Enabling CO2 Reuse Value Chains

Arturo Castillo-Castillo, Centre for Environmental Policy, Imperial College London
Athanasios Angelis-Dimakis, School of Applied Sciences, University of Huddersfield

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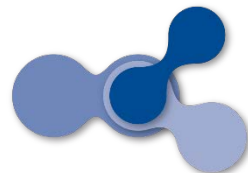
ENCO$_2$RE=

The "enCO$_2$re" Programme

□ enCO$_2$re: "**en**abling CO$_2$ **re**use"
  ◘ Climate-KIC Flagship Programme (2014-2017)
  ◘ Project Coordinator: Covestro
  ◘ Organized in discrete Projects (formerly Activity Lines)

□ Project 1. Value Chain Analysis

Building the value chain

Various Alternative Configurations…

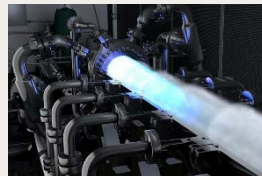*Large scale low purity stream*

Small scale high purity stream

Simple gas compression

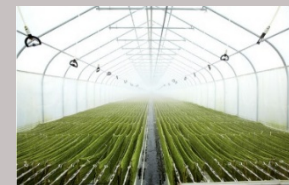
Amine absorption

Oxyfuel combustion

Pipelines

Trucks

Tanker

Algae cultivation

Polymer production

Concrete curing

Source | **Capture** | Transport | End Use

CO$_2$ Sources

Table 1. *Sources Classification Matrix*

	High Level (>90%)	Moderate Level (20%-90%)	Low Level (<20%)
Small Scale (<0.1 Mtpa)	Fermentation Biogas Upgrading Facilities		
Medium Scale (0.1-0.5Mtpa)	Ethylene Oxide Plant Syngas Production Ethanol Plant Methanol Plant	Cement Production Kiln Flue Gas Scrubbing	Biomass Power Plant Fluid Catalytic Cracking Aluminium Production Textile Industry Glass Industry Waste Incineration
Large Scale (≥0.5Mtpa)	Ammonia Synthesis Hydrogen Production Natural Gas Sweetening Oxy-firing Process	Blast Furnace Oxygen Blast Furnace	Oil, Coal and Natural Gas Power Plants Oil Refinery Iron-Steel Mill Pulp & Paper Mill

Source ➤ **Capture** ➤ Transport ➤ End Use

CO$_2$ Capture & Treatment

Table 2. *Overview of CO$_2$ capture technologies applicability*

CO$_2$ Source	Post Combustion			Pre Combustion				Other		
	Chemical Absorption	Solid Sorbents	Membranes	Chemical Absorption	Physical Absorption	Solid Sorbents	Membranes	Oxy fuel combustion	Chemical Looping Combustion	Chemical Looping Reforming
Power Plants										
Steam Turbine	★★★		★					★		
Gas Turbine	★★★		★					★	★	★
IGCC	★★	★	★		★★★		★			
NGCC	★★	★	★		★★		★			
Industrial Processes										
Natural Gas Processing				★★★	★★★	★★	★★★			
Ammonia Production				★★★	★★	★★	★★			
Biogas Production				★★	★					
Cement Production	★★	★						★		
Steel Production	★★★							★		

Note: ★★★ represent the preferable commercially available options, ★★ represent all other commercially available options and ★ represents promising alternatives which are still in the R&D phase.

Source | **Capture** | Transport | End Use

CO$_2$ Capture Cost

☐ Indicative cost curves, based on literature review, for the most important CO$_2$ sources and preferably commercially available options (★★★ in the previous table).
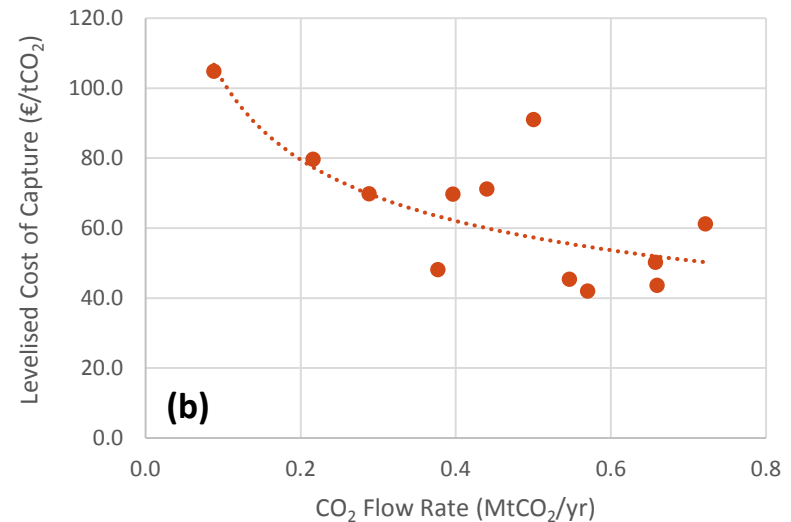

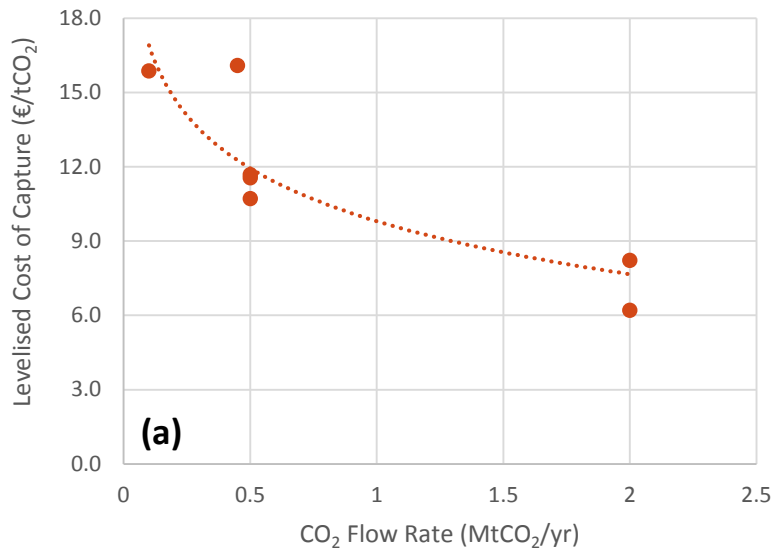*Figure 1.* *Capture cost for (a) high purity source input purity >95%) and (b) cement industry using post combustion MEA capture*

Source Capture Transport End Use
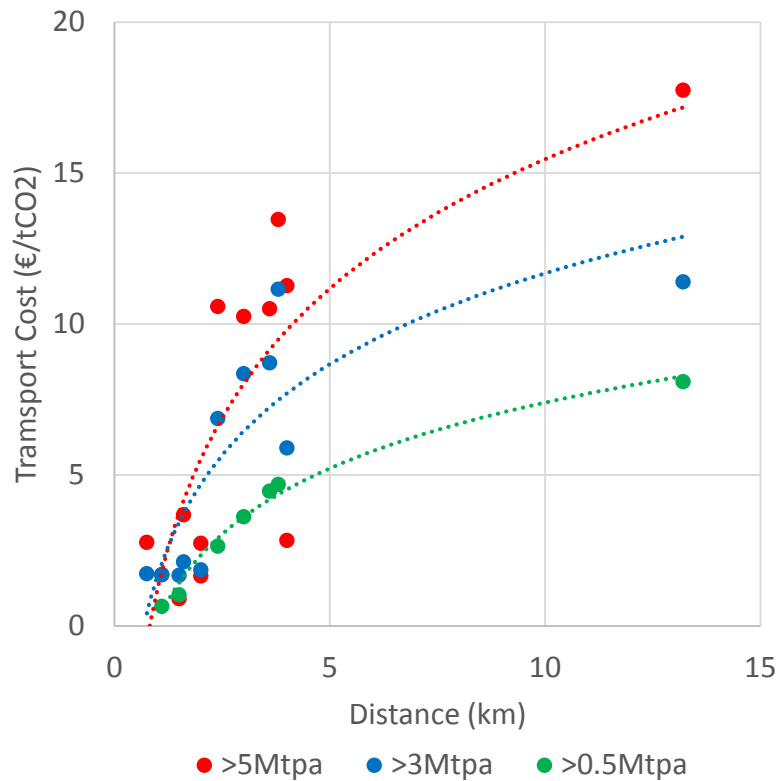
CO$_2$ Transport

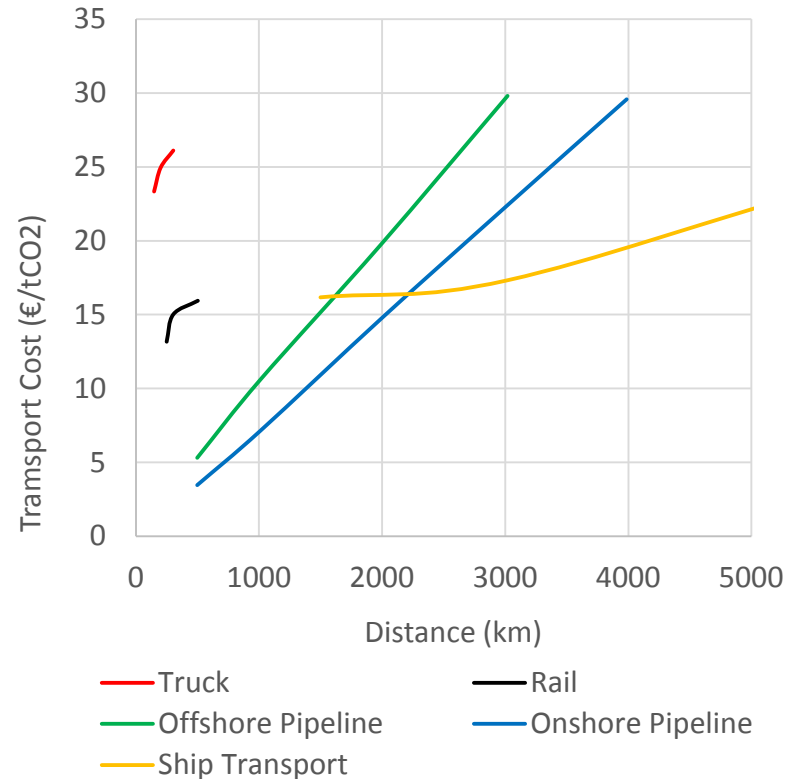**Figure 2.** *Short distance CO$_2$ transportation using onshore pipelines*

Figure 3. *Transportation cost for various options for medium and long distances*

Source | **Capture** | **Transport** | End Use

Tipping Point Analysis

□ By combining the capture and transportation cost, the economic tipping points have been calculated

Table 3. *Capture and transportation cost (€/tCO$_2$ captured) as a function of the total mass flow (MtCO$_2$/yr) and the distance covered, for short distances (0-100 km) using onshore pipelines for a high purity source*

		Distance Covered (km)																
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.5	2	2.5	3	10	50	100
Total Mass Flow (MtCO2/yr)	0.01	23.1	26.4	28.3	29.6	30.7	31.5	32.2	32.9	33.4	33.9	35.8	37.1	38.2	39.0	44.7	52.2	55.5
	0.02	19.9	23.1	25.0	26.4	27.4	28.3	29.0	29.6	30.2	30.7	32.6	33.9	35.0	35.8	41.4	49.0	52.2
	0.03	18.0	21.2	23.1	24.5	25.5	26.4	27.1	27.7	28.3	28.8	30.7	32.0	33.1	33.9	39.6	47.1	50.3
	0.04	16.7	19.9	21.8	23.1	24.2	25.0	25.8	26.4	26.9	27.4	29.3	30.7	31.7	32.6	38.2	45.7	49.0
	0.05	15.6	18.9	20.8	22.1	23.1	24.0	24.7	25.3	25.9	26.4	28.3	29.6	30.7	31.5	37.2	44.7	47.9
	0.06	14.8	18.0	19.9	21.2	22.3	23.1	23.9	24.5	25.0	25.5	27.4	28.8	29.8	30.7	36.3	43.8	47.1
	0.07	14.0	17.3	19.2	20.5	21.6	22.4	23.1	23.8	24.3	24.8	26.7	28.1	29.1	30.0	35.6	43.1	46.4
	0.08	13.4	16.7	18.6	19.9	20.9	21.8	22.5	23.1	23.7	24.2	26.1	27.4	28.5	29.3	35.0	42.5	45.7
	0.09	12.9	16.1	18.0	19.4	20.4	21.3	22.0	22.6	23.2	23.6	25.5	26.9	27.9	28.8	34.4	42.0	45.2
	0.1	12.4	15.6	17.5	18.9	19.9	20.8	21.5	22.1	22.7	23.2	25.0	26.4	27.4	28.3	33.9	41.5	44.7
	0.2	9.1	12.4	14.3	15.6	16.7	17.5	18.2	18.9	19.4	19.9	21.8	23.2	24.2	25.1	30.7	38.2	41.5
	0.3	7.2	10.5	12.4	13.7	14.8	15.6	16.4	17.0	17.5	18.0	19.9	21.3	22.3	23.2	28.8	36.3	39.6
	0.4	5.9	9.1	11.0	12.4	13.4	14.3	15.0	15.6	16.2	16.7	18.6	19.9	21.0	21.8	27.5	35.0	38.2
	0.5	4.9	8.1	10.0	11.3	12.4	13.2	14.0	14.6	15.1	15.6	17.5	18.9	19.9	20.8	26.4	33.9	37.2
	0.6	4.0	7.3	9.1	10.5	11.5	12.4	13.1	13.7	14.3	14.8	16.7	18.0	19.1	19.9	25.6	33.1	36.3
	0.7	3.3	6.5	8.4	9.8	10.8	11.7	12.4	13.0	13.6	14.1	16.0	17.3	18.4	19.2	24.8	32.4	35.6
	0.8	2.7	5.9	7.8	9.2	10.2	11.0	11.8	12.4	12.9	13.4	15.3	16.7	17.7	18.6	24.2	31.7	35.0
	0.9	2.1	5.4	7.3	8.6	9.6	10.5	11.2	11.8	12.4	12.9	14.8	16.1	17.2	18.0	23.7	31.2	34.4
	1	1.6	4.9	6.8	8.1	9.2	10.0	10.7	11.4	11.9	12.4	14.3	15.6	16.7	17.5	23.2	30.7	34.0
	2	0.0	1.6	3.5	4.9	5.9	6.8	7.5	8.1	8.7	9.2	11.1	12.4	13.4	14.3	19.9	27.5	30.7

Source ▶ Capture ▶ Transport ▶ End Use

Total Profit for a CO_2 source

- The total profit for each CO_2 source is calculated as:

    Total Profit = CO_2 Price + Carbon Tax - Capture and Transportation Cost

- Where:
  - CO_2 Price is the CO_2 commercial selling price
  - Carbon Tax is the price level of tradable emissions certificates;
  - Capture and Transportation Cost is the cost related to the corresponding stages of the chain
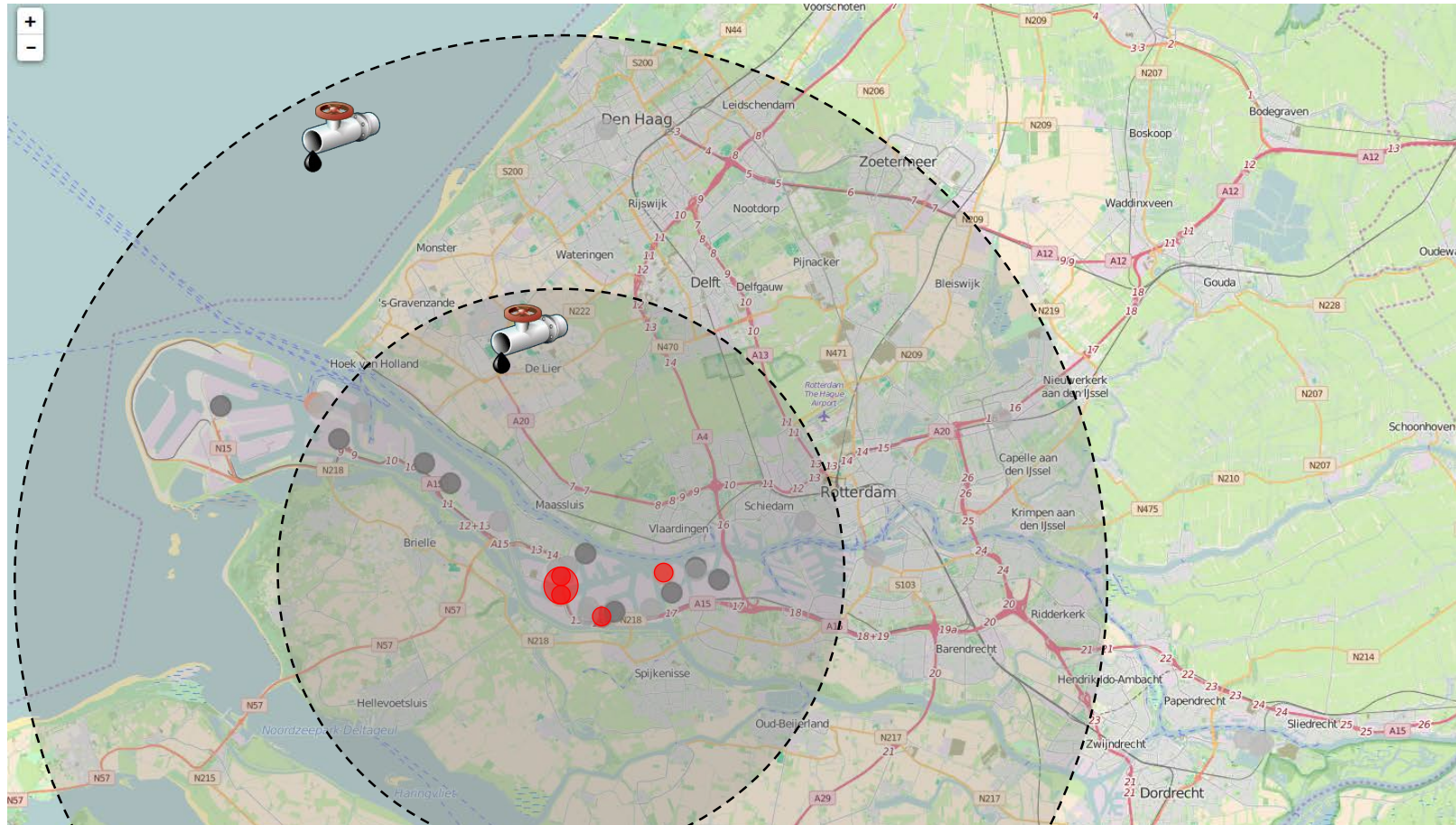- Also, 15% is considered the lowest acceptable margin for a potential investment by industry.

What is the radius of search?

Source | Capture | Transport | End Use

Potential Synergies

☐ Are there nearby sources that could act as an add-on and reduce the overall cost?

- ❑ A small industrial plant / brewery (≈0.1 Mtpa)?
- ❑ Another high purity source (≈0.3 Mtpa)?
- ❑ A large power plant (≈0.8 Mtpa)?

Total Mass Flow (MtCO2/yr)	Distance Covered (km)																
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.5	2	2.5	3	10	50	100
0.1	12.4	15.6	17.5	18.9	19.9	20.8	21.5	22.1	22.7	23.2	25.0	26.4	27.4	28.3	33.9	41.5	44.7
0.2	9.1	12.4	14.3	15.6	16.7	17.5	18.2	18.9	19.4	19.9	21.8	23.2	24.2	25.1	30.7	38.2	41.5
0.3	7.2	10.5	12.4	13.7	14.8	15.6	16.4	17.0	17.5	18.0	19.9	21.3	22.3	23.2	28.8	36.3	39.6
0.4	5.9	9.1	11.0	12.4	13.4	14.3	15.0	15.6	16.2	16.7	18.6	19.9	21.0	21.8	27.5	35.0	38.2
0.5	4.9	8.1	10.0	11.3	12.4	13.2	14.0	14.6	15.1	15.6	17.5	18.9	19.9	20.8	26.4	33.9	37.2
0.6	4.0	7.3	9.1	10.5	11.5	12.4	13.1	13.7	14.3	14.8	16.7	18.0	19.1	19.9	25.6	33.1	36.3
0.7	3.3	6.5	8.4	9.8	10.8	11.7	12.4	13.0	13.6	14.1	16.0	17.3	18.4	19.2	24.8	32.4	35.6
0.8	2.7	5.9	7.8	9.2	10.2	11.0	11.8	12.4	12.9	13.4	15.3	16.7	17.7	18.6	24.2	31.7	35.0
0.9	2.1	5.4	7.3	8.6	9.6	10.5	11.2	11.8	12.4	12.9	14.8	16.1	17.2	18.0	23.7	31.2	34.4
1	1.6	4.9	6.8	8.1	9.2	10.0	10.7	11.4	11.9	12.4	14.3	15.6	16.7	17.5	23.2	30.7	34.0
2	0.0	1.6	3.5	4.9	5.9	6.8	7.5	8.1	8.7	9.2	11.1	12.4	13.4	14.3	19.9	27.5	30.7

Source ▸ Capture ▸ Transport ▸ End Use

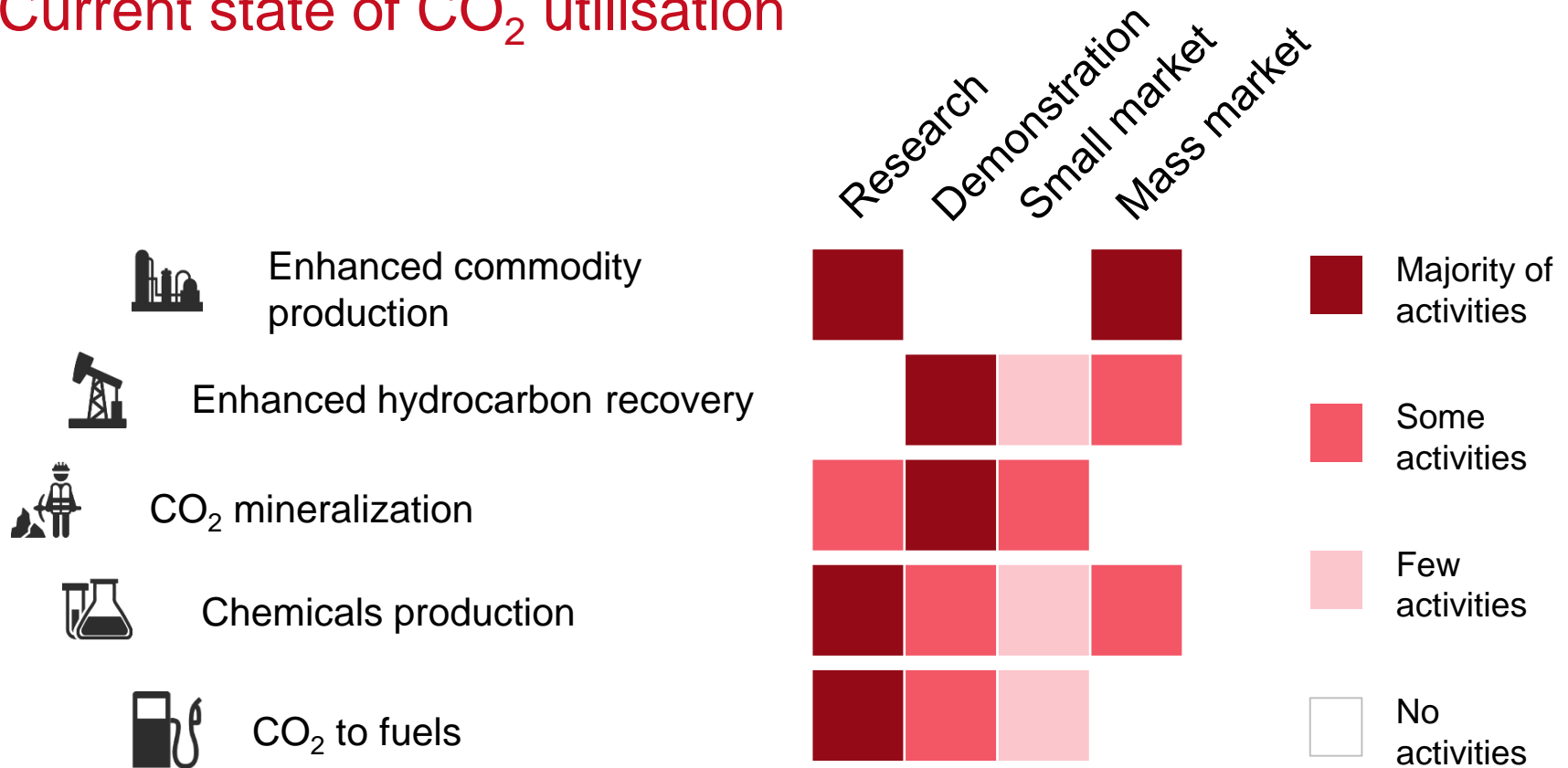# Potential Synergies

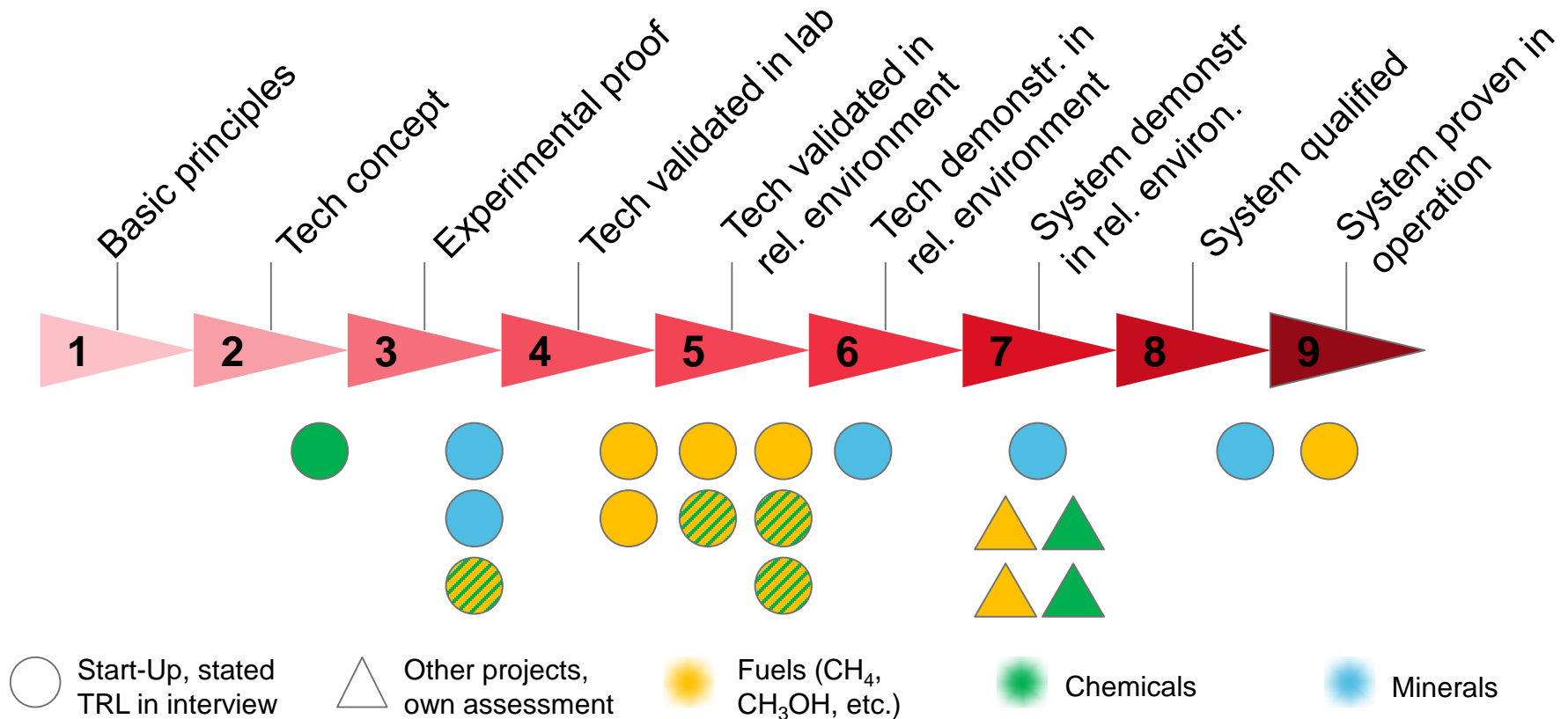**Source** ➤ **Capture** ➤ **Transport** ➤ End Use

Considerations and Trade-offs

□ Important Assumption
  ◻ The CO_2 source is the sole responsible for covering all the costs related to capture, purification and transportation technologies

□ More viable business models can be developed…
  ◻ If costs can be shared among <u>value chain participants</u>.
  ◻ If <u>case-specific characteristics</u> are taken into account (e.g. existing transportation infrastructure)
  ◻ Such an analysis can only be performed on a case by case level, <u>embedded in its socio-economic context</u>
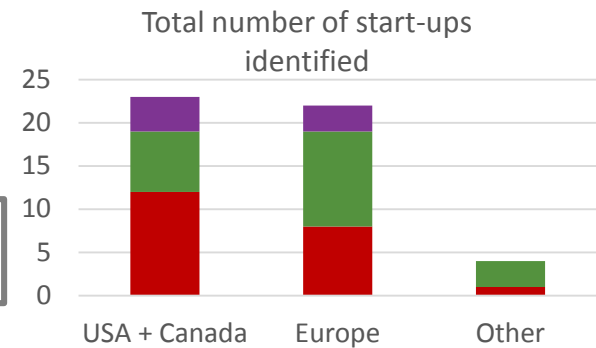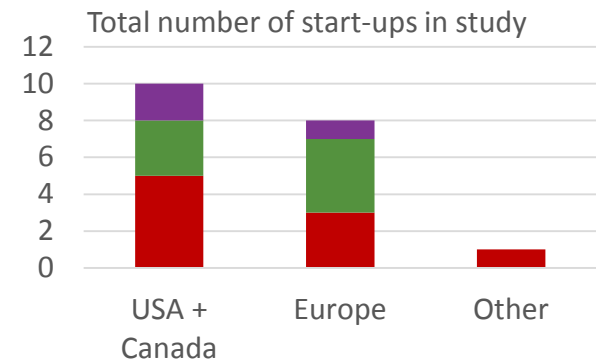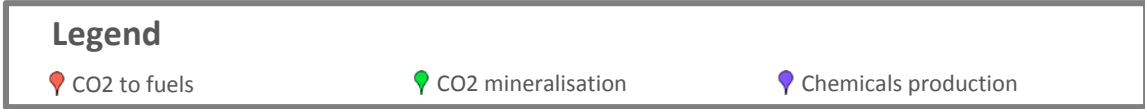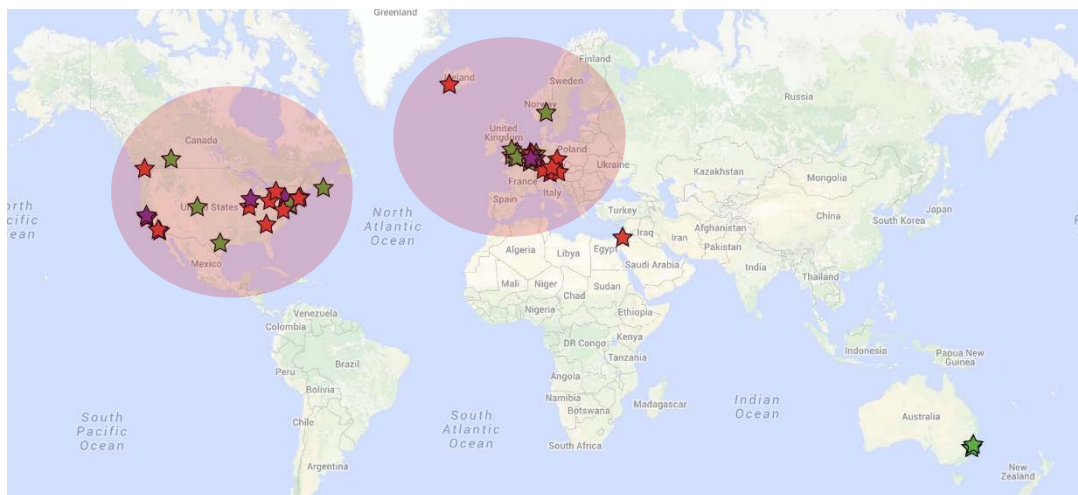
Current state of CO$_2$ utilisation

	Research	Demonstration	Small market	Mass market
Enhanced commodity production	Majority of activities			Majority of activities
Enhanced hydrocarbon recovery		Majority of activities	Few activities	Some activities
CO$_2$ mineralization	Some activities	Majority of activities	Some activities	
Chemicals production	Majority of activities	Some activities	Few activities	Some activities
CO$_2$ to fuels	Majority of activities	Some activities	Few activities	

Legend:
- Majority of activities
- Some activities
- Few activities
- No activities

Current state of CO$_2$ utilisation – in TRL stages

Current state of CO$_2$ utilisation – in start-up activities

Legend

🔴 CO2 to fuels   🟢 CO2 mineralisation   🟣 Chemicals production

Total number of start-ups in study

| | USA + Canada | Europe | Other |

Total number of start-ups identified

| | USA + Canada | Europe | Other |
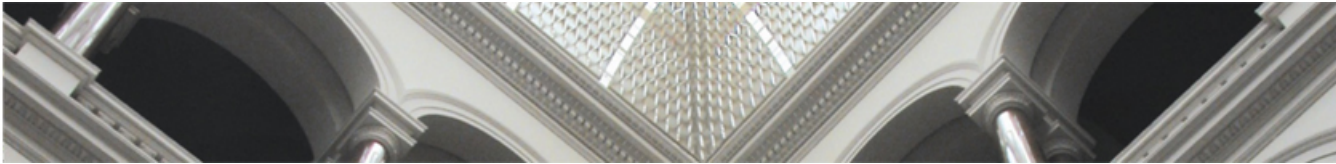
Current state of CO$_2$ utilisation – in valleys of death

Process	Technology Research		Technology Development	Manufacturing		Rollout (project finance)
Activity	Basic R&D	Applied R&D	Demonstration	Market Development (Scale-up)		Commercial Diffusion
Funding Source	Government and University Labs	Angel	Technology Valley of Death	Venture Capital	Commercialization Valley of Death	Private Equity

CO$_2$ Utilisation Start-up Concentration in study

Thank you

Dr. Arturo Castillo Castillo

+44-(0)20-7594 7312

a.castillo@imperial.ac.uk