Overview of Industrial CCS

CSLF Workshop – Tokyo

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September 2016

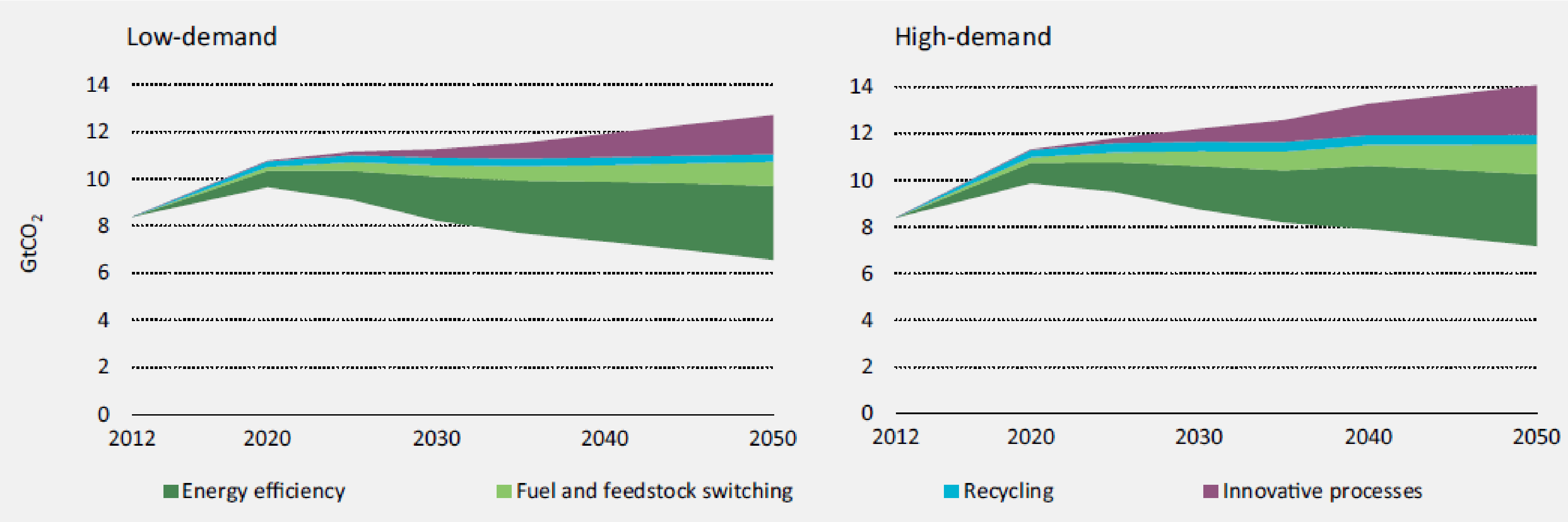
Industrial processes can not simply be switched out of the global economy

- These Industrial processes produce the building blocks of modern society
  - Steel, cement, fertiliser, various chemicals from coal (CTX), plastics, methane production, oil refining, hydrogen production
- Demand for these products will continue to grow through to the middle of this century:
  - Global population to increase by 25%
  - Global GDP to increase by 150%
  - Global electricity demand to increase by 50-70%

These products are necessary inputs to the transition to a lower emissions energy system

Approximately 9Gt* or one quarter of Anthropogenic CO2 Emissions arise from Industrial Processes

Emission Trajectories for Industrial Emissions; IEA 6DS and 2DS



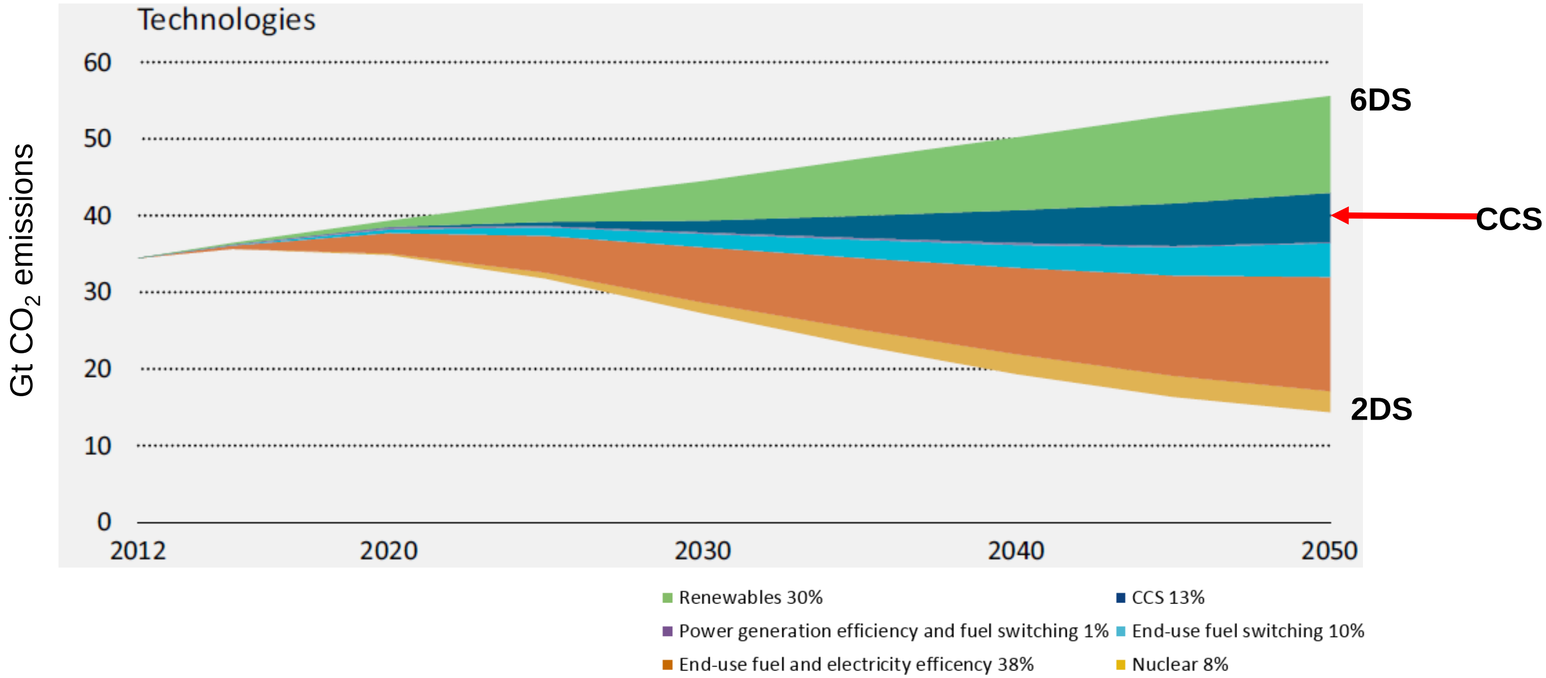
CCS is one of the main contributors to the innovative processes required to reduce emissions to limit warming to 2 degrees.

Source: IEA, Energy Technology Perspectives 2015

*in 2013

CCS is the only feasible emissions reduction technology for many industrial CO2 process emissions

- CO2 is a process emission independent of the source of electricity
- Not possible to eliminate these CO2 emissions through the use of nuclear or renewable energy sources



The IEA, in its *2013 CCS Roadmap*, projected that almost half (45 per cent) of the CO2 captured between 2015 and 2050 consistent with its 2˚C Scenario would come from industrial applications

Source: IEA, Energy Technology Perspectives 2015

Industrial CCS compared with Power Generation CCS

- Natural gas processing
- Iron and steel making
- Hydrogen production
- Fertiliser production
- Coal gasification
- Factories

VS

Power generation

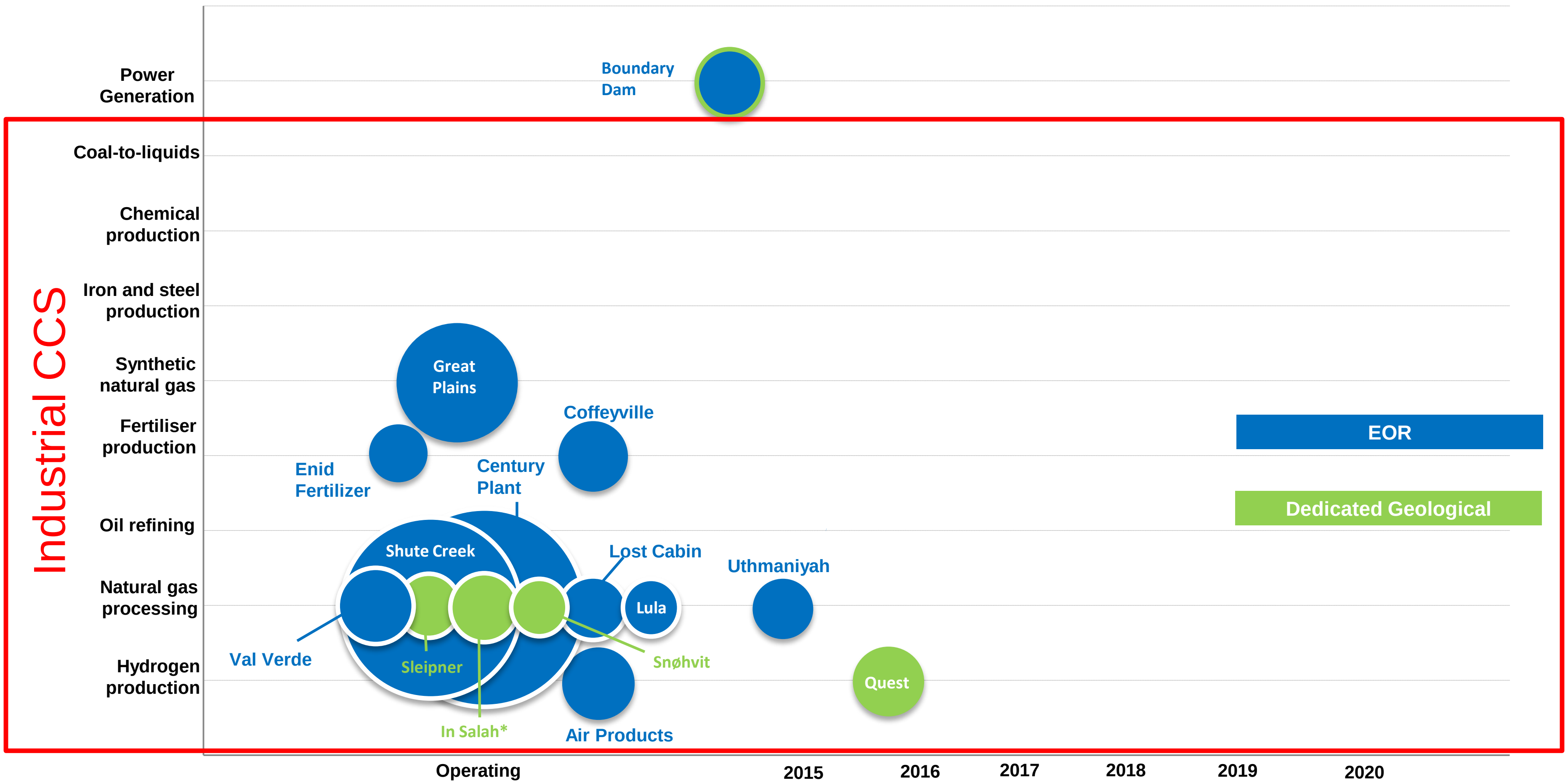
Industrial CCS

- Can’t eliminate via substitution with nuclear/renewable energy sources
- More concentrated CO2 stream
- Smaller capture cost
- Tends to be higher margin business
- Smaller commercial challenge

Power Generation CCS

- Can substitute nuclear/renewable
- Dilute CO2 stream
- Larger capture cost
- Tends to be lower margin business
- Larger commercial challenge

Large Scale CCS Projects in Operation – Industrial CCS leading the way

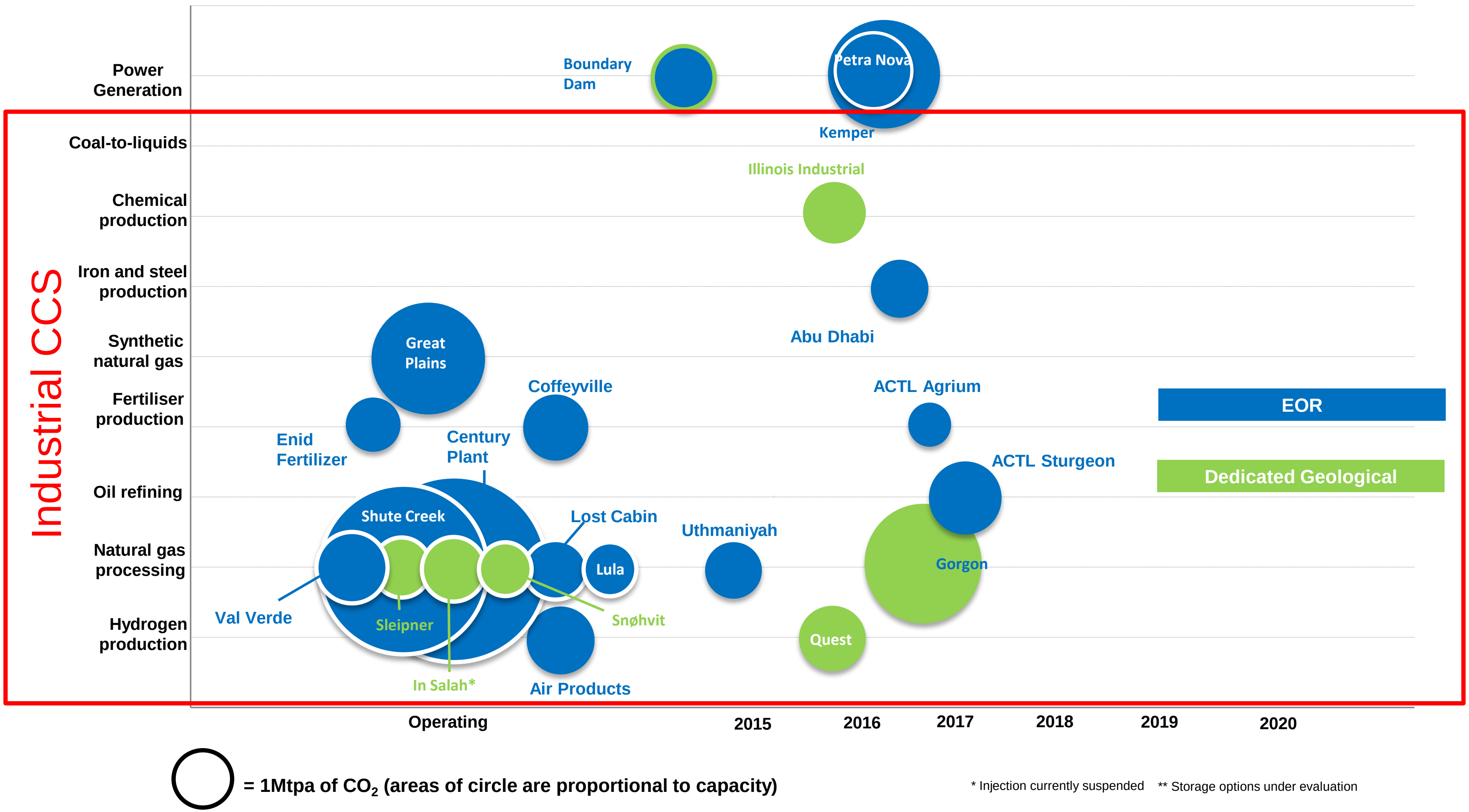


= 1Mtpa of CO_2 (areas of circle are proportional to capacity)

* Injection currently suspended ** Storage options under evaluation

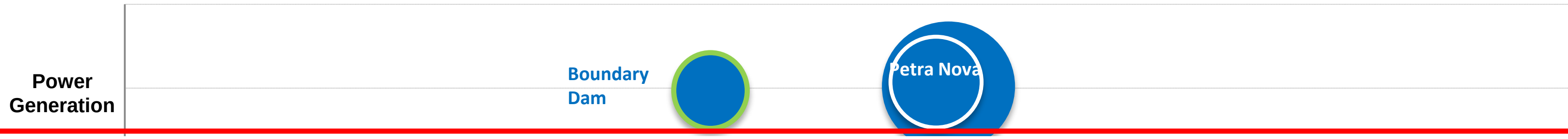
14 of 15 operating large scale CCS projects are industrial: ~27/28Mtpa CO_2

Large Scale CCS Projects in Operation + projects under construction



7 more projects expected to commence operation in 2016/17: ~40Mtpa CO_2

CCS, particularly Industrial CCS, is making a contribution to emissions reduction now



These 19 Industrial CCS projects have the capacity to store 35Mt of CO2 each year. This is approximately equivalent to the emissions abatement from:

- 19GW of solar PV (if displacing coal)
- More than the total installed solar PV capacity of the United Kingdom, Australia, Greece and Switzerland in 2015.

Operating 2015 2016 2017 2018 2019 2020

= 1Mtpa of CO_2 (areas of circle are proportional to capacity)

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Industrial CCS projects in operation by the end of 2017: ~35Mtpa CO_2

Assumptions: PV 21% capacity factor, coal emissions intensity 1000kg/MWh. Installed PV Capacity from Solar Power Europe Global Solar Market Outlook 2016-2020

CCS on Gas Production

Project	Location	Start date	Scale	Characteristics/Approach
Val Verde	US	1972	1.3 Mtpa	Physical solvent-based capture; CO_2 content of NG = 25 - 50%
Shute Creek	US	1986	7 Mtpa	Physical solvent-based capture; CO_2 content of NG = ~65%; test site for CFZ™ cryogenic capture technology test (see Case Study)
Sleipner	Norway	1996	0.85 Mtpa	Chemical solvent-based capture; CO_2 content of NG = 4 – 9%; storage incentivized by Norwegian carbon tax ~USD50/tonne
Snøhvit	Norway	2008	0.7 Mtpa	Chemical solvent-based capture; CO_2 content of NG = 5 – 8%; storage incentivized by Norwegian carbon tax ~USD50/tonne
Century Plant	US	2010	8.4 Mtpa	Physical solvent-based capture; CO_2 content of NG = 60+%
Lost Cabin	US	2013	0.9 Mtpa	Physical solvent-based capture; CO_2 content of NG = ~20%
Petrobras Lula	Brazil	2013	0.7 Mtpa	Membrane-based capture; CO_2 content of NG = 8 – 15%;
Uthmaniyah	Saudi Arabia	2015	0.8 Mtpa	Solvent-based capture
Gorgon	Australia	2017*	3.4 - 4 Mtpa	Chemical solvent-based capture; CO_2 content of NG = 7 – 14%

CCS on Hydrogen & Fertiliser/Ammonia Production

Hydrogen Production

Project	Location	Start date	Scale	Characteristics/Approach
Air Products Port Arthur	US	2012	1 Mtpa	Vacuum swing adsorption
Shell Quest	Canada	2015	1 Mtpa	Physical solvent-based absorption
Jerome	France	2015	0.1 Mtpa	Cryogenic separation
Tomakomai	Japan	2016	0.1 Mtpa	Solvent-based absorption

Fertiliser/Ammonia Production

Project	Location	Start date	Scale	Characteristics/Approach
Enid Fertilizer	US	1982	0.68 Mtpa	Fraction of high-purity CO_2 stream not needed for urea production used for EOR
Coffeyville	US	2013	1 Mtpa	Petroleum coke feed

CCS on Bioethanol Production

Project	Location	Start date	Capture capacity	Characteristics/Approach
Arkalon	US	2009	0.31 Mtpa	EOR, Texas
Bonanza	US	2011	0.16 Mtpa	EOR, Kansas
Rotterdam	Netherlands	2012	0.3 Mtpa	CO_2 supplied to greenhouses
Illinois industrial Project	US	2017	1 Mtpa	Geological storage
Lantmännen Agroetanol	Sweden	Planned	0.17 Mtpa	Storage under evaluation
CPER Artenay	France	Planned	0,2 Mtpa	Storage under evaluation
Sao Paulo	Brazil	Planned	0.02 Mtpa	Storage under evaluation

CCS on Cement Production

Project	Location	Start date	Capture capacity	Characteristics/Approach
ECRA studies	EU	2007	Desktop study	Screening CO_2 capture technologies for cement plants
ITRI pilot	Taiwan	2013	1 t/h	CaL pilot
Norcem's tests	Norway	2014 (ongoing)	Multiple tests	Pilot tests (amine, membranes, solid sorbents)
CEMCAP project	EU	2015 (ongoing)	Multiple tests	Oxy-fuel (burner, calciner, clinker cooler), chilled ammonia, membranes and CaL tests.
Calix pilot	Belgium	2017	~80 tpd	Direct separation pilot

CCS on Iron and Steel Production

Project	Location	Start date	Capture capacity	Characteristics/Approach
ULCOS	EU	2009	Desk study	Screening of CO_2 capture technologies for steel plants
COURSE 50	Japan	2011	30 tpd	Chemical absorption based capture from blast furnace gas
POSCO	Korea	2012	10 tpd	Ammonia-base capture from blast furnace gas
Shougang Jingtang Iron and Steel	China	2014	Feasibility Study	300 tpd chemical absorption pilot, from hot blast stove and lime kiln flue gas
Abu Dhabi CCS Project	UAE	2016	2400 tpd	Solvent-based capture in Direct Reduction Iron unit
STEPWISE	Sweden	2017	14 tpd	Sorption Enhanced Water-Gas Shift (SEWGS) pilot for blast furnace gas

CCS on Oil Refining (Non- H2 Production)

Project	Location	Start Date	Scale	Characteristics/Approach
Sinopec Zhongyuan Oil Field	China	2006	360 tpd	Solvent-based capture from FCC flue gas
CO_2 Capture Project (CCP)	Brazil	2011	<1 tpd	Oxy-firing trials on FCC
Technology Centre Mongstad	Norway	2012	240 tpd	Solvent-based capture from FCC flue gas

CCS on Pulp & Paper Production

Project	Location	Start Date	Scale	Characteristics/Approach
Piteå Black Liquor Gasification	Sweden	2005	Desktop	Analysis evaluating development of a 60 tpd, physical solvent-based capture system
Boise White Paper Mill Case Study	USA	2006	Desktop	Study for 1 Mtpa facility using solvent-based capture
Quebec Pulp Mill Utilisation Project	Enzyme-based solvent	Planning	30 tpd	Quebec, Canada

Japanese Industrial CCS Interests – 2 examples

Tomakomai CCS Demonstration Project - Hokkaido

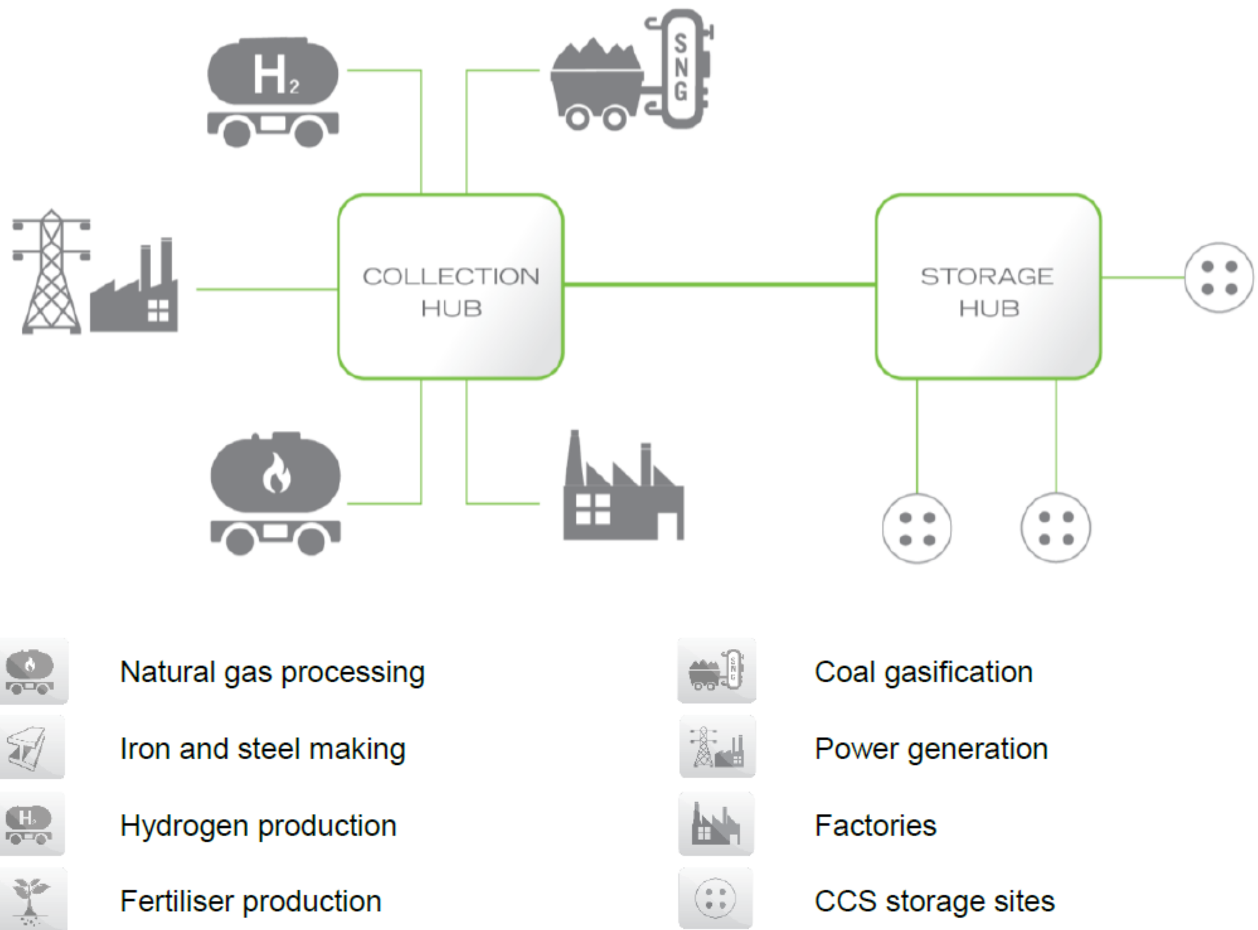
- Operating
- CCS on hydrogen production unit
- 100,000tpa CO_2
- Onshore injection and storage in near offshore reservoir

Victoria, Australia Hydrogen Production

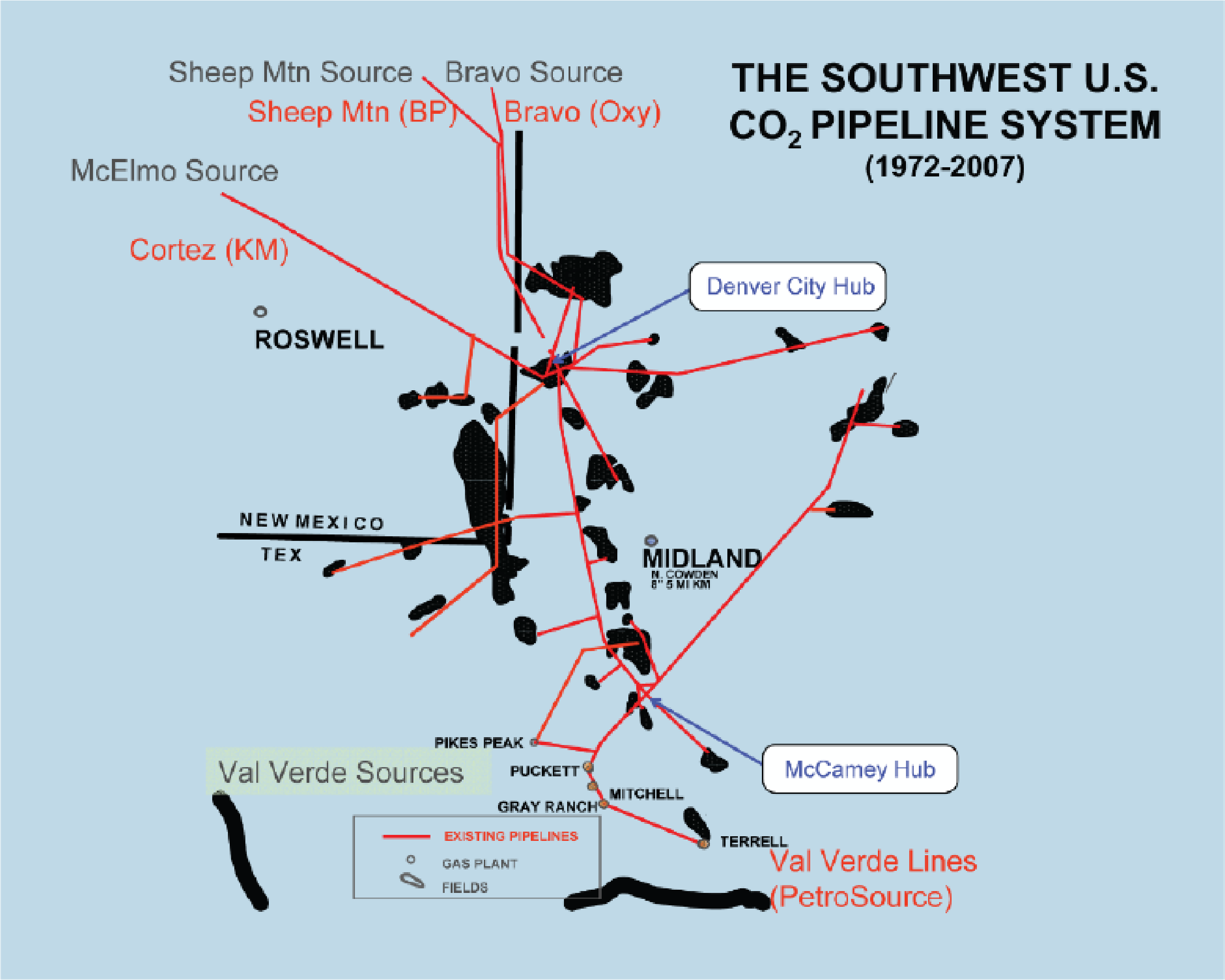
- Concept
- Gassify lignite, produce hydrogen
- Store CO_2 in Gippsland Basin
- Potential opportunity for CarbonNet Project
- Ship hydrogen to Japan

Hubs and Clusters

- Industrial CO_2 sources often located in industrial complexes
- Opportunity to reduce cost and risk through hubs and clusters

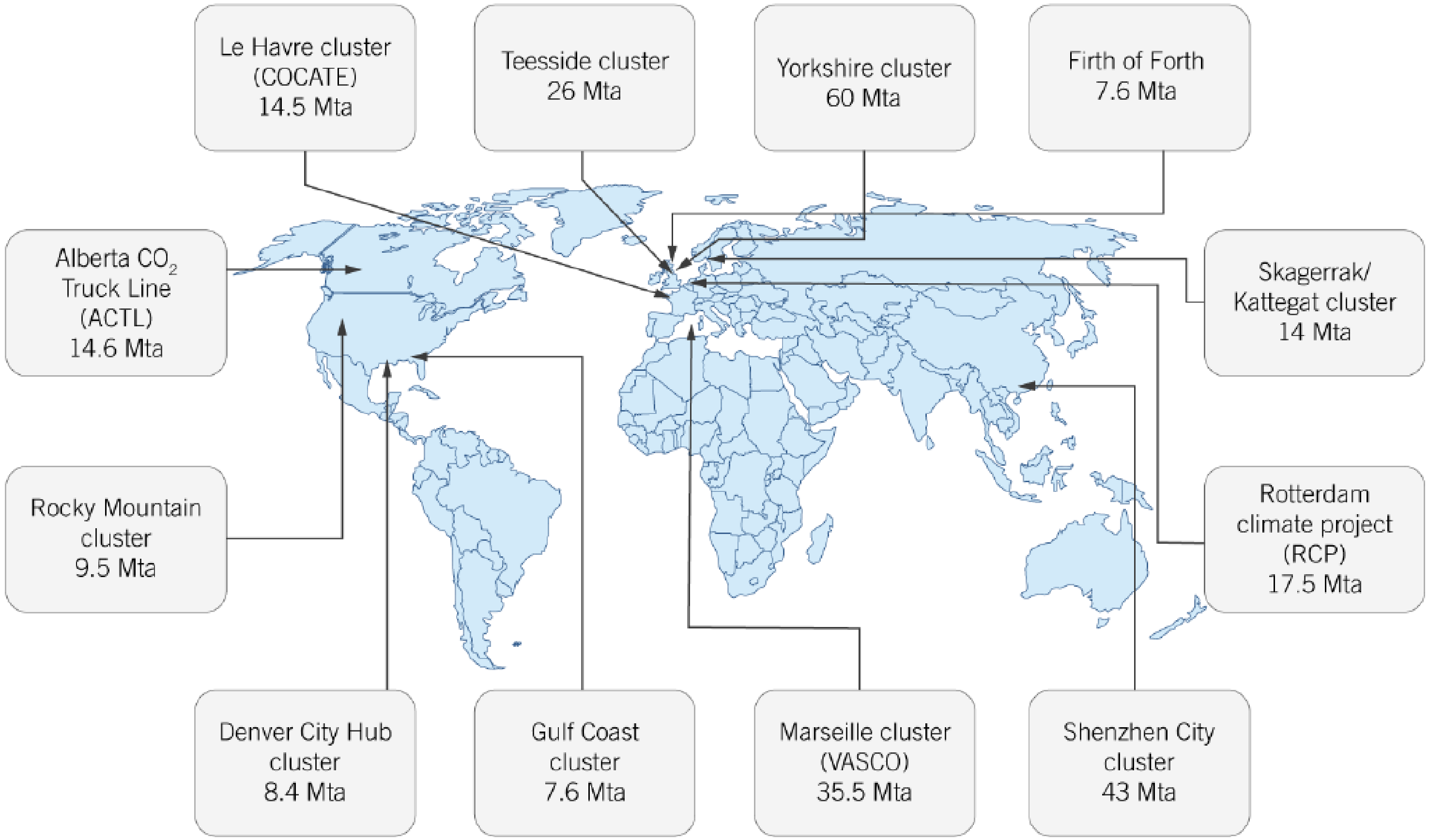


Southwest US CO_2 Pipeline System



Adapted from Melzer 2007.

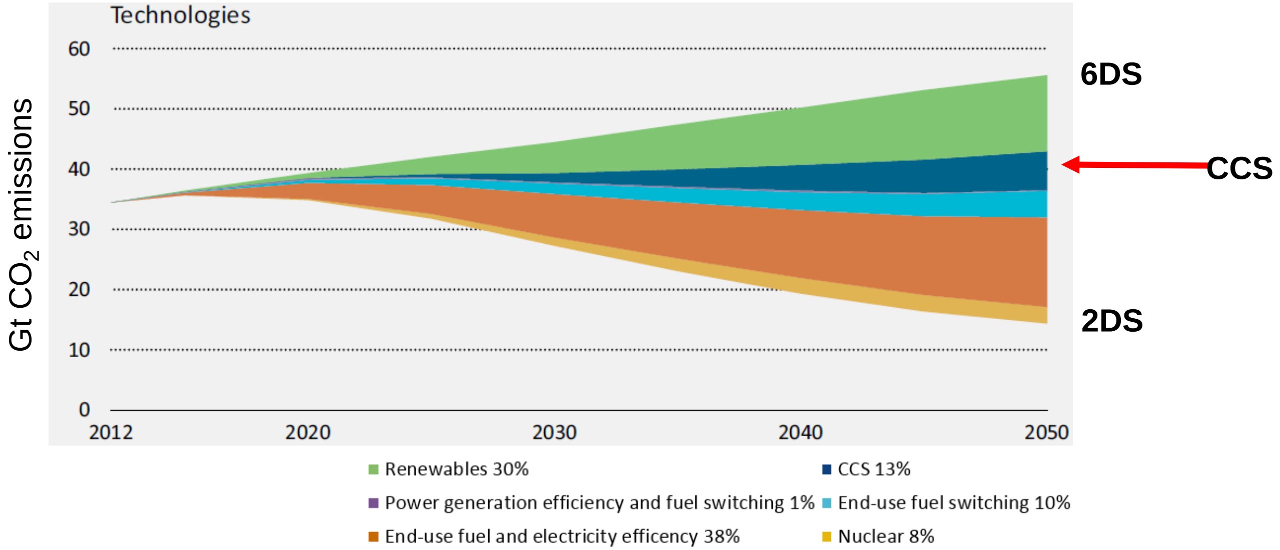
Major CCS Clusters – Proposed or in Development



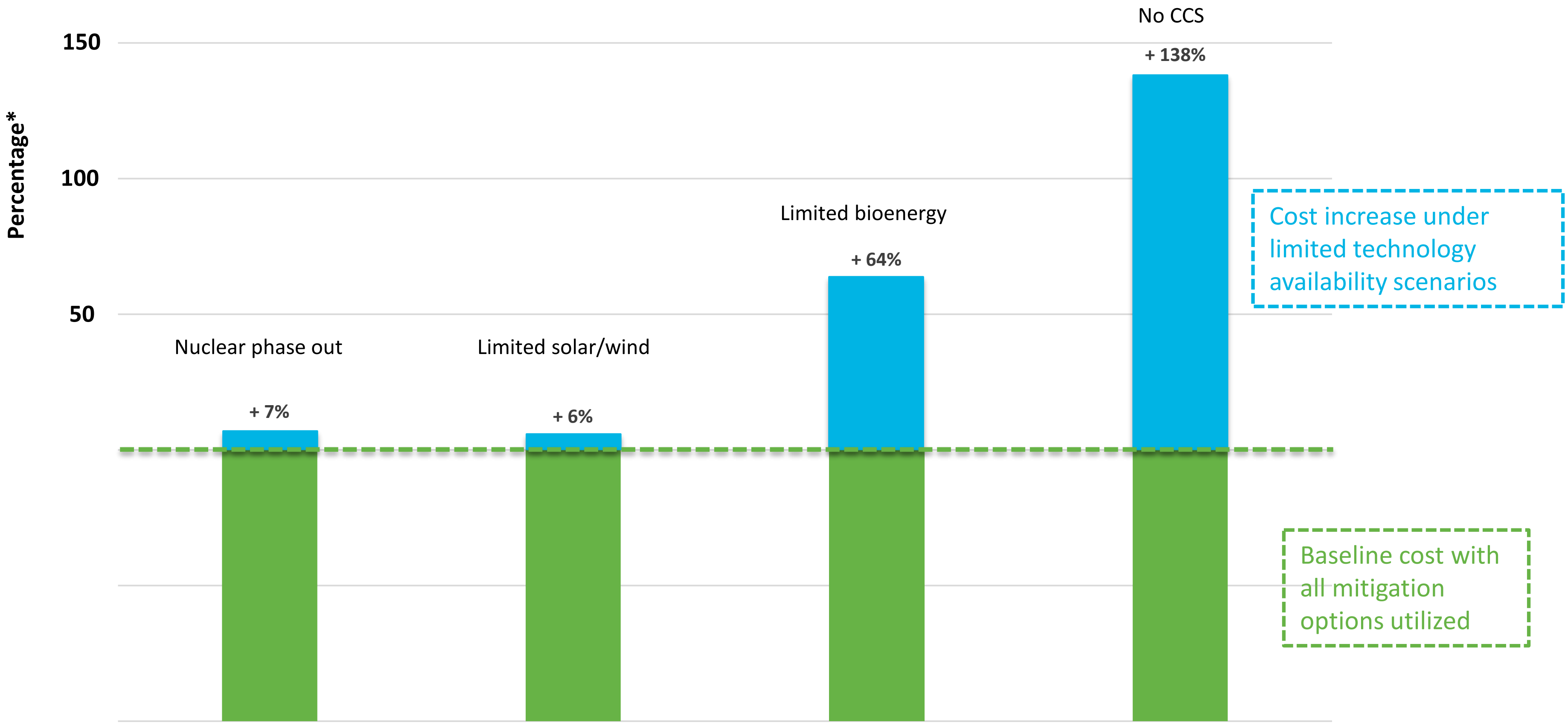
Adapted from IEAGHG 2015a and ZEP 2014 data. Figure 1 identifies existing industrial clusters with estimated annual CO2 emissions. CCS infrastructure exists in some of the clusters identified in the figure. The figure is illustrative only.

CoP21 – The need for CCS will become more visible

- CoP21 was a significant step forwards:
  - 195 countries agreed a higher level of ambition; limiting global warming to1.5 - 2 degrees Celcius
  - Established bottom-up architecture for emission reduction targets allowing nations to determine their national contributions
  - Established a process of regular (5 yearly) reviews of national emission reduction targets and an expectation that targets will become more stringent



Mitigation costs more than double **in scenarios with** limited availability of CCS



*Percentage increase in total discounted mitigation costs (2015-2100) relative to default technology assumptions – median estimate

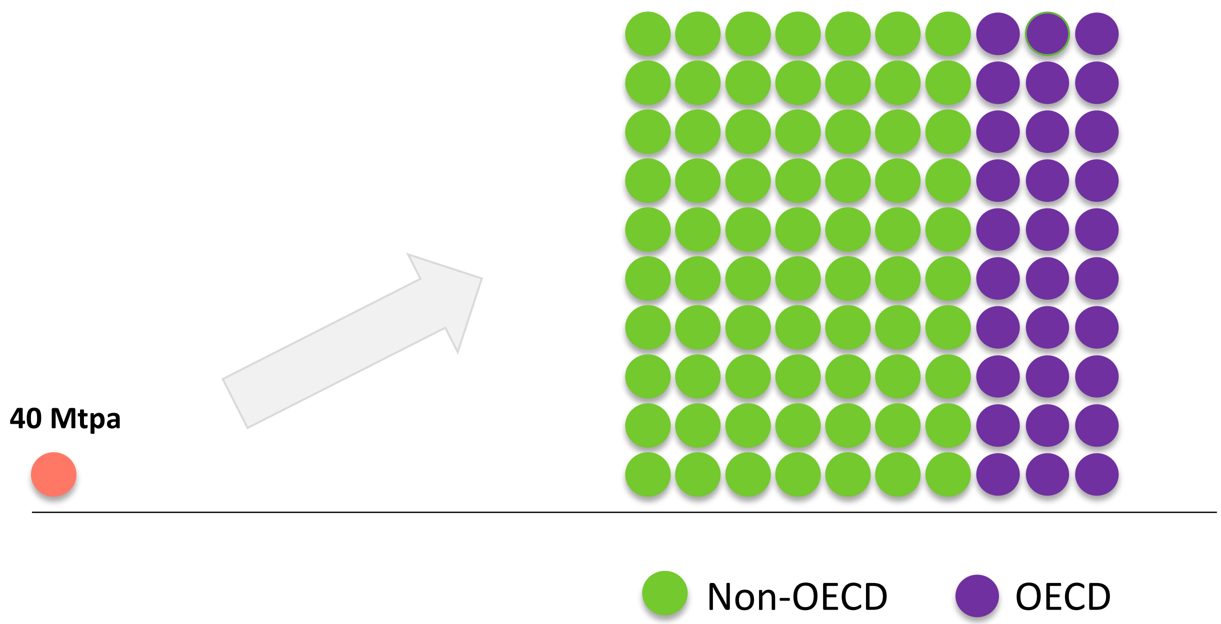
Source: *IPCC Fifth Assessment Synthesis Report, Summary for Policymakers, November 2014.*

A significant task within one generation

Global Status of CCS → **~4,000 Mtpa of CO_2 captured by CCS by 2040** **(IEA 450 Scenario)****

40 large-scale CCS projects - combined capture capacity of approximately 71 Mtpa*:

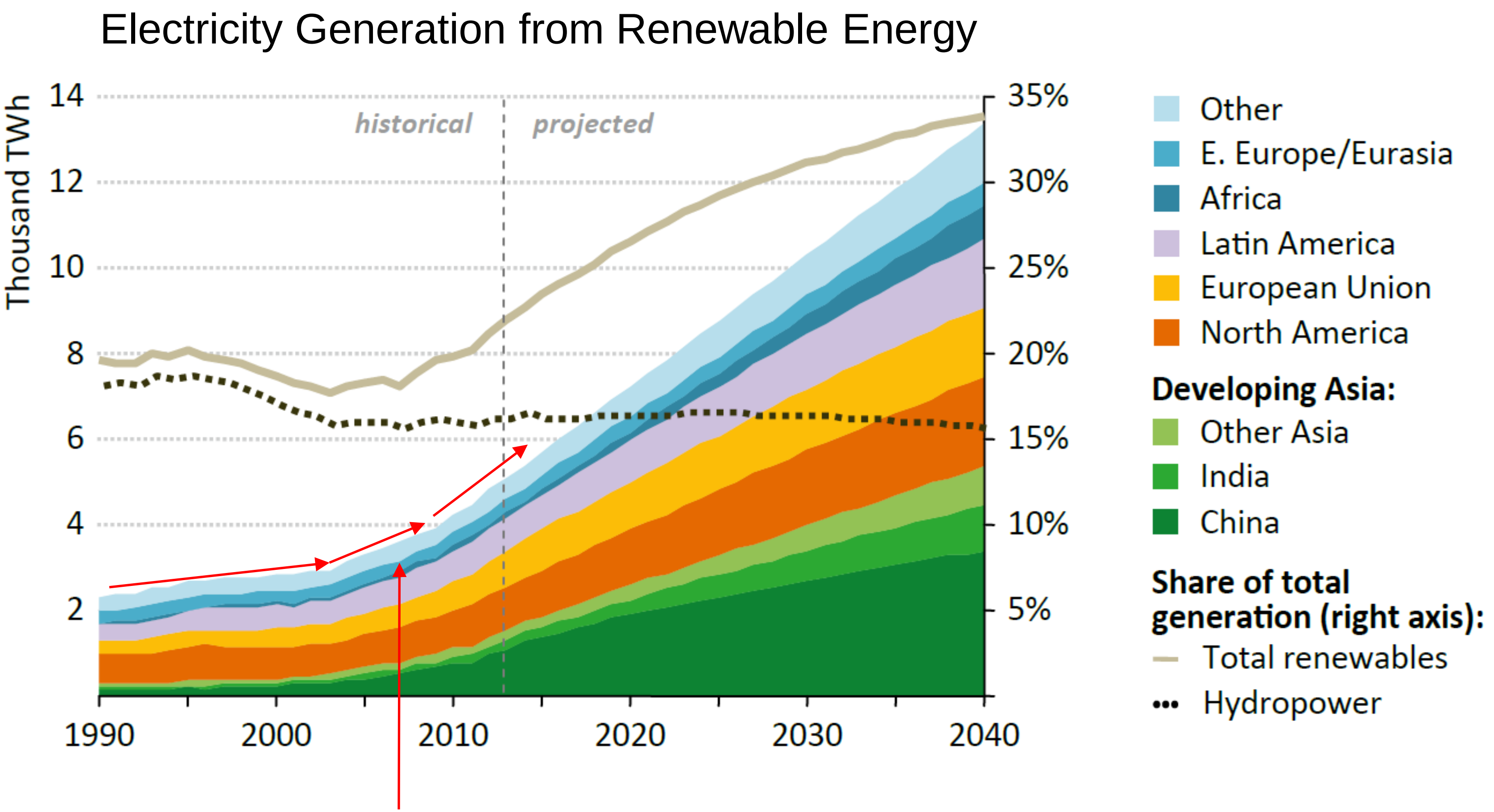
- 22 projects in operation or construction (**40 Mtpa**)
- 6 projects in advanced planning (6 Mtpa)
- 12 projects in earlier stages of planning (25 Mtpa)



Mtpa = million tonnes per annum

****Source**: *IEA, Energy Technology Perspectives (2016).*

Renewables – a fantastic success story! What can we learn?

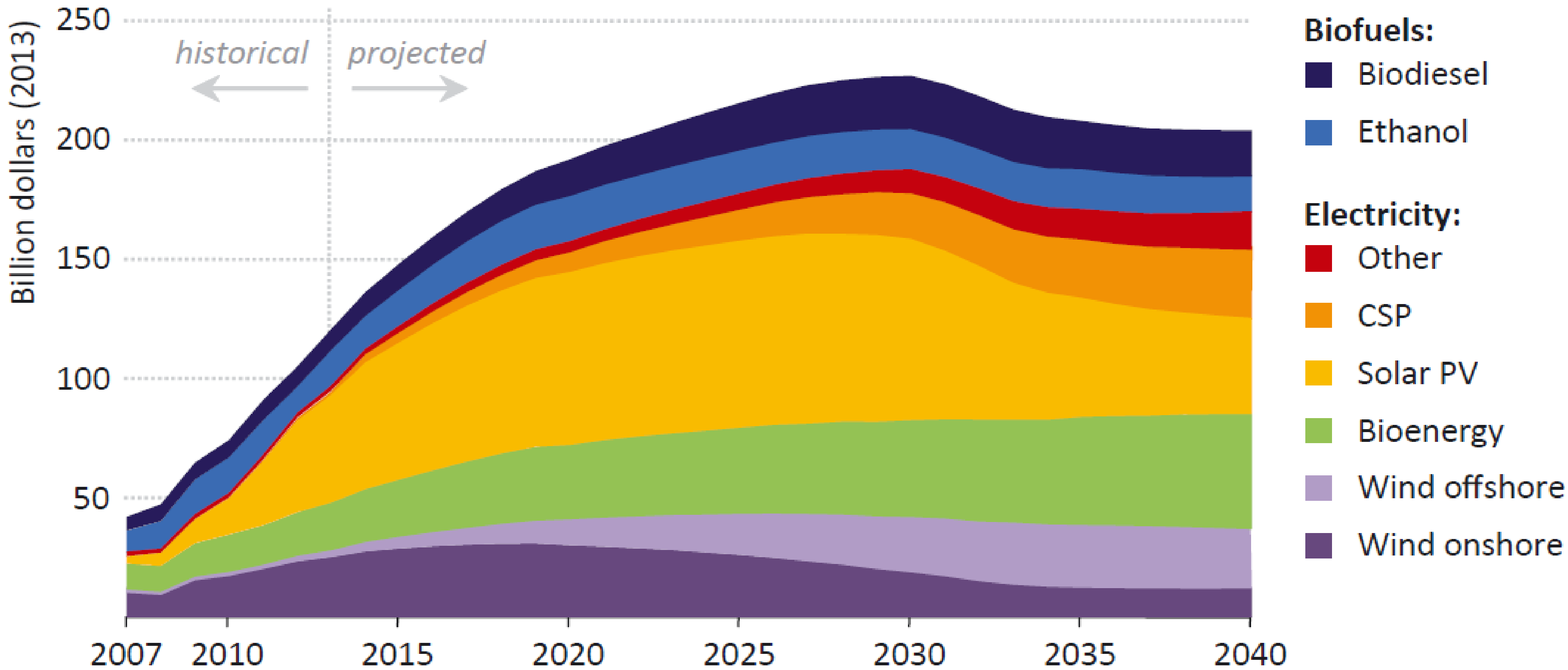


Rapid increase in renewable electricity generation

Data source: IEA, World Energy Outlook 2015

Renewables – a fantastic success story – driven by policy

Annual Subsidy provided to Renewable Energy (US$ Billion)

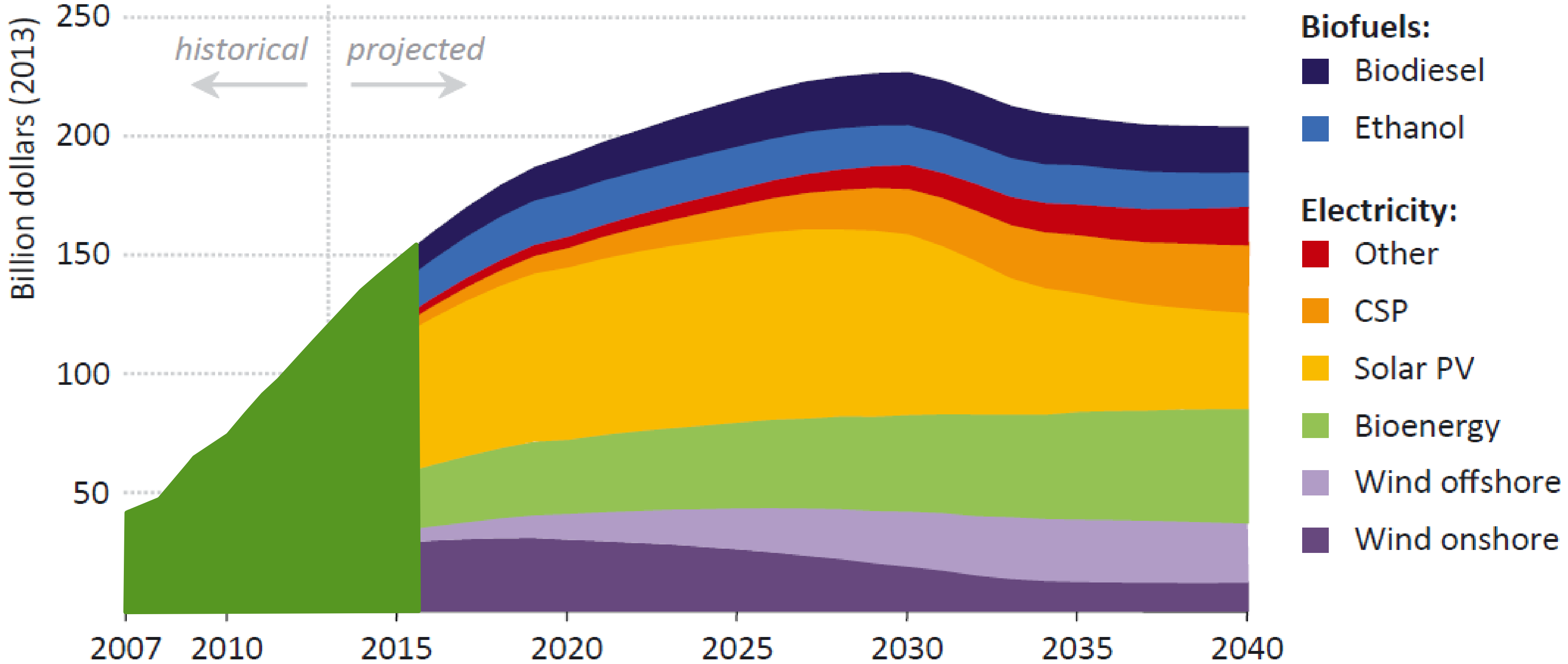


Significant and sustained policy support has incentivised massive private sector investment, resulting in rapid deployment and cost reductions arising from competition between suppliers and economies of scale.

Data source:IEA, World Energy Outlook 2014

Renewables – a fantastic success story! Policy parity is required for CCS to play its part in emission reductions.

Annual Subsidy provided to Renewable Energy (US$ Billion



- In the period 2007 to 2016, value of global policy support for renewable energy deployment was around US$800B.

- Total value of policy support for deployment of CCS over all time is around $20B

Data source:IEA, World Energy Outlook 2014, Global CCS Institute

Thank you for your attention

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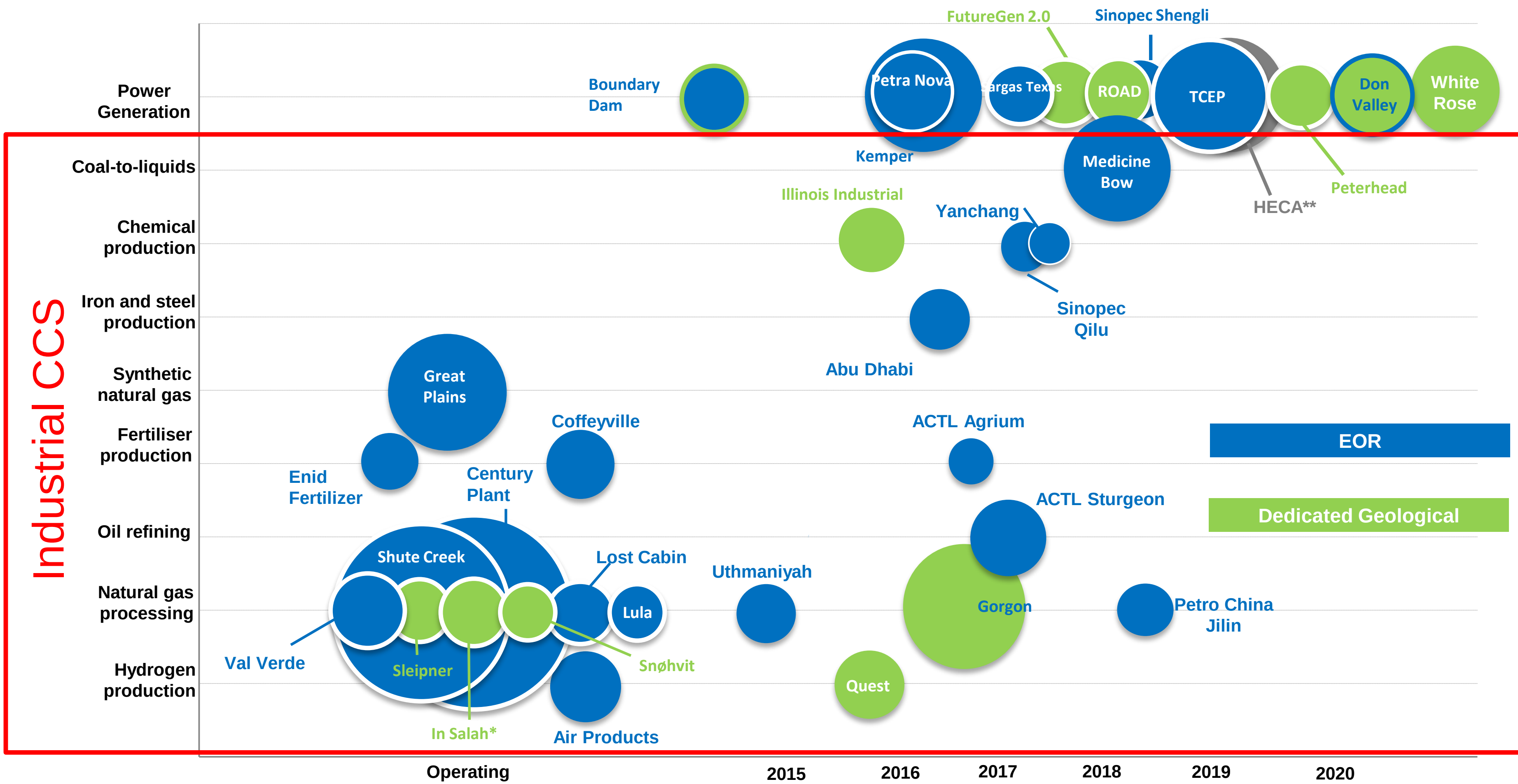
Large Scale CCS Projects in Operation + projects under construction and in planning



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Looking forwards, more power projects are in the pipeline than industrial projects.