTRIAL NETPs

MARINE NETPs

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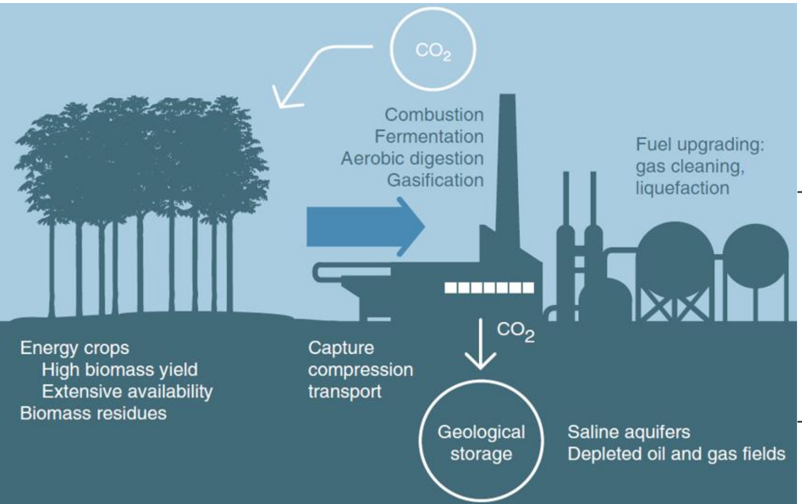
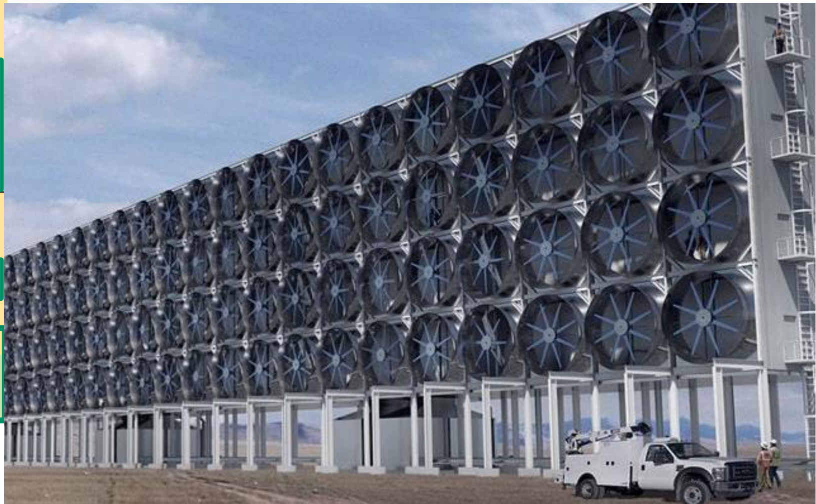
BECCS



CHEMICAL NETPs



How to assess the sustainability of NETPs?

Key Performance Indicators

Technical KPIs

1. CO_2 removal efficiency (net/gross CO_2 removed)
2. Avoided emissions
3. Energy consumption
4. *Sequestration potential*
5. *Storage lifetime*
6. *TRL*

Environmental KPIs

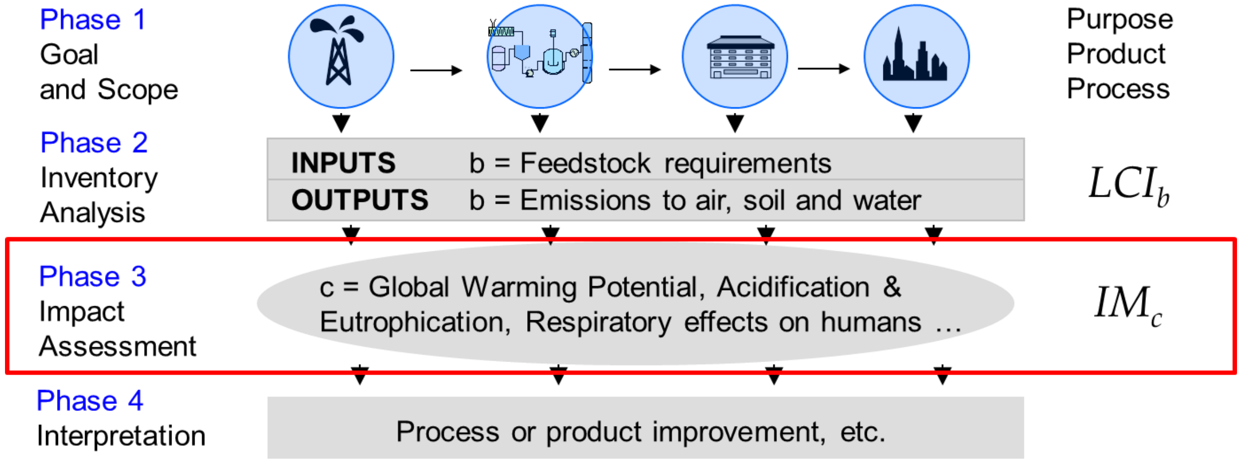
7. Recipe 2016 (midpoint)
8. EU Environmental footprint

Economic KPIs

9. Levelized cost of CO_2
10. Externalities

Social KPIs

11. Human health



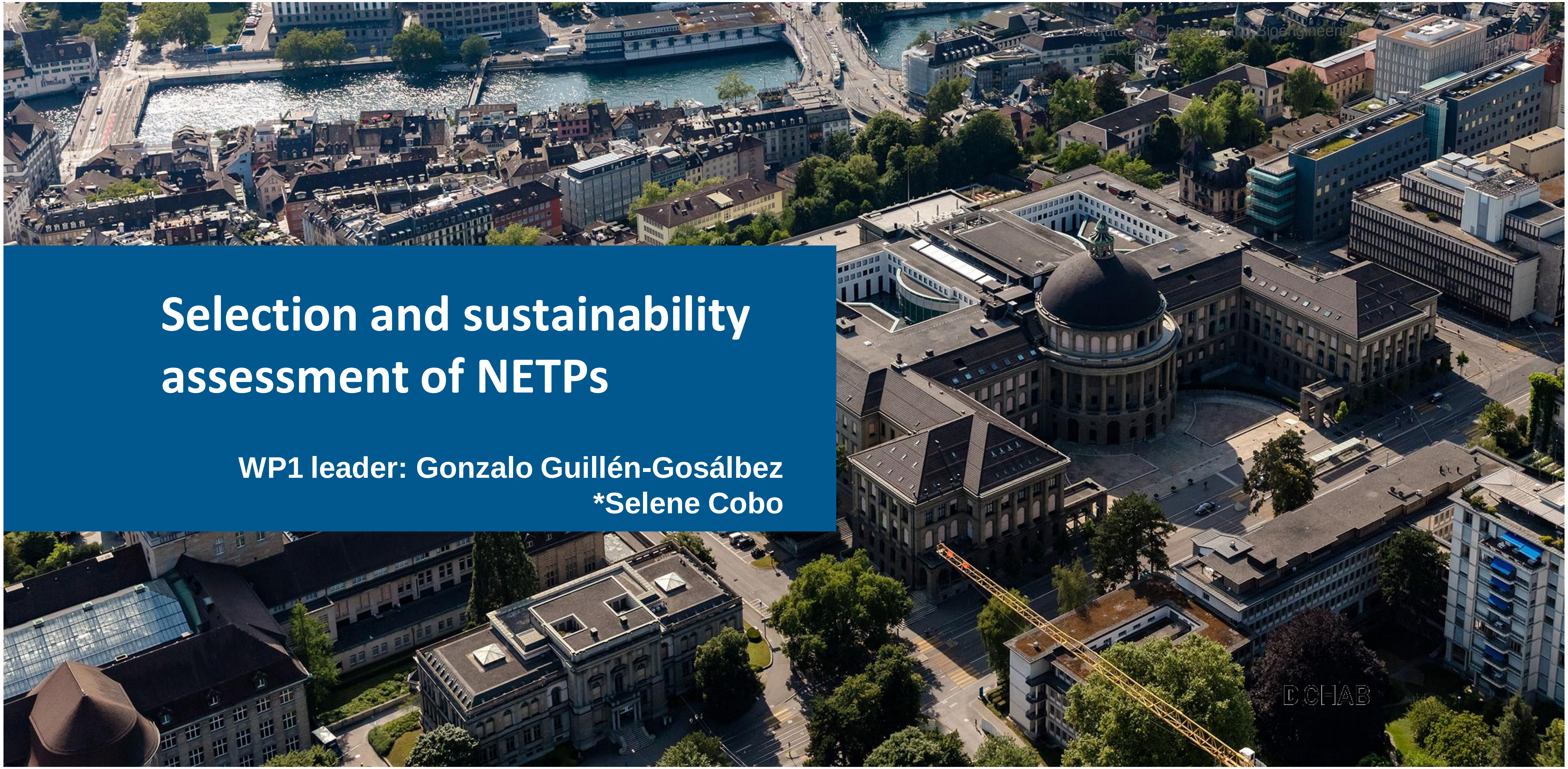
Life Cycle Assessment

Conclusions

- Deployment potential of NETPs currently constrained by their
  - Technical maturity
  - Economic feasibility
  - Resource use
  - Sequestration capacity
  - Local/region-specific environmental impacts

- Investment on a portfolio of NETPs required to meet 1.5 ^{o}C target

- Trade-offs between global warming and other environmental impacts → sustainability assessment required to plan for the deployment of NETPs



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