The post-2020 Cost-Competitiveness of CCS Cost of Storage

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Main Messages Overall ZEP cost study
Capture, Transport & Storage for low CO2 Power

- ZEP reports indicate post-demonstration low carbon CCS power will be cost-competitive with other low-carbon power technologies (on-/offshore wind, solar power & nuclear)

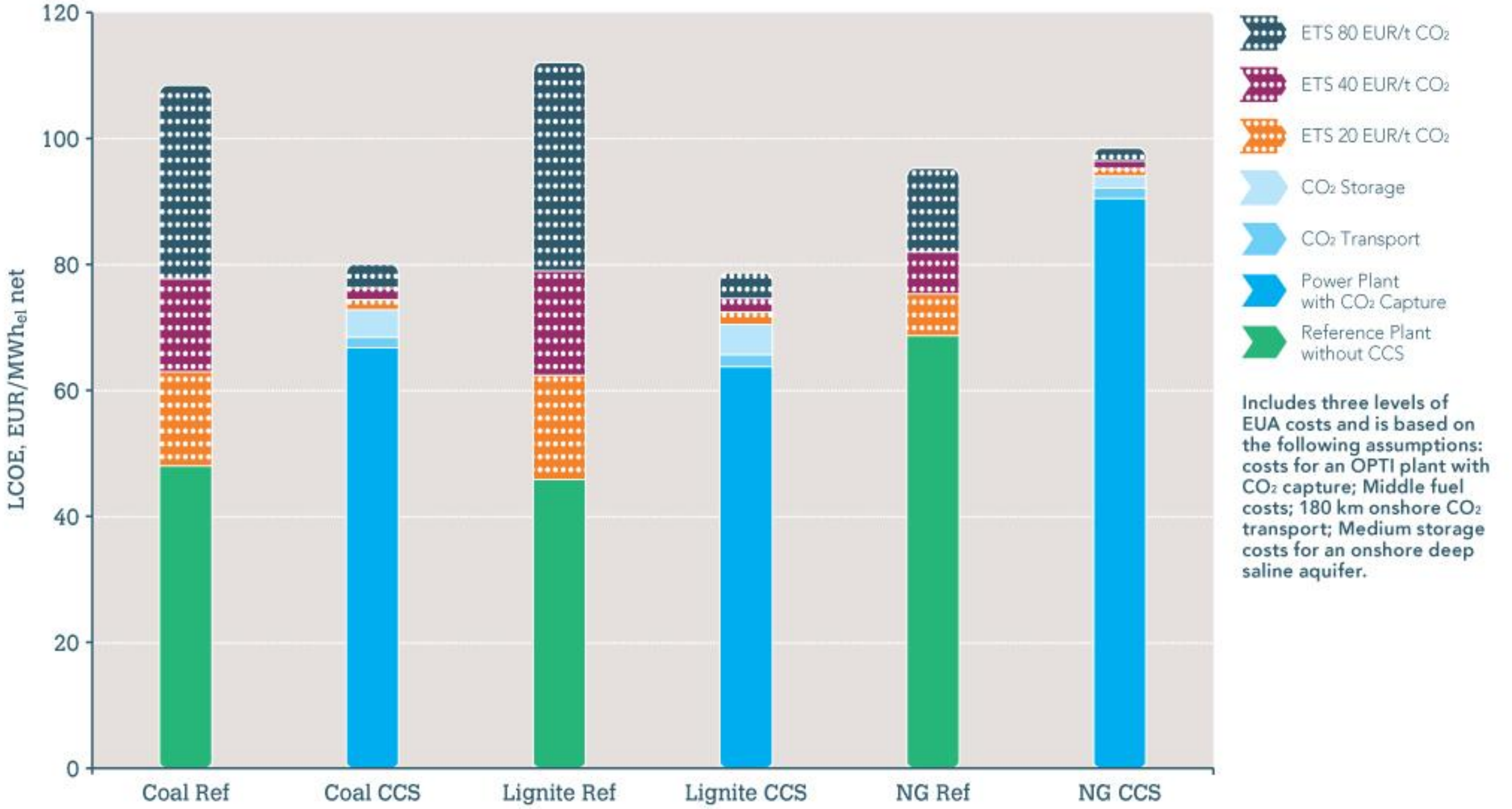
- CCS can technically be applied to both coal- and gas-fired power plants

- Relative economics depend on power plant cost levels, fuel prices and market positioning, whereas applicability is mainly determined by load regime

- CCS requires a secure environment for long-term investment
  - Price of Emission Unit Allowances (EUAs) will not, initially, be a sufficient driver for investment after the first generation of CCS demonstration projects is built (2015 - 2020)
  - Enabling policies required in the intermediate period – after the technology is commercially proven, but before the EUA price has increased sufficiently to allow full commercial operation

Levelized Cost of Electricity (LCOE) for Integrated CCS projects (coal and gas)

Cost of Low CO2 Product Euro/MWh



The Levelised Cost of Electricity (LCOE) of integrated CCS projects (blue bars) compared to the reference plants without CCS (green bars)

Key Messages Cost of Storage

- A risk-reward mechanism is needed to realise the needed significant aquifer potential for CO_2 storage
- Definition of storage may be rate limiting
- CCS requires a secure environment for long-term investment
- The EU CCS Demonstration Programme is essential to verifying storage performance with costs likely significantly higher than early commercial phase.

Background of CO_2 storage

Potential Storage

FID

Operational Storage

CO2 Injection

Post-closure

Closure

- ***Exploration: Storage definition and assurance***
  - Depleted O&G Fields are known, entailing less need for exploration and data gathering
  - Saline Aquifers A are less known, entailing need for timely exploration – with potential "misses"

- ***Construction and operation***
  - Number of wells, surface facilities, measurements
  - Operate CO2 injection
  - Measure, monitor and verify stored CO_2 for regulatory purposes

- ***Closure***
  - After injection, fields and wells are closed down and handed over to the state
  - Monitoring and verification of the field after injection
  - A 'potential liability fund', which is build up during its economic lifetime and the size of which is determined by the amount of CO_2 stored

SOURCE: Team analysis

ZEP Storage Cost for Six Cases

Case	Location	Type	Re-useable Legacy wells
1	Onshore	DOGF	Yes
2	Onshore	DOGF	No
3	Onshore	Aquifer	No
4	Offshore	DOGF	Yes
5	Offshore	DOGF	No
6	Offshore	Aquifer	No

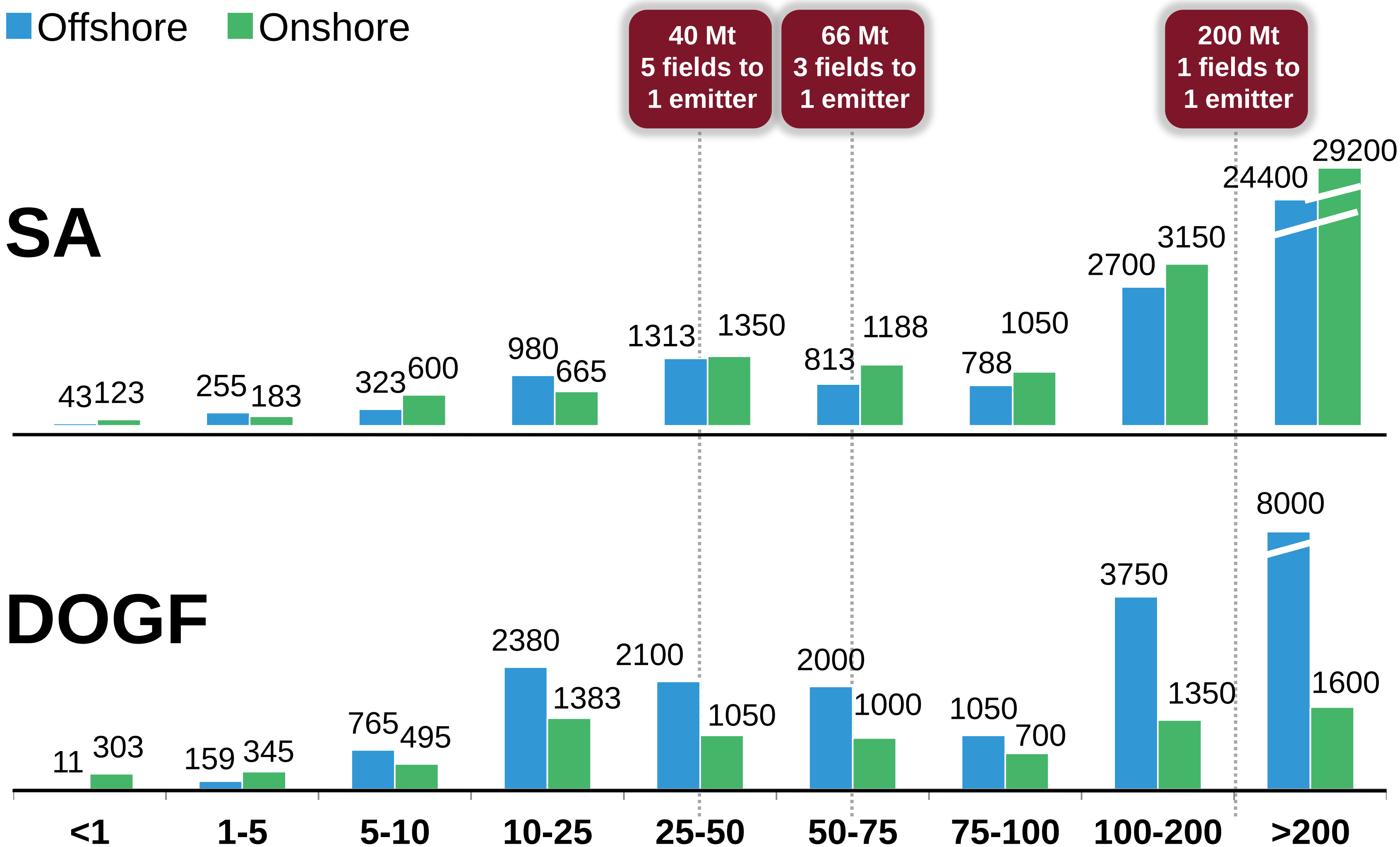
Sensitivities for the 8 key cost drivers

Cost driver	Medium case assumption	Sensitivities	Rationale
▪ **Field capacity**	66Mt per field	▪ 200Mt per field ▪ 40Mt per field	▪ Based on Geocapacity data
▪ **Well injection rate**	0.8 Mt/year per well	▪ 2.5 Mt/year ▪ 0.2 Mt/year[1]	▪ See deep dive page
▪ **Liability transfer costs**	€ 1.00 per ton CO_2 stored	▪ € 0.50 ▪ € 2.00	▪ Rough estimate of liability transfer cost ▪ Wide ranges reflect uncertainty
▪ **WACC**	8%	▪ 6% ▪ 10%	▪ Same range as previous (September 2008) study
▪ **Well depth**	2000 meters	▪ 1500m ▪ 3000m	▪ Well costs strongly dependant on depth[2]
▪ **Well completion costs**	Based on industry experience, offshore cost three times onshore cost	▪ -50% ▪ +50%	▪ Ranges based on actual project experience
▪ **# Observation wells**	1 for onshore; nil for offshore	▪ 2 for onshore; 1 for offshore	▪ 1 well extra to better monitor the field
▪ **# Exploration wells**	4 for SA; nil for DOGF	▪ 2 for SA, nil for DOGF ▪ 7 for SA, nil for DOGF	▪ DOGF are known, therefore no sensitivities needed ▪ SA reflects expected exploration success rate

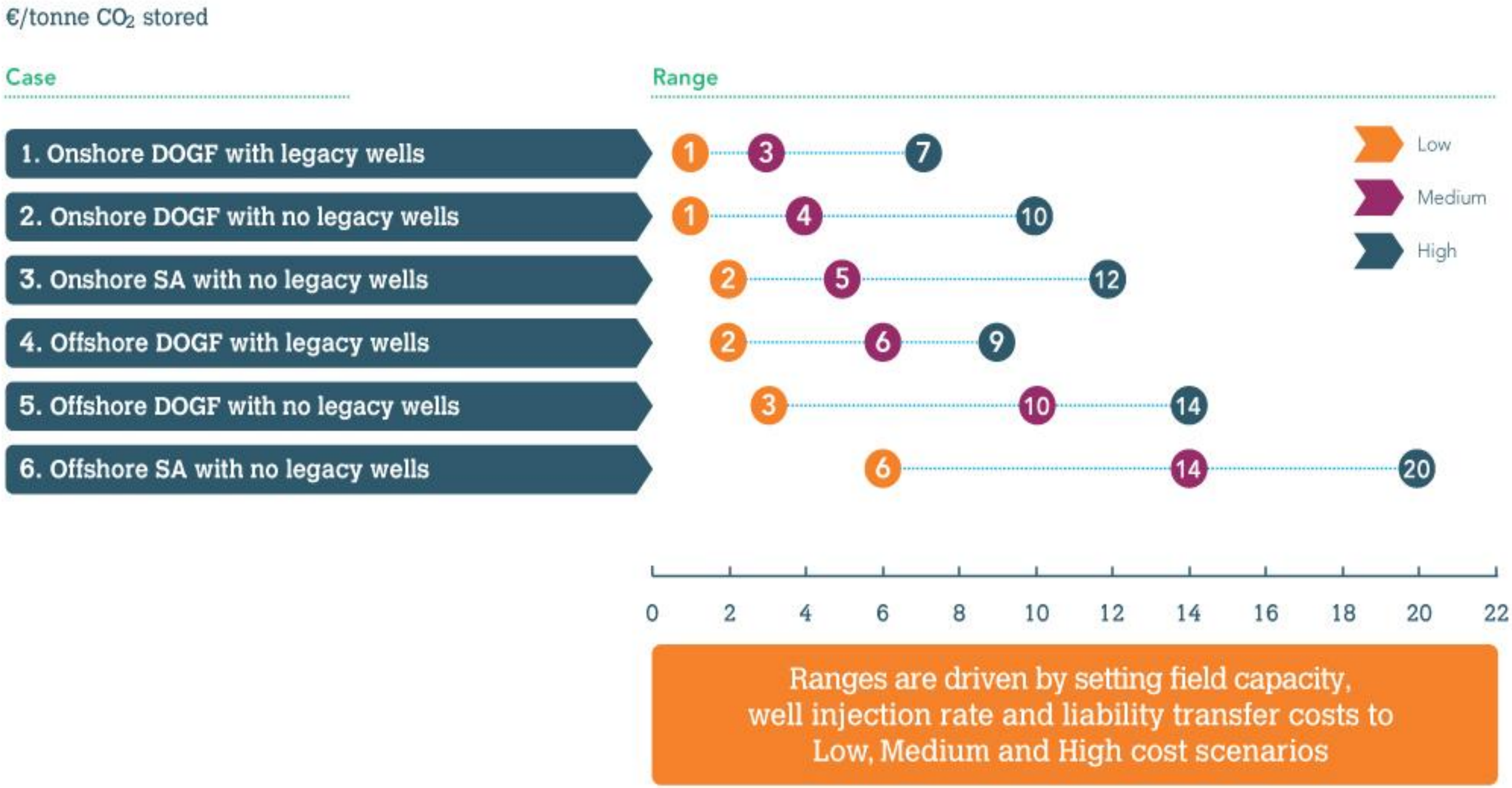
1 0.2 Mt/yr not modeled for offshore cases, as costs would become to high to be viable
2 1500 meter was taken since this depth was also used in Sept. 2008 report; supercritical state of CO_2 occurs at depths of 700-800 meter

SOURCE: Geocapacity Final Report, EU project no. SES6-518318 , team analysis

Storage Capacity Estimates Field sizes vary strongly



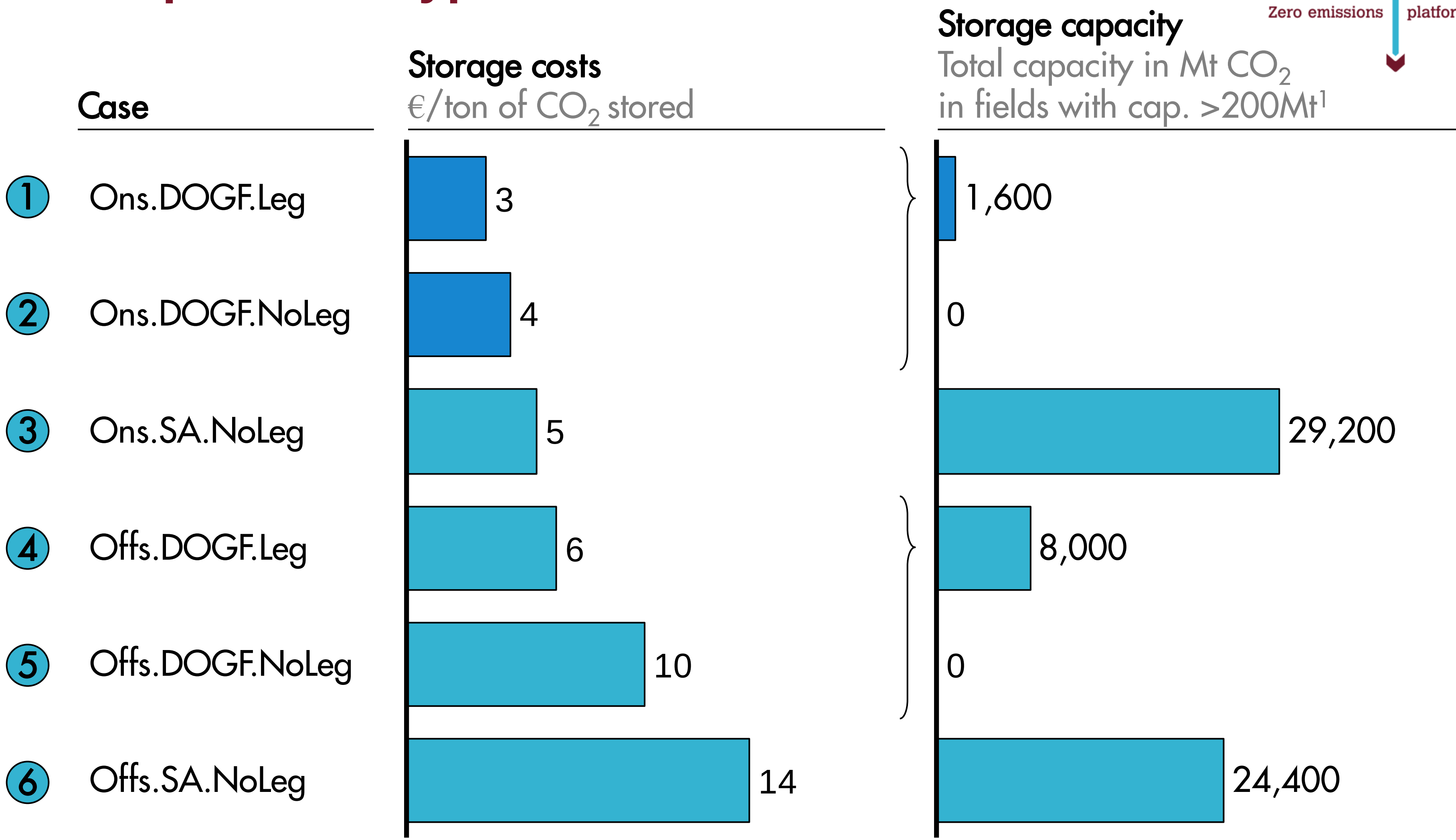
CO_2 Storage Cost Range Outcome



Costs vary significantly from 1-7€/tonne CO2 stored for onshore DOGF to 6-20€/tonne for offshore SA.

Storage cost per case, with uncertainty ranges; purple dots correspond to base assumptions

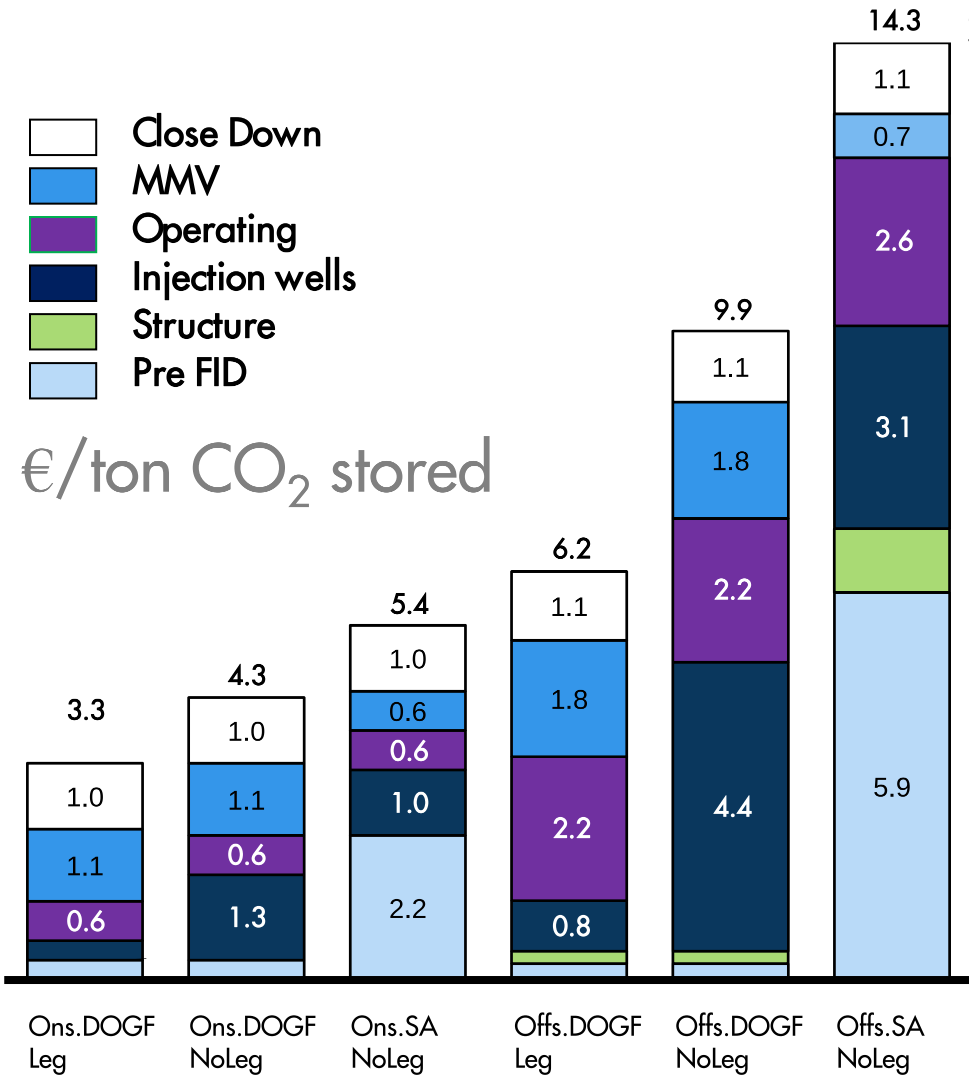
Cheapest field types are also the rarest



1 Typical emitter requires 200Mt of storage in its economic lifetime

SOURCE: Geocapacity Final Report, EU project no. SES6-518318, team analysis

Breakdown of cost components



Cost component	Description
Close down	▪ Decommissioning ▪ Liability transfer
MMV	▪ Including Opex, new observation wells and post-closure monitoring ▪ Final seismic survey
Operating	▪ Operations and maintenance
Injection wells	▪ New and re-used injection wells ▪ Legacy well remediation
Structure	▪ Platform new/ re-use
Pre FID	▪ Modeling/ Logging costs ▪ Seismic survey ▪ Injection testing ▪ New exploration wells ▪ Permitting

1 Pre FID excludes MMV baseline costs. Pre FID costs are high for SA due to seismic survey costs

2 Because SA needs initial seismic survey, MMV baseline costs and total MMV are lower for SA. Higher Pre FID for SA thus partially offset by lower MMV.

SOURCE: Team analysis

Sensitivities Ons.SA.NoLeg

Sensitivity of cost[1] (€/ton CO_2 stored)	Low	High	Sensitivity range	Medium
Medium scenario	5.4			
Field capacity	-2.2	2.1	200 – 40Mt[4]	66Mt[4]
Well Injection Rate	-1.0	3.9	100 – 8 Mt	32 Mt
Liability	-0.5	1.0	€ 0.5 – 2/ton CO_2	€ 1/ton CO_2
Well completion	-1.3	1.3	€ 3.9M – 9.1M/well	€ 6.5M/well
Depth	-0.8	1.6	1500 – 3000 m	2000 m
WACC[2]	-0.7	0.8	6% – 10%	8%
New observation wells	0	0.3	1 – 2 wells	1 well
New exploration wells	-0.5	0.7	No sensitivity for DOGF	0 wells
Total[3]	-4.2	22.2		

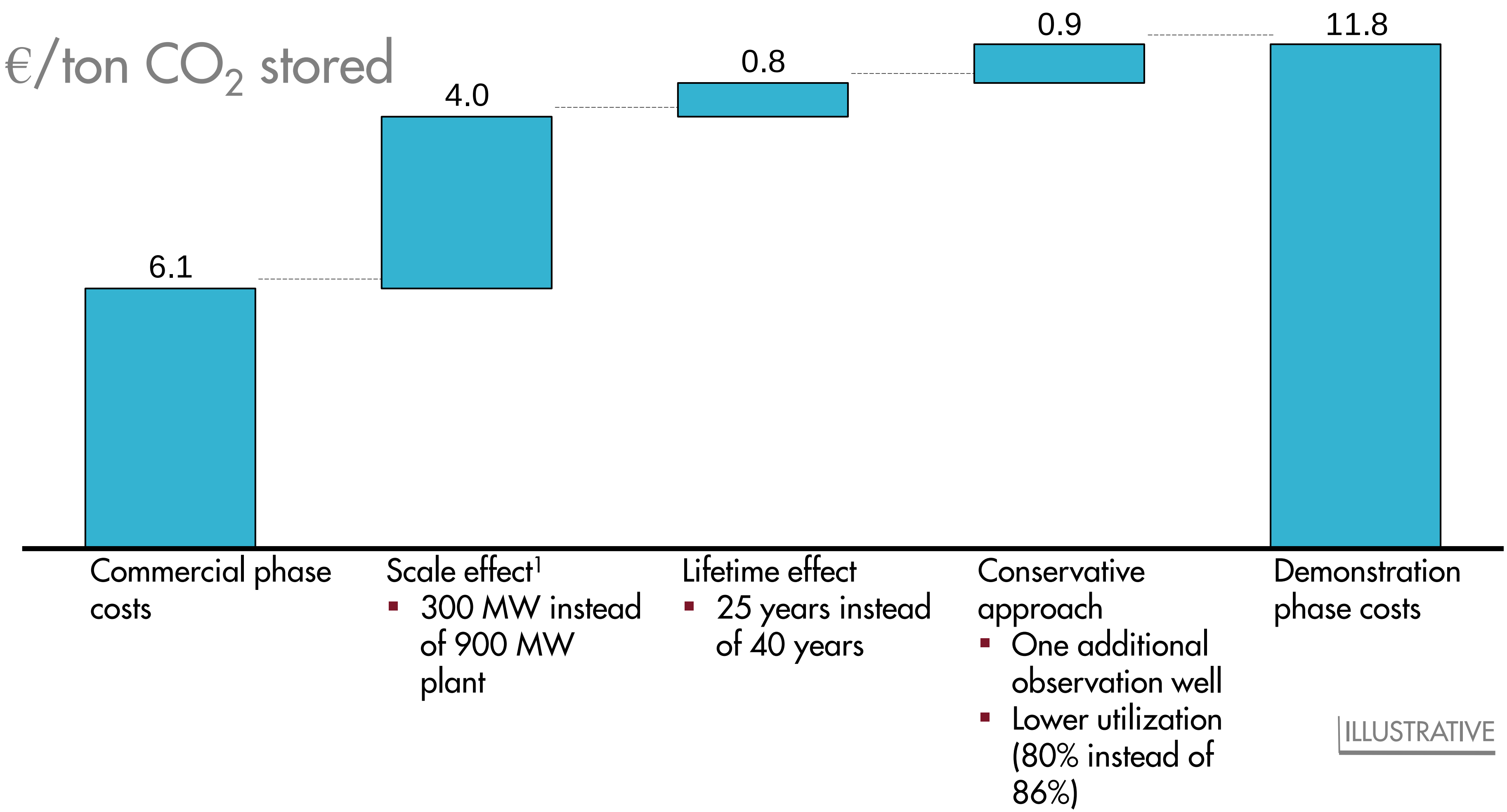
Parameters used on ranges page (Field capacity, Well Injection Rate, Liability)

1 The sensitivity denotes the individual effect of ranging a parameter on the total cost in medium scenario
2 Weighted Average Cost of Capital
3 Parts do not add to total. Combined effect of variables is larger due to interdependencies
4 High scenario is 1 emitter to 1 field, medium scenario is 1 emitter to 3 field, low scenario is 1 emitter to 5 fields

SOURCE: Team analysis

For any demonstration phase project, costs will be significantly higher

(Ons.SA.NoLeg) medium scenario



1 Scale effect has been taken as factor 2 rather than 3 since absolute scale effect is mitigated somewhat by expected 'cherrypicking' of storage fields

SOURCE: Team analysis

Key insights Cost of Storage

- Type and location of field is the main determinant of costs; - onshore is cheaper than offshore, - DOGF is cheaper than SA, - large cheaper than small, - high injectivity cheaper than low
- The cheapest forms of storage (big onshore DOGF) are also the least available, because these are rare
- High Pre FID costs for Aquifers reflect higher need of exploration compared to DOGF and risk of spending money on exploring SA that are deselected later.
- Well costs are ~40-70% of total costs, sensitivities corresponding to well capital costs have highest impact. Resulting wide cost ranges are driven more by (geo)physical variation than by uncertainty around estimating resulting costs
- Costs vary significantly from 1-7€/tonne CO2 stored for onshore DOGF to 6-20€/tonne for offshore SA.

A risk-reward mechanism is needed to realise the significant aquifer potential for CO_2 storage

BACK UP

Assumptions on other parameters (1/2)

Cost driver	Assumption	Why no sensitivities
Re-use of exploration wells	One out of three exploration wells is re-usable as injection well; others are not located correctly, do not match the injection depth, etc.	① Sensitivity range would be small as cost driver is small
Utilization	Utilization is 86%, implying a peak production of 116% average	
Contingency wells	10% of the required number of injection wells is added as contingency, with a minimum of one per field	
Well retooling cost	Re-tooling legacy wells as exploration wells, or exploration wells as injection wells, costs 10% of building the required well from scratch	
Operations & Maintenance	4% of CapEx costs for platform and new wells	② Sensitivity range would be small as cost driver is well understood from E&P experience
Injection testing	Fixed cost per field	
Modeling / logging costs	Fixed cost per field, SA costs ~2 times as high as DOGF	
Seismic survey costs + MMV Baseline	Fixed cost per field, offshore costs ~2 times as high as onshore. In addition, at end of economic life, final seismic survey is performed prior to handover (costs discounted for time value of money)	
MMV recurring costs	Fixed cost per field, offshore costs ~2 times as high as onshore	

SOURCE: Team analysis

Assumptions on other parameters (2/2)

Cost driver	Assumption	Why no sensitivities
▪ Permitting costs	€ 1M per project	① Sensitivity range would be small as cost driver is small
▪ Well remediation costs	Provision ranging from nil to 60% of new well costs, based on chances of risky wells and costs to handle them.	
▪ Platform costs	For offshore there are platform costs; SA is assumed to require a new platform, DOGF is assumed to require refurbishment of an existing platform	
▪ Decommissioning	15% of CapEx of all operational wells and CapEx of platform	
▪ Post-closure monitoring	20 years after closure, at 10% of yearly MMV expenses during first 40 years	
▪ Economic life	40 years, demonstration phase 25 years. In line with Capture assumptions;	② Sensitivity range would be too small as cost driver is well understood from E&P experience
▪ Learning rate	0% as CO_2 storage technologies are well known and builds on oil& gas industry experience[1]	
▪ Exchange rate	1.387 USD/EUR (as of October 6, 2010)	
▪ Plant CO_2 yearly captured	CO_2 captured is assumed to be 5Mt per year. A potential variation is not modeled explicitly as it does not affect the costs per ton CO_2 because it such variation is equivalent to the variation in storage field capacity which is already modeled as a sensitivity	▪ Sensitivity modeled with other parameter

SOURCE: Team analysis

METHODOLOGY

1 Early commercial phase as basis	▪ Starting point of the model is the **early commercial phase** – Demonstration phase is modeled as a special situation – Mature commercial phase is assumed to be similar to the early commercial phase, i.e. it is assumed that there is only a low learning rate. This is because of the re-utilisation of existing technologies from the mature E&P industry
2 Six discrete, realistic cases	▪ The model computes CO_2 storage costs for **six discrete cases**, based on **Industry experience**, and varying on **three dimensions**: – Onshore vs. Offshore fields – Depleted Oil/Gas Field vs. Saline Aquifer – Legacy wells present vs. no legacy wells present[1]
3 High number of parameters and sensitivity ranges	▪ **26 parameters** are modeled to determine the CO_2 storage cost ▪ For **8 of these parameters**, sensitivity ranges have been run since these have a **material effect** on the outcome
4 All costs annualized	▪ All costs are **annualized** with the weighted average cost of capital, taking into account the time value of costs
5 Costs in €/ton CO_2 stored	▪ The model computes the CO_2 storage costs in Euro per ton CO_2 **stored**, not per ton CO_2 abated. This ensures neutrality for different capture technologies ▪ The scope is Europe, for other regions global variations in costs need to be taken into account (e.g. rig costs). However the trends between the six cases are expected to be the same

1 SA fields have no legacy wells, so the three dimensions result in 6 discrete cases

What's Next?

- ZEP acknowledges costs of CCS will be inherently uncertain until further projects come on stream
- Cost reports don't provide a forecast of cost development but…
- …will be updated every two years in line with technological developments and the progress of the EU CCS demo programme
- Future updates will also refer to co-firing with biomass, combined heat and power plants, and the role of industrial applications
- ZEP aims to undertake further work on costs to put the cost of CCS in perspective with other low carbon energy technology options

Zep

Zero emissions platform

European Technology Platform for Zero Emission Fossil Fuel Power Plants