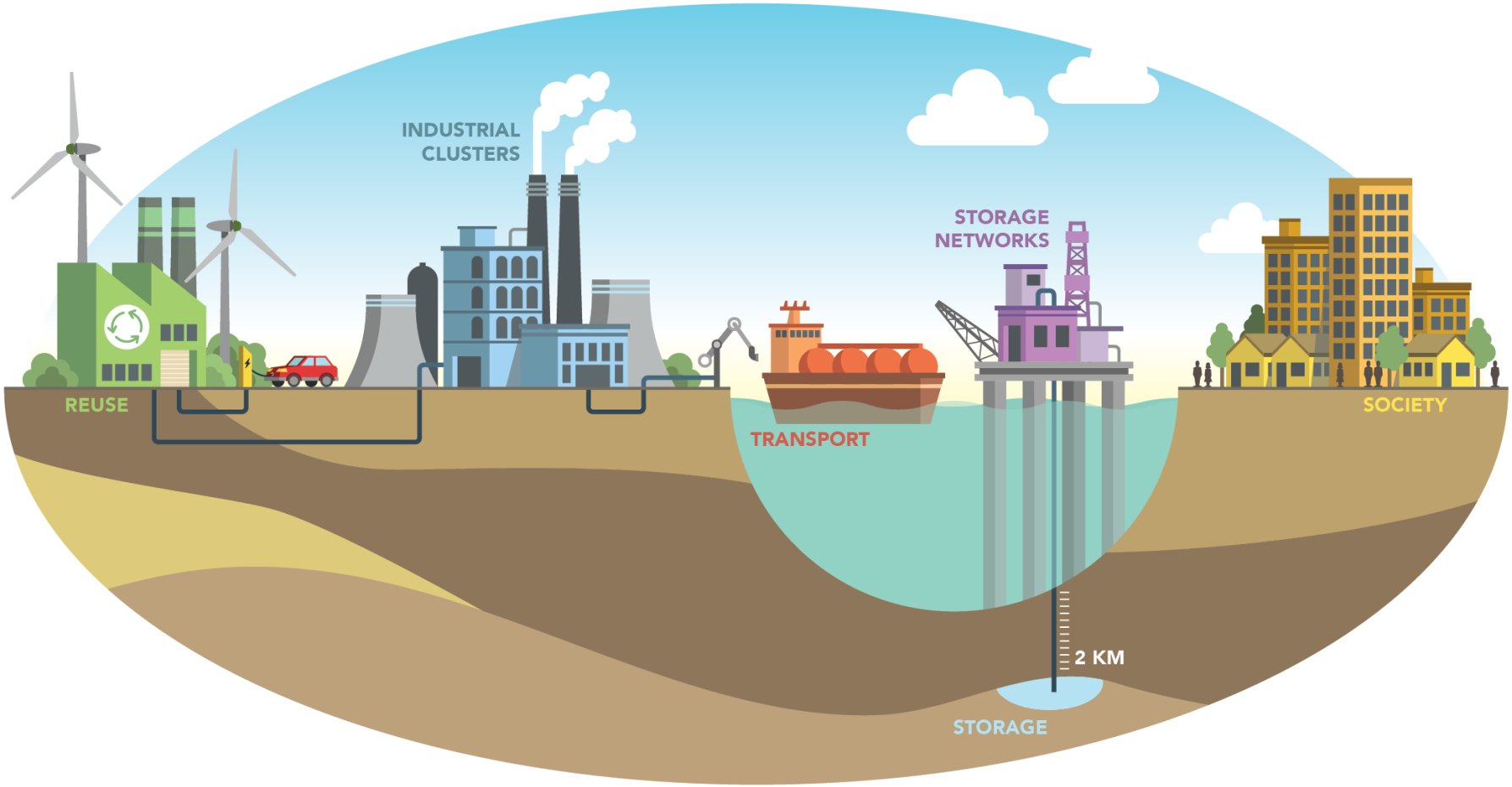
ALIGN CCUS


INDUSTRIAL CLUSTERS
STORAGE NETWORKS
REUSE
TRANSPORT
SOCIETY
2 KM
STORAGE

Knowledge sharing workshop

Project no 271501, ACT – Accelerating CCS technology

Peter van Os (TNO)

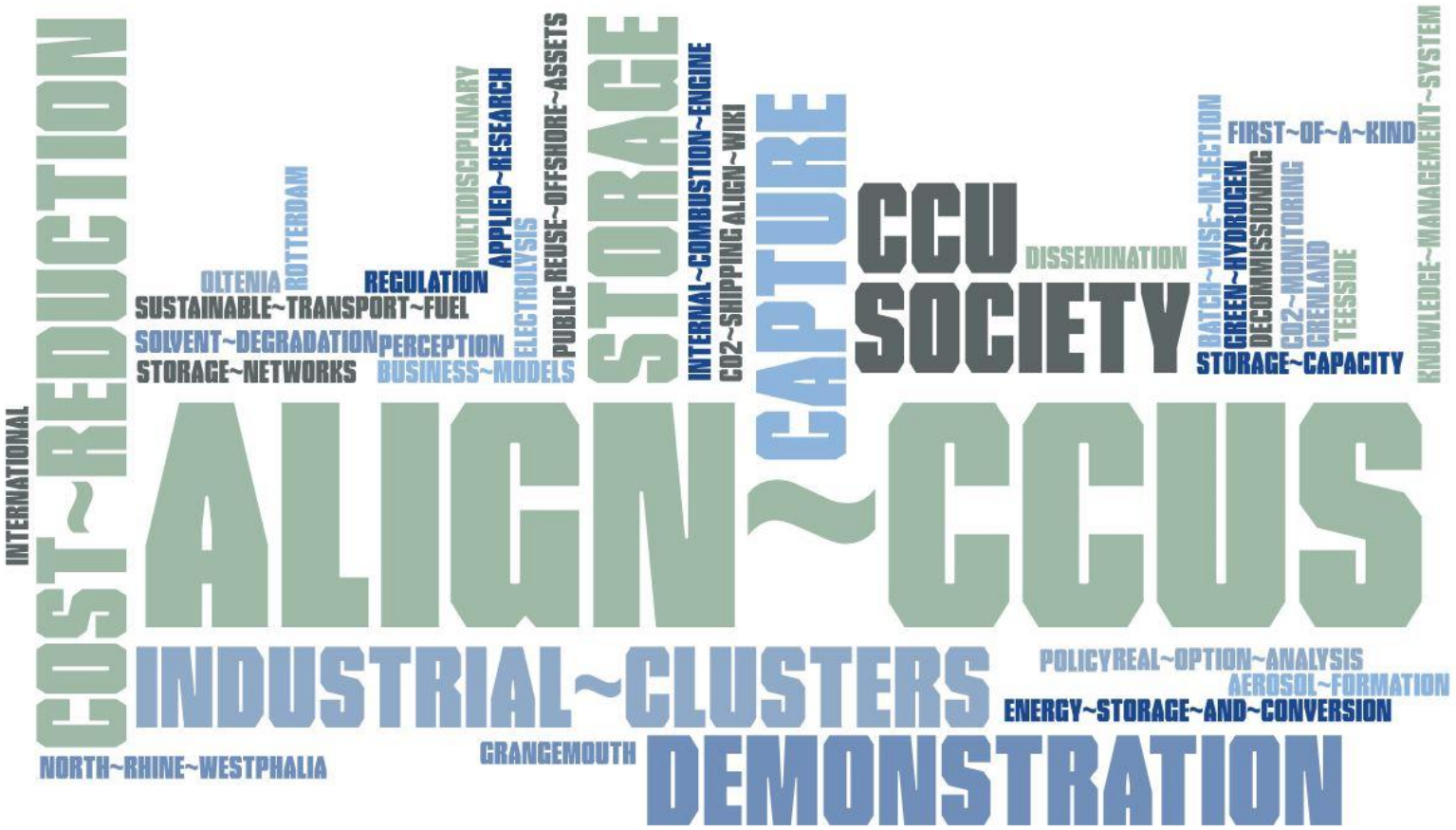
Coordinator

Bucharest, Romania, October 24th 2017

ALIGN CCUS

Accelerating Low CarboN Industrial Growth through CCUS 'ALIGN-CCUS'

ALIGN CCUS is a full chain project

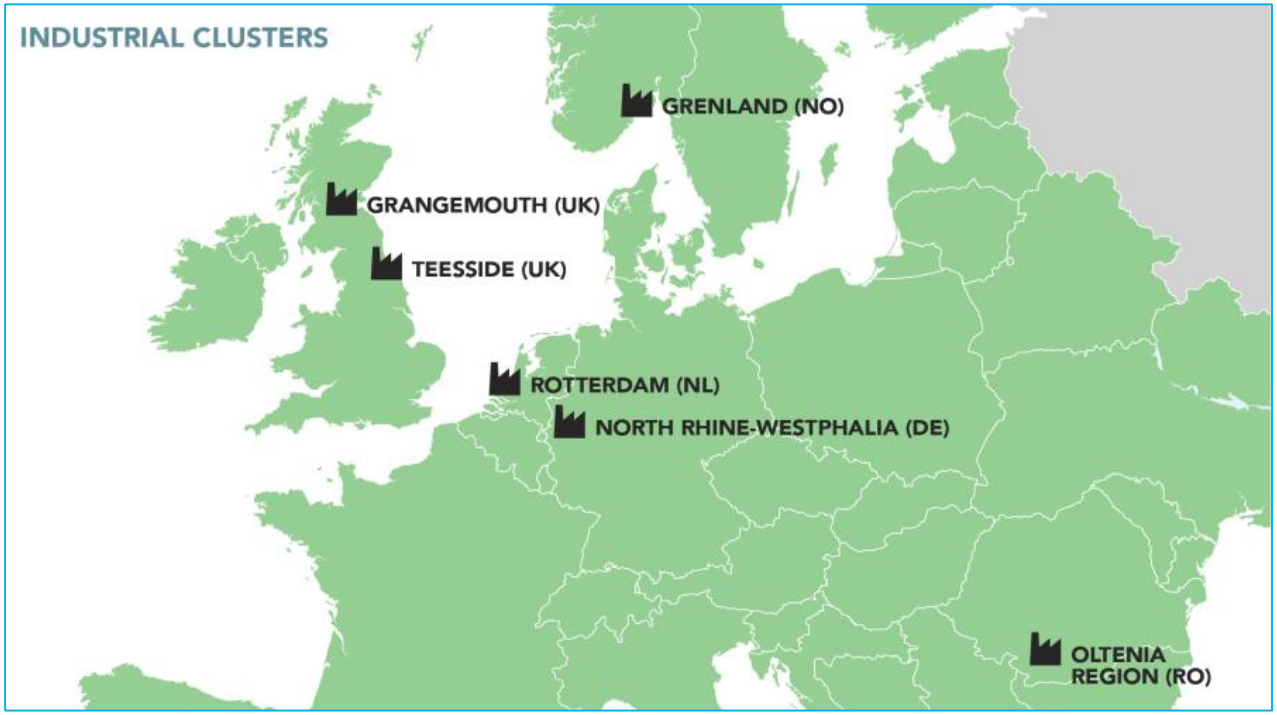


Objectives (1)

- ALIGN addresses specific issues across the CCUS chain for industrial regions in ERA-NET ACT countries, enabling large scale, cost effective implementation of CCUS by 2025. To reach the overall aim of ALIGN, the project encompasses a number of focused but interlinked objectives:
  - Capture: Enable near-term deployment of CO_2 capture by improving performance and reducing costs
  - Transport: Optimising large-scale CO_2 transport
  - Storage: Reduce uncertainty in the provision of large-scale storage networks
  - Utilisation: Establish the contribution of CCUS as an element for large-scale energy storage and conversion
  - Social acceptance: Implementing CCUS in society

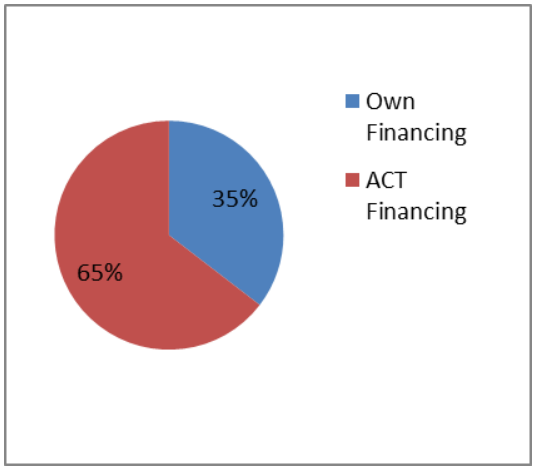
Objectives (2)

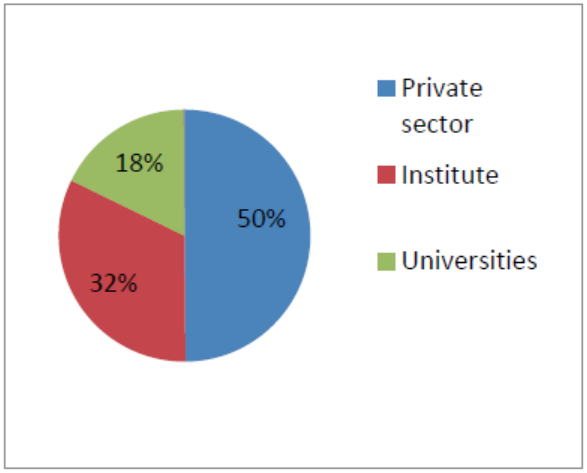
- ALIGN will combine the results from each of these objectives to deliver actionable blueprints in ERA-NET ACT countries: Teesside and Grangemouth (UK), Rotterdam (NL), North Rhine-Westphalia (DE), Grenland (NO) and Oltenia (RO, in which CCUS enables low-emission industries, through geological storage or through utilization of CO_2.

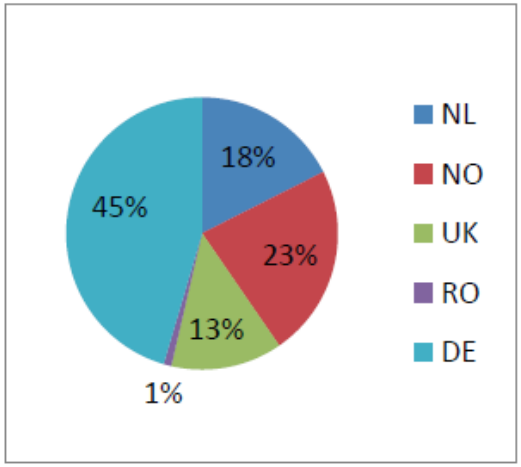


Key Figures

- 31 partners in the project from Germany, Norway, Romania, United Kingdom, The Netherlands
- ~23 Million Euro project budget, ~15 Million Funding
- September 1st 2017 until September 1st 2020
- Budget division as below



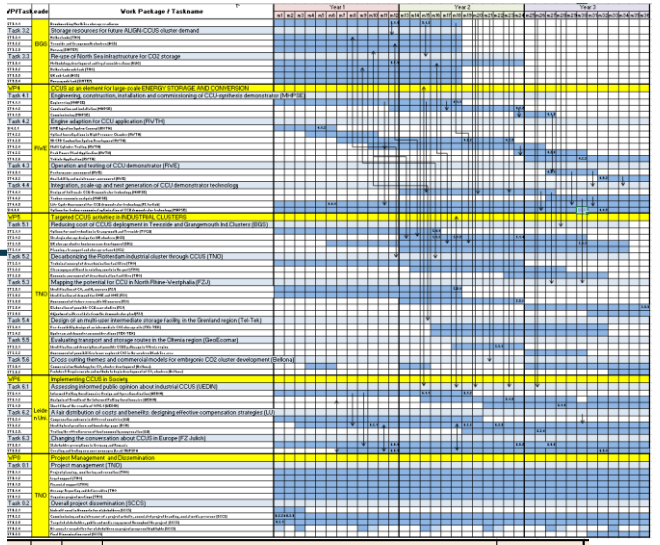




ALIGN CCUS

- Testing at world-class research facilities
- Multidisciplinary research teams
- Exceptional industrial commitment
- Demonstration of FOAK full-CCU chain
- Accessible and inclusive dissemination plan
- Links to Industry (IAG) and Australia (CSIRO)

We have a big project

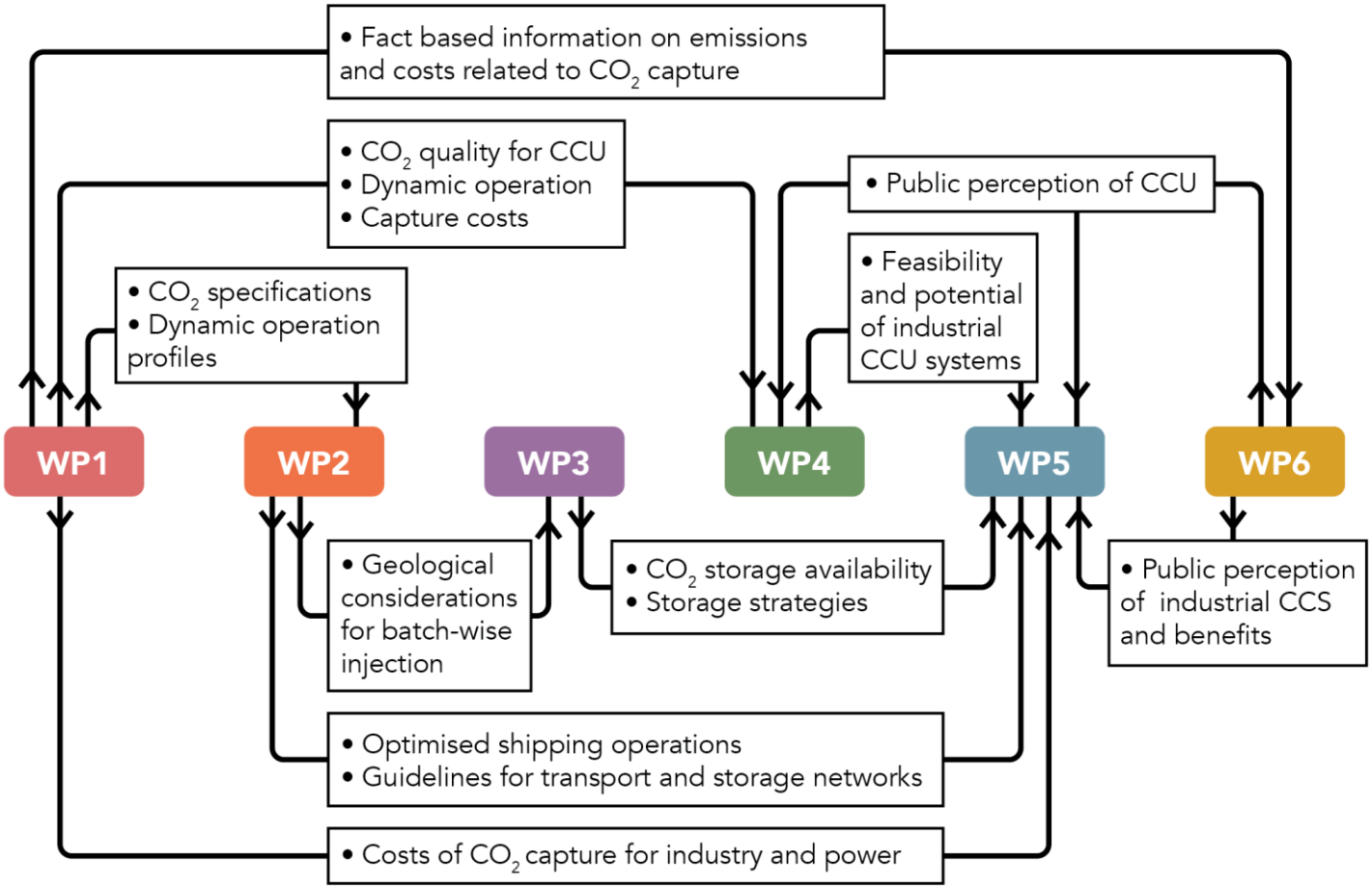


Name	Short name	Country
Nederlandse Organisatie voor toegepast natuurwetenschappelijk Onderzoek TNO, the Coordinator	TNO or the Coordinator	The Netherlands
Name	Short name	Country
Stifelsen SINTEF by its institute Materials and Chemistry (WP1 coordinator)	SINTEF M&C	Norway
Tel-Tek (WP2 coordinator)	Tel-Tek	Norway
Natural Environment Research Council, as represented by the British Geological Survey (WP3 coordinator)	BGS	United Kingdom
RWE Generation (WP4 coordinator)	RWE	Germany
University of Leiden (WP6 coordinator)	UL	The Netherlands
Asahi Kasei Europe GmbH	AKAEU	Germany
Bellona	BELLONA	Norway
CO2 Club Association	CO2CA	Romania
Energy Research Centre of the Netherlands	ECN	The Netherlands
FEV Europe GmbH	FEV	Germany
Forschungszentrum Juelich GmbH	Jeulich	Germany
GeoEcomar	GeoEcomar	Romania
Heriot-Watt University	HWU	United Kingdom
Institute for Energy Technology, IFE	IFE	Norway
Imperial College of Science Technology and Medicine	ICL	United Kingdom
Mitsubishi Hitachi Power Systems Europe GmbH	MHPS	Germany
NORCEM AS / Heidelberg Cement	NORCEM	Norway
Norwegian University of Science and Technology	NTNU	Norway
National University of Political Studies & Public Administration	SNSPA	Romania
PicOil Info Consult	PicOil	Romania
Rijksuniversiteit Groningen	RUG	The Netherlands
RWTH Aachen University for its Institute for Combustion Engines represented by the Rector or a person commissioned thereby, Templergraben 55, 52062 Aachen, Germany	RWTH	Germany
Scottish Enterprise as an agency of The Scottish Government	SEP	United Kingdom
SINTEF Petroleum AS	SINTEF PR	Norway
TAQA Energy B.V.	TAQA	The Netherlands
Technology Centre Mongstad	TCM	Norway
Tees Valley Combined Authority	TVCA	United Kingdom
University of Edinburgh	UnivEdin	United Kingdom
University of Sheffield	UnivShef	United Kingdom
Yara International ASA	YARA	Norway

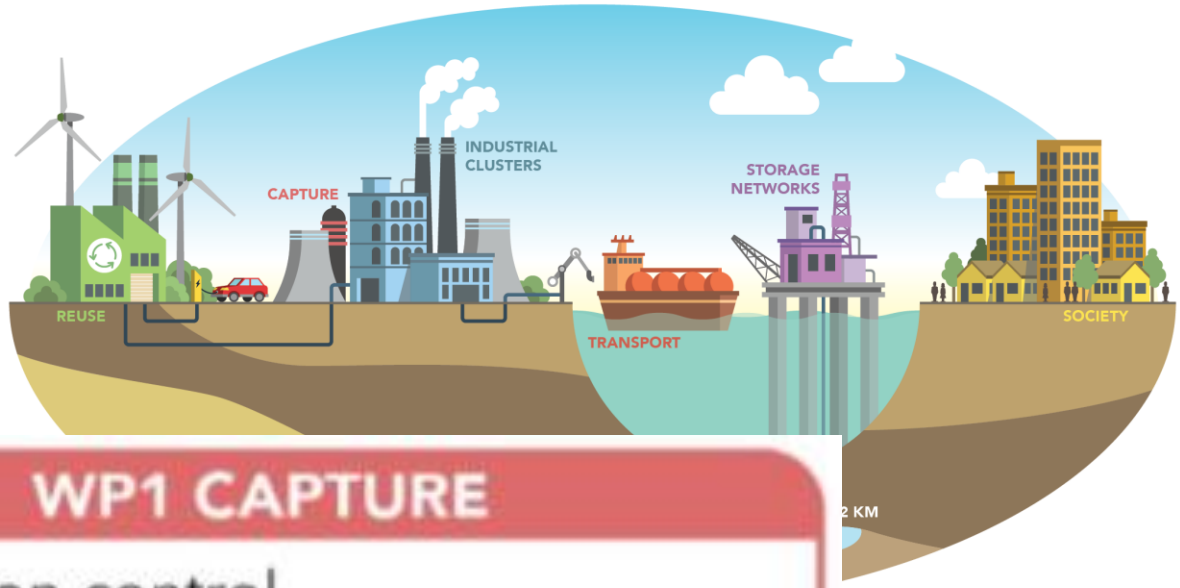
WP	Task	#	Description	Month	
1	1.1	MS1.1.1	Aerosol behaviour understood and validated - D1.1.1 finished	M18	Jan-19
		MS1.1.2	Understanding the effect of dynamics on solvent emissions - Pilot test of RWE and TCM	M24	Jul-19
		MS1.1.3	Qualification for test CESAR-1 at TCM - Pilot test at Tiller finished	M24	Jul-19
		MS1.1.4	Validated and demonstrated aerosol countermeasures - D1.1.4 finished	M33	Apr-20
	1.2	MS1.2.1	Online solvent monitoring tool in operation at pilot plant (Tel-Tek)	M12	Jul-18
		MS1.2.2	Degradation countermeasure implemented on pilot plant scale (TNO)	M18	Jan-19
		MS1.2.3	Guidelines for effective solvent management compiled (RWE)	M35	Jun-20
	1.3	MS1.3.1	Identification of chain integration constraints (SINTEF MC)	M8	Mar-18
		MS1.3.2	Description of flexible operational scenarios (HVU)	M12	Jul-18
		MS1.3.3	Optimised process control strategy taking into account flexibility, emissions and degradation (SINTEF MC)	M30	Jan-20
	1.4	MS1.4.1	Non-power plants reference cases described and methodology for cost estimation defined (SINTEF MC)	M25	Aug-19
		MS1.4.2	Techno-economic evaluations of the integration of MEA and CESAR-1 (HVU)	M32	Mar-20
2	2.1	MS2.1.1	Pressure and temperature ranges and injection schedules which are technically and economically feasible for ship transport and offloading (Tel-Tek)	M12	Jul-18
	2.3	MS2.3.1	Meeting agreeing on the CO_2 specifications to be experimentally verified (IFE)	M9	Apr-18
3	3.1	MS3.1.1	Completion of national discussions with regulators and operators in Netherlands (TNO), UK (BGS) and Norway (SINTEF PR)	M12	Jul-18
		MS3.1.2	Hold international benchmarking workshop (BGS)	M15	Oct-18
	3.3	MS3.3.1	Workshop, legal issues (RUG)	M12	Jul-18
4	4.1	MS4.1.1	Engineering completed	M18	Jan-19
		MS4.1.2	Erection completed	M24	Jul-19
		MS4.1.3	Commissioning completed	M27	Oct-19
	4.2	MS4.2.1	Definition and procurement of base injection systems (pump, injector, storage) for passenger car and peak power plant	M5	Dec-17
		MS4.2.	Procurement of optimized vehicle injector and piston bowl	M19	Feb-19
		MS4.2.	Procurement of optimized peak power plant injector & piston bowl	M23	Jun-19
		MS4.2.	First operation of CCU-DME-peak-power engine Niederaussem	M27	Oct-19
		MS4.2.	First operation of OME demonstrator vehicle	M30	Jan-20
	4.3	MS4.3.1	Start operational parameter variation	M27	Oct-19
		MS4.3.	Start long-term testing with optimal parameter settings	M32	Mar-20
	4.4	MS4.4.1	Survey of LCA studies of DME production, data collection	M6	Jan-18
		MS4.4. 3	Benchmarking against existing CCU technologies and evaluation of competing pathways for CO_2 and H_2 provision	M32	Mar-20
5	5.1	MS5.1.1	Provision of relevant data from any CCUS pilot plants on Teesside	M28	Nov-19
		MS5.1.2	Select agreed storage option	M12	Jul-18
		MS5.1.3	Complete refinement of existing storage site model	M18	Jan-19
		MS5.1.4	Complete simulation of storage scenarios	M24	Jul-19
		MS5.1.5	Complete analysis of technology and operational impacts on storage cluster business	M30	Jan-20
	5.2	MS5.3.1	Specifications on CO_2 and H_2 sources and DME/OME demand received from WP4	M18	Jan-19
		MS5.3.	Matching of sources and sinks	M24	Jul-19
		MS5.3.	Description of possible CCU pathways completed	M36	Jul-20
	5.5	MS5.5.1	Matching of sources and sinks	M22	May-19
6	6.1	M6.1.1	Preparation of informed polling questionnaire	M14	Sep-18
		M6.1.2	Completion of data collection	M19	Feb-19
		M6.1.3	Completion of data analysis	M23	Jun-19
		M6.1.4	Preliminary film shown at meeting plenary + debate	M28	Nov-19
	6.2	MS6.2.1	Interview protocols finished	M10	May-18
		MS6.2.	Stakeholder interviews completed	M18	Jan-19
		MS6.2.	Workshop with key stakeholders	M22	May-19
		MS6.2.	Data collection completed	M26	Sep-19
	6.3	MS6.3.1	Completion of desk research	M12	Jul-18
		MS6.3.	Completion of stakeholder interviews	M24	Jul-19
		MS6.3.	Completion of analysis	M27	Oct-19
		4	Completion of focus group research	M32	Mar-20
0	0.1	MS0.1.1	Grant agreement in place	M3	Oct-17
	0.2	MS0.2.1	Communication plan agreed with WP and project lead	M1	Aug-17

Bucharest, Romania, October 24th 2017

Well integrated



Work Packages (WP1)



WP1 CAPTURE

- Emission control
- Solvent management
- Dynamics and control
- Cost reduction

WP3 STORAGE

tandardizing storage readiness
lorth sea storage appraisals
e-use of existing assets

WP6 SOCIETY

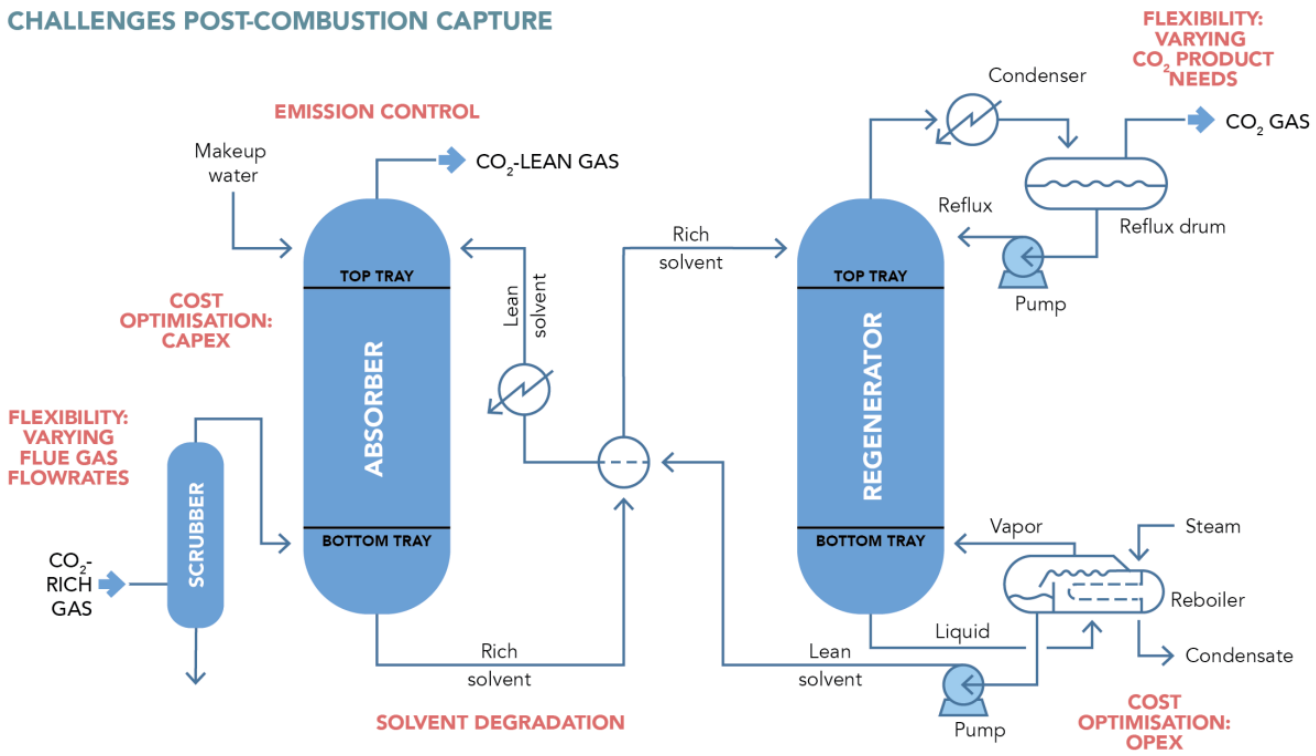
ssessing public opinion
ompensation strategies
mproving EU dialogue on CCUS

WP0 MANAGEMENT

• Commercial models for CCUS clusters

WP1 Capture (SINTEF, NTNU, TNO, HWU, RWE, UoS, TCM, Tel-Tek)

Enable near-term deployment of integrated capture facilities and cluster development.



WP1 Pilot plants in the project

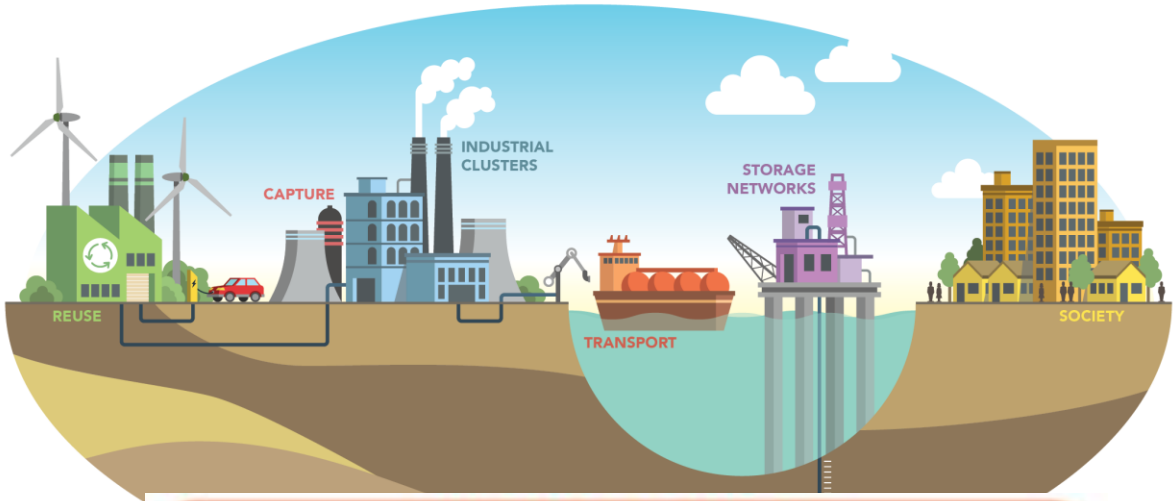
- Using pilot plants for testing and validate models

Pilot plant	Scale & flue gas source	ALIGN Focus
Mongstad, Norway (TCM) **~2000 hrs CESAR1**	12.5 tCO_2 captured/h Flue gas from a natural-gas-fired Combined Heat and Power (CHP) plant and from a Residue Fluid Catalytic Cracker (RFCC)	- Long-term test of CESAR1 solvent system - Test Brownian Demister - Varying process conditions and dynamic tests - Reclaiming - Degradation and corrosion testing - Deliver data for modeling
Niederaussem, Germany (RWE) **~12.000 hrs MEA** **~12.000 hrs CESAR1**	0.3 tCO_2 captured/h Flue gas from raw lignite-fired power plant	- Very long term testing - Emission control - Solvent management - Study dynamic effects - CCUS re-use - Testing On line solvent monitoring tools - Deliver data for modeling
Tiller, Trondheim, Norway (SINTEF) **~700 hrs CESAR1**	0.03-0.04 tCO_2 captured/h Flue gas from propane, coal or biomass burner with CO_2 up to 30 vol.%	- Solvent management CESAR1 solvent system - Test and evaluate online liquid and emission measurement equipment - Evaluate NMPC (Nonlinear Model Predictive Control) strategies - Deliver data for modeling
PACT facilities, UK (UoS) **~600 hrs MEA** **~600 hrs CESAR1**	0.04 tCO_2 captured/h Flue gas from either air combustion plant or gas turbine	- Solvent management for natural gas derived flue gases - Test degradation counter measures - Test flexibility options - Effect of inhibitors - Deliver data for modeling

WP1 Key expected results

WP	Key expected results	Impacts
WP1. Capture	Complete characterisation of aerosol-based emission and demonstration of countermeasures at TRL 6/7	Validation of the performance of proposed countermeasures for aerosols at industrial scale
	Ensuring solvent consumption below 0.3kg amine/ton capture at TRL 6	Significant OPEX reduction compared with published solvent consumption and reduction of waste streams
	Guidelines for reliable and cost-efficient operation at varying feed conditions and CO_2 product requirements	Improved CO_2 capture plant design for flexible operation and niche applications.

Work Packages (WP2)



WP2 TRANSPORT

- CO_2 shipping
- Batch-wise injection
- CO_2 specifications
- Planning for flexible networks

- Operation and testing
- CCU integration and scale-up

- North Rhine-Westphalia (DE)
- Grenland (NO)
- Oltenia region (RO)
- Commercial models for CCUS clusters

- Improving EU dialogue on CCUS

WP0 MANAGEMENT

WP2Removing technical barriers to large-scale CO_2 transport.

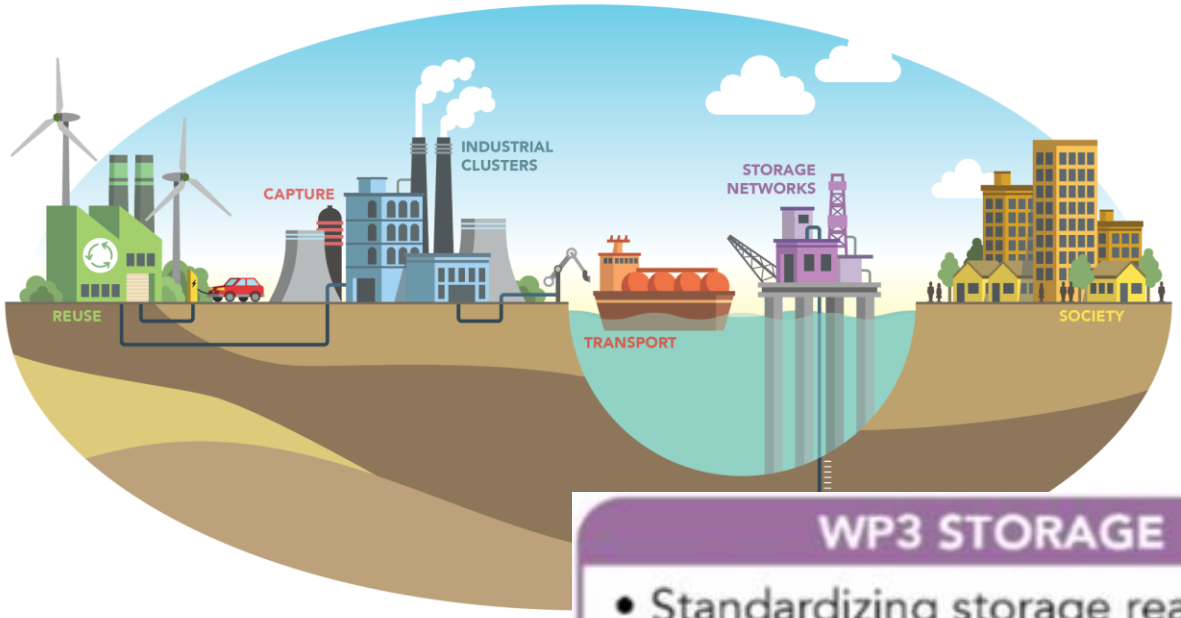
(**Tel-Tek**, ICL, TNO, IFE, TAQA)

- Not just straight forward
  - Pipeline and/or ship?
  - Shipping temperature and pressure conditions: different combinations have different advantages and disadvantages
  - Ships introduce batch-wise delivery
  - Handling of impurities
  - Design of transport (and storage) networks
  - Cost

WP2 Key expected results

WP	Key expected results	Impacts
WP2. Transport	Derive cost estimates and benchmarks for CO_2 shipping and offshore unloading with reduced uncertainty	Improved understanding of the business case for shipping and direct injection
	Quantification of the impacts of batch-wise injection on the integrity of the storage system	Allow operational guidelines to be developed for batch-wise injection
	CO_2 specifications expected from pilot-scale post-combustion capture systems are evaluated in dense-phase CO_2 corrosion lab	Allow the identification of an optimum balance between stream composition and transport infrastructure needs
	A real-options multi-period CCS network optimisation model including capture from power and industry, energy storage and conversion is developed	Improved cost-benefit analysis capabilities for planning full-chain CCUS projects and CCUS clusters

Work Packages (WP3)



WP1 CAPTURE
- Emission control
- Solvent management
- Dynamics and control
- Cost reduction

WP2 T
- CO_2 shipping
- Batch-wise inje
- CO_2 specificati
- Planning for fle

WP3 STORAGE
- Standardizing storage readiness
- North sea storage appraisals
- Re-use of existing assets

WP4 RE-USE
- CCU demonstrator construction
- Engine adaption
- Operation and testing
- CCU integration and scale-up

WP5 INDUS
- Teesside and C
- Rotterdam (NL)
- North Rhine-Westphalia (DE)
- Grenland (NO)
- Oltenia region (RO)
- Commercial models for CCUS clusters

- Compensation strategies
- Improving EU dialogue on CCUS

MENT

WP3 Large-scale storage networks

(**BGS**, TNO, SINTEF PR, TAQA, TVCA, Scottish Enterprise, RUG, SDL)

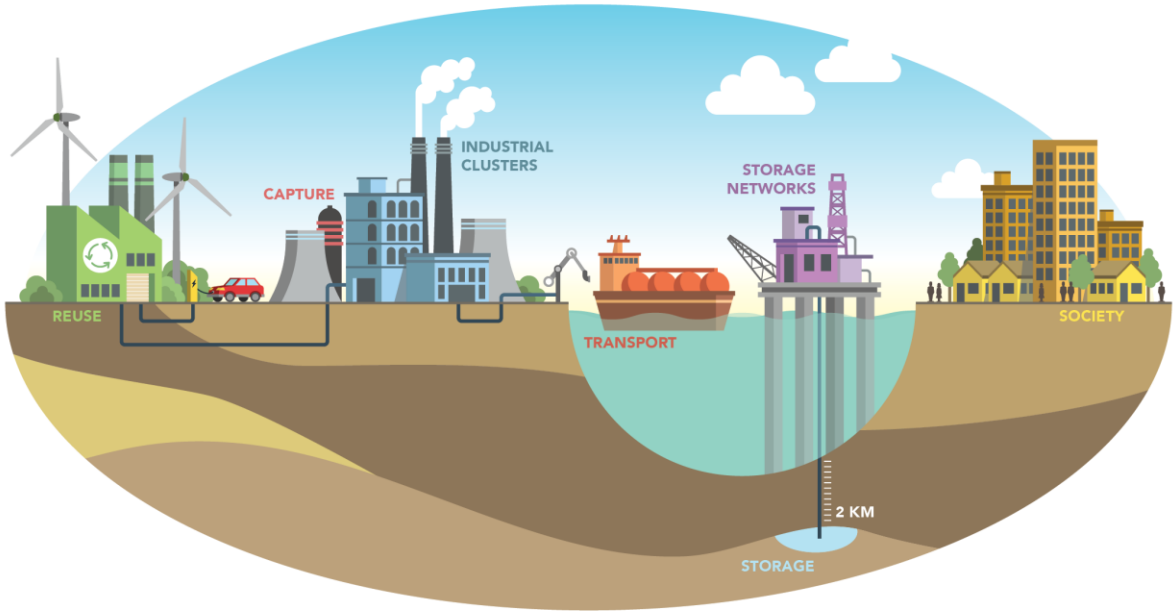
- Vast potential storage capacity beneath the North Sea (fields and formations)
- Prospective industry CCS operators require:
  - increased confidence in availability
  - sufficient capacity
  - realistic costs and timing of storage provision.

- European resource of learning from operating projects, planned and permitted storage capacity
- Increase operator certainty in future storage provision

WP3 Key expected results

WP	Key expected results	Impacts
WP3. Storage	Provide a classification framework for storage readiness levels benchmarked against existing storage sites	Increased investor confidence in timeframe and resource needs for follow-on storage development.
	A portfolio of selected storage sites in the UK, Netherlands and Norway to provide certainty on storage for ALIGN clusters	Enables FIDs on transport and storage infrastructure and supporting development plans for storage roll-out.
	An asset register of existing North Sea oil and gas infrastructure and assessments of their suitability for re-use for CCUS projects	Supports decommissioning policy and regulation for transport and injection infrastructure.

Work Packages (WP4)



WP4 RE-USE

- CCU demonstrator construction
- Engine adaption
- Operation and testing
- CCU integration and scale-up

WP3 STORAGE

- Standardizing storage readiness
- North sea storage appraisals
- Re-use of existing assets

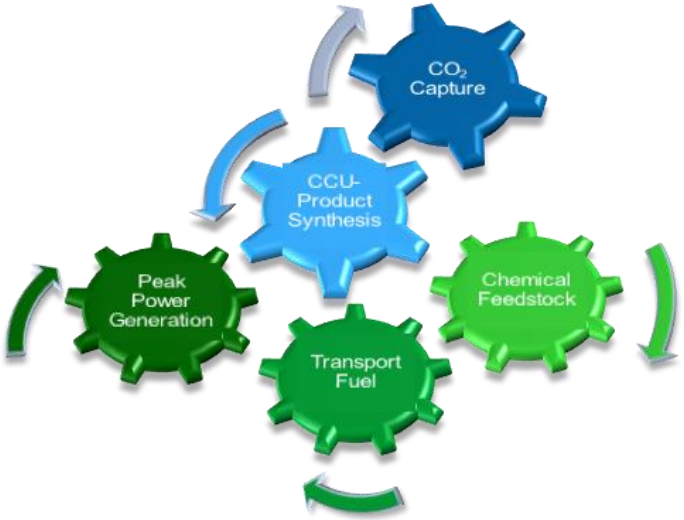
WP6 SOCIETY

- Assessing public opinion
- Compensation strategies
- Improving EU dialogue on CCUS

WP0 MANAGEMENT

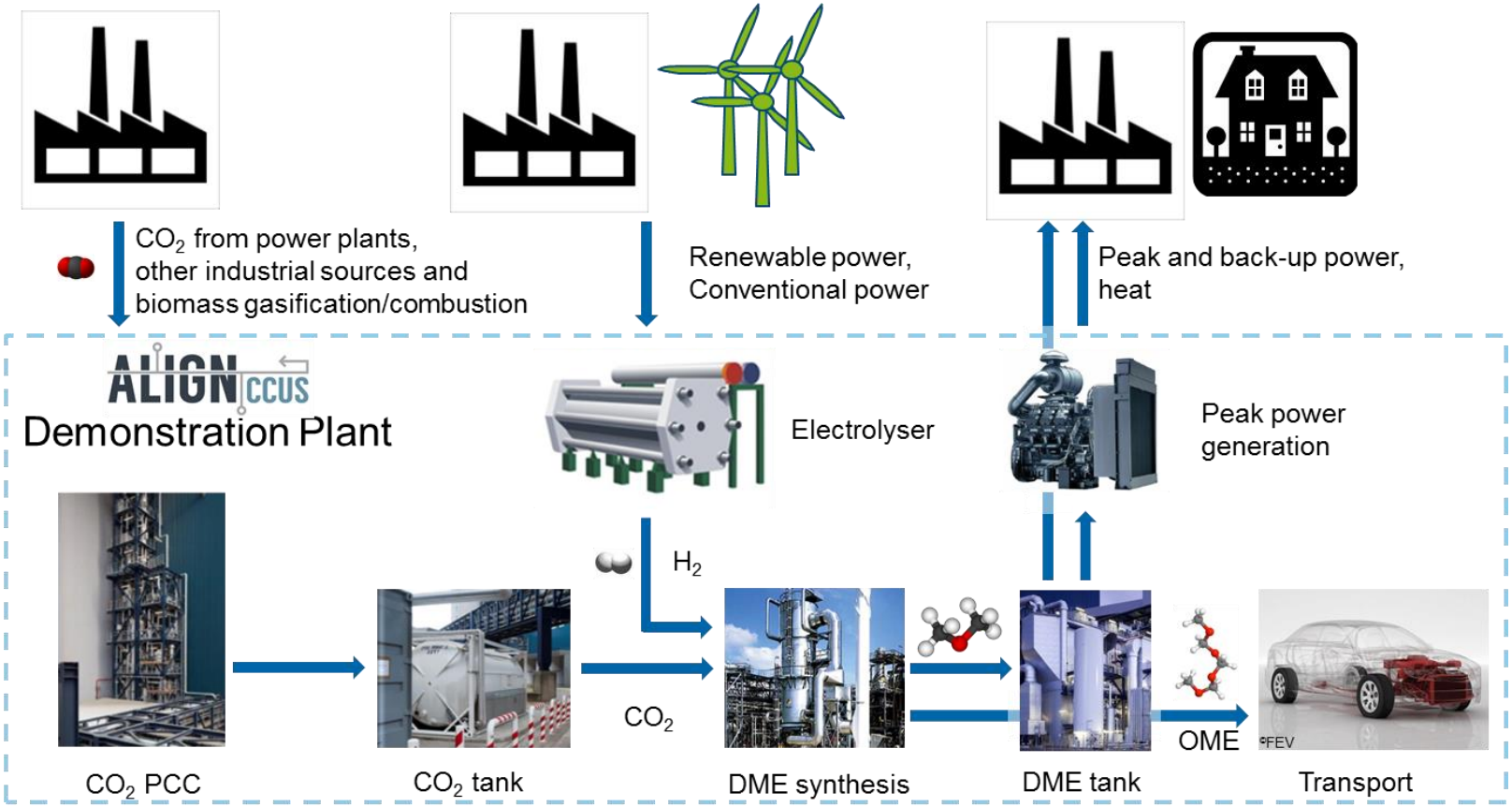
WP4 CCUS as an element for large-scale energy storage and conversion (RWE, MHPSE, AKEU, FEV, FZ Julich, TNO, RWTH, ECN, Bosch, Deutz)

- WP4 aims at accelerating the integration of CCU applications into the energy system by:
  - Demonstrating the full CCU-chain and utilisation of CCU-products in the power and transport sectors
  - Obtaining acceptance for CCU by additional benefits: security of supply and low-emission fuels
  - Generating added value by CCUS and gain cost reduction potential by innovative technology
  - Assessing socio-economic value and benefits of CCUS



WP4 Demonstration setup

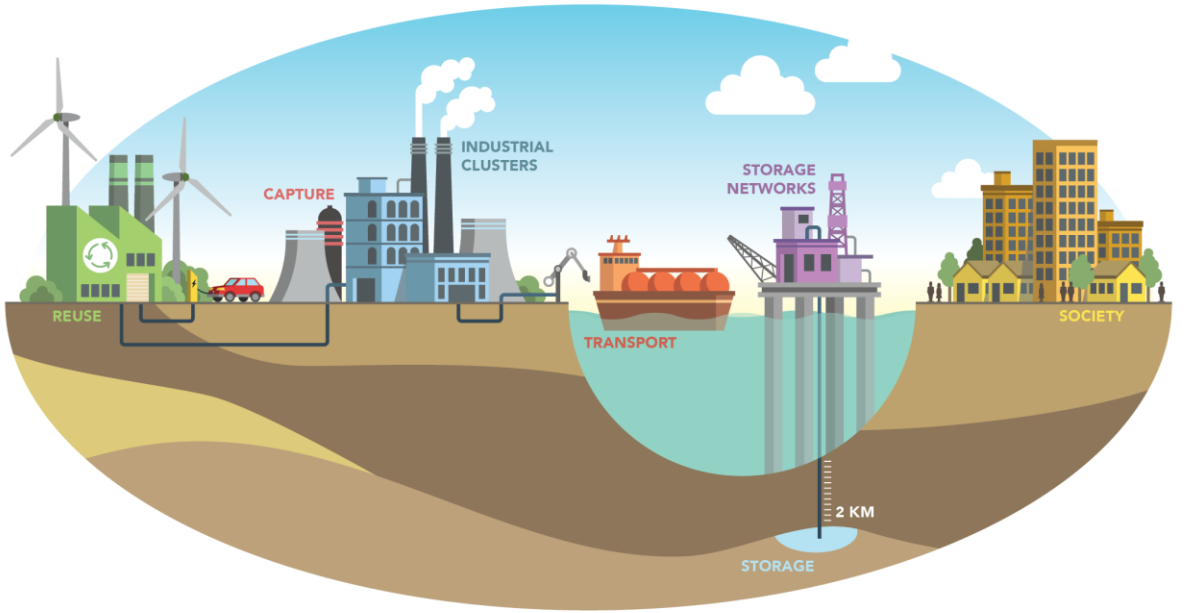
- Demonstration of CCU and Sector Coupling
  CCU, chemical long-term energy storage, fuel for peak power generation and transport sector Co-benefit: DME lowers emissions of Diesel engines (NOx, Particulates, CO2)



WP4 Key expected results

WP	Key expected results	Impacts
WP4. Re-use	Demonstration of the full CCS/CCU chain	Proven feasibility and viability of a utilisation chain, increases public awareness and acceptance of CCS/CCU as a climate protection technology
	Understand the additional multi-sector benefits of establishing a CCUS chain producing low-emission transportation fuels	Quantifies the potential socio-economic effects of CCS/CCU beyond climate protection by intelligent coupling of the sectors energy, industry and transport.
	Techno-economic optimisation of the CCU demonstrator technology	Enhances the chance for accelerated implementation of CCU due to better economic performance.
	Quantify the environmental performance of a full CCUS chain using data derived from actual operation	Makes the advantages of CCUS transparent in comparison with other competing climate protection technologies.

Work Packages (WP5)



WP1 CAPTURE
- Emission control
- Solvent manageme
- Dynamics and con
- Cost reduction

WP2 TRANSPORT
- CO2 shipping

WP3 STORAGE
- Standardizing storage readiness

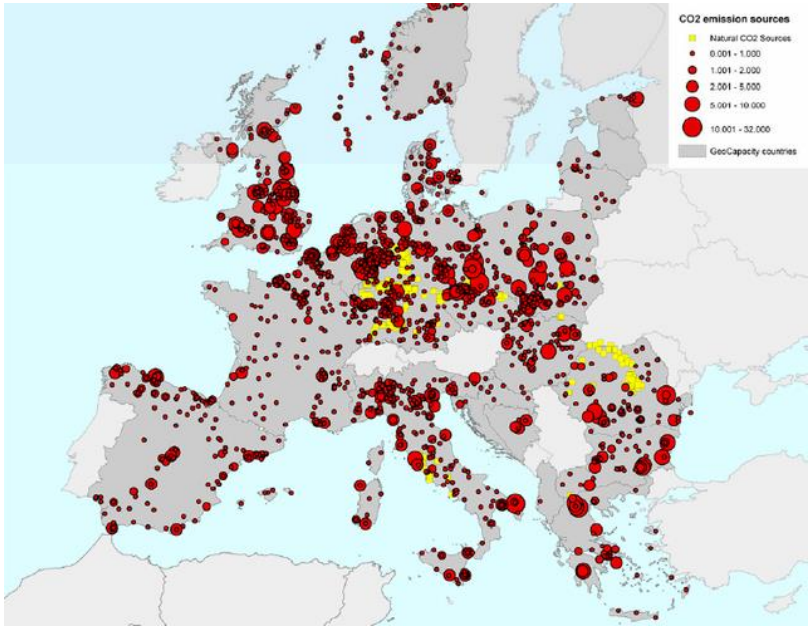
WP4 RE-
- CCU demonstrator
- Engine adaption
- Operation and tes
- CCU integration a

WP5 INDUSTRIAL CLUSTERS
- Teesside and Grangemouth (UK)
- Rotterdam (NL)
- North Rhine-Westphalia (DE)
- Grenland (NO)
- Oltenia region (RO)
- Commercial models for CCUS clusters

CUS

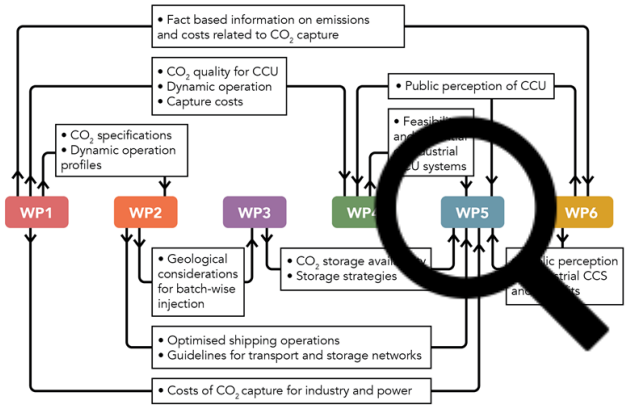
WP0 MANAGEMENT

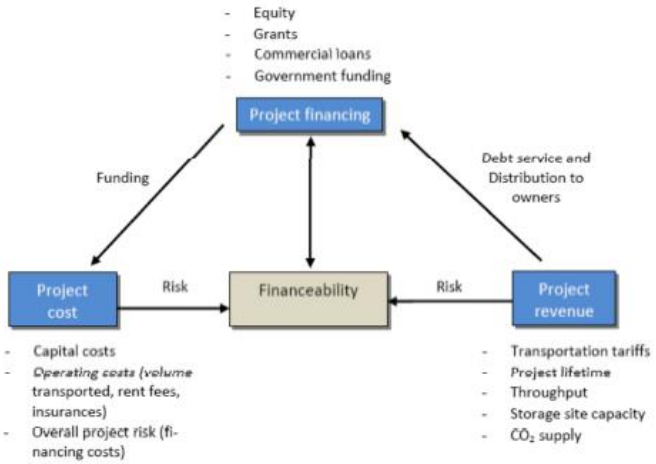
WP5 Targeted CCUS activities in industrial clusters (TNO, BGS, TCVA, SDL, ICL, Scottish Enterprise, Bellona, FZ Julich, Tel-Tek, Yara, Norcem, GeoEcomar, PicOil, CO2Club)



WP5 Industrial clusters

Industrial cluster/ region	Development priority in ALIGN	Existing appraised storage			Extended storage capacity to be identified in ALIGN
		Storage site	Capacity	Status	Target stores
Rotterdam (NL)	Develop plans for centralised CO_2 removal from natural gas, and increased H_2 use in power generation and industry	P18-4 Gas Field	8 Mt	Permit awarded	P18, P15 and Ijmuiden fields and sandstone formations
Teesside (UK)	Identify cost reduction opportunities through shared infrastructure / optimise transport and storage plans	Endurance structure	200 Mt	Permit ready	Depleted fields, closures in the Bunter and other sandstone formations
Grangemouth (UK)	Identify cost reduction opportunities through shared infrastructure / optimise transport and storage plans	Goldeneye Field	10-15 Mt	Permit ready	Depleted fields, closures in the Captain and other sandstone formations
North Rhine-Westphalia (GER)	Evaluate CCU as a multi-sector CO_2 mitigation option in the region	n/a	n/a	n/a	n/a
Grenland (NOR)	Advance engineering plans for an intermediate CO_2 surface storage facility capable of handling CO_2 from multiple sources	Smeaheia area	100 Mt	Feasibility study	Closures in the Sognefjord Sandstone and in deeper formations.
Oltenia Region (ROM)	Evaluate multi-modal CO_2 transportation routes and use in enhanced oil recovery with permanent storage	Deep saline aquifers within a 50km radius of Turceni	1.5 Mt/yr	Feasibility study	Potential storage sites in the Moesian Platform

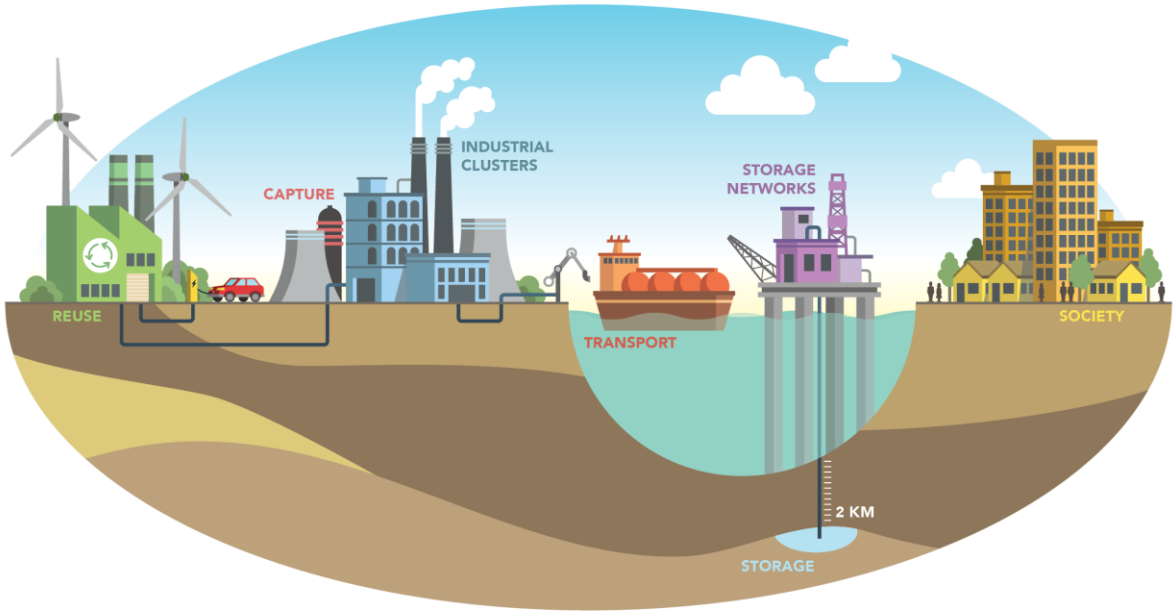




WP5 Key expected results

WP	Key expected results	Impacts
WP5. Industrial clusters	Provide a set of actionable development plans for targeted CCUS activities in 6 key industrial clusters across the EU	Supports national and regional governments in decision-making for industrial decarbonisation strategies
	Develop commercial models for embryonic CO_2 cluster infrastructure using results from pilot-testing and optimisation modelling completed in ALIGN	Greater clarity on the expected investment requirements and benefits for public and private actors

Work Packages (WP6)



WP1 CAPTURE
- Emission control
- Solvent management
- Dynamics and control
- Cost reduction

WP2 TRANSPORT
- CO_2 shipping
- Batch-wise injectior
- CO_2 specifications
- Planning for flexible

WP3 STORAGE

WP4 RE-USE
- CCU demonstrator construction
- Engine adaption
- Operation and testing
- CCU integration and scale-up

WP5 INDUSTRI
- Teesside and Grang
- Rotterdam (NL)
- North Rhine-Westp
- Grenland (NO)
- Oltenia region (RO)
- Commercial model

WP6 SOCIETY
- Assessing public opinion
- Compensation strategies
- Improving EU dialogue on CCUS

WP6 Implementing CCUS in Society

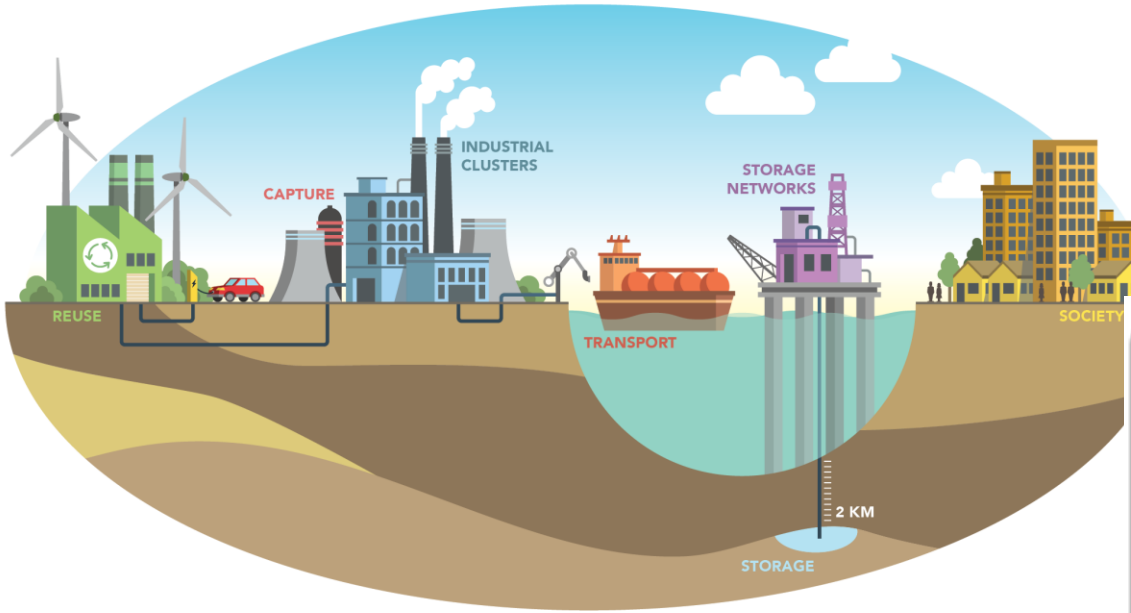
(**LU**, UEDIN, ECN, FZ Julich, Bellona, NUPSPA)

- Reduction of non-technical risk for CCUS implementation by
  - Assessing public and stakeholder perception about CCUS, specifically towards industrial CCUS and CO_2 utilisation projects
  - Developing theory-based, evidence-based communication and compensation strategies that instigate trust and have a positive effect on societal acceptance of CCUS

WP6 Key expected results

WP	Key expected results	Impacts
WP6. Society	Understanding of public and stakeholder perception concerning CCUS projects in industrial applications, including CO_2 utilisation	Provides tools for making site selection decisions and developing effective consultation and communication strategies
	Evidence-based insight in best practices regarding the use of compensation schemes for CCUS projects	The identified success factors and pitfalls support project developers and national governments in designing effective compensation strategies
	Development and testing of new communication materials for CCUS	Provides strategic elements for a dialogue with society about the need and necessity of CCUS

Work Packages (WP0)



WP1 CAPTURE
- Emission control
- Solvent management
- Dynamics and control
- Cost reduction

WP2 TRANSPORT
- CO_2 shipping
- Batch-wise injection
- CO_2 specifications
- Planning for flexible networks

WP3 STORAGE
- Standardizing storage readiness
- North sea storage appraisals
- Re-use of existing assets

WP4 RE-USE
- CCU demonstrator construction
- Engine adaption
- Operation and testing
- CCU integration and scale-up

WP5 INDUSTRIAL CLUSTERS
- Teesside and Grangemouth (UK)
- Rotterdam (NL)
- North Rhine-Westphalia (DE)
- Grenland (NO)
- Oltenia region (RO)
- Commercial models for CCUS clusters

WP6 SOCIETY
- Assessing public opinion
- Compensation strategies
- Improving EU dialogue on CCUS

WP0 MANAGEMENT

WP0 Management and Dissemination (TNO, Tel-Tek, SINTEF, BGS, LU, NUPSPA, UEDIN)

- Project management
  - Coordinator, Project Management Team
- Industrial Advisory Group
  - Leading industry companies on CCUS
- Professional dissemination partner (SCCS-UEDIN)

ALIGN CCUS Outreach

www.alignccus.eu

@alignccus

ALIGN-CCUS

ALIGN CCUS connection with other ACT projects

- On cluster activities
- On social acceptance
- Combining dissemination activities
- We will learn more during this workshop

Acknowledgements

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