carbon
sequestration leadership forum

6th CSLF Ministerial Conference
Riyadh, Saudi Arabia
November 4, 2015
Briefing Documents

Carbon Sequestration Leadership Forum
www.cslforum.org

6th CSLF Ministerial Meeting

Riyadh, Kingdom of Saudi Arabia
04 November 2015

Briefing Documents

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CSLF Technology Roadmap Interim Report

Executive Summary and Conclusions

At the 5th CSLF Ministerial Conference, convened in 2013, Ministers stressed that the next seven years were critically important for creating the conditions for CCS to be ready for large-scale deployment by the end of the decade. The 2013 CSLF Technology Roadmap (TRM) established that the year 2020 was an achievable timeframe for demonstration of the 1st generation of CCS technologies and that by the year 2030, 2nd generation technologies should be moved through demonstration and into commercialization. However, now, two years later, barriers are still in place that inhibit the accomplishment of these goals.

Overall, except for a very few niche industrial sector applications, for the current generation technologies, *none* of the ten technology needs areas were generally perceived as progress being ‘fast moving’. To the contrary, ‘slow-to-moderate’ progress was perceived as the norm for almost all of the ten areas, mainly because of policy and economic barriers that currently exist. The technical readiness of these technologies were perceived, in general, as ready for large-scale commercial deployment.

CCS is considered a key contributor in strategies for decreasing the impacts of climate change and global warming. The main takeaway from this interim report is that the next several years are a critical time period when not only technologies, but also regulatory policies and approaches toward project financing must become mature. In this context, the following recommendations are made to accelerate progress:

- Concerning economic barriers, governments should urgently consider methods to assist stakeholders to significantly drive down the cost of CCS deployment, since it is the stakeholders who will be making the majority of the financial investments.
- Concerning policy barriers, governments should review institutional regulatory policies to identify how these barriers to CCS deployment may be reduced.
- Concerning any remaining technology barriers, stakeholders should increase their mechanisms for sharing best practices, particularly regarding communications, regulation and cost reduction, and pledge to engage in public-private partnerships to encourage the development of additional demonstration projects and facilitate the development of CCS projects internationally.

Finally, Ministers should be champions of CCS, and should ensure that they understand how critical CCS is to reaching target goals for CO_2 emissions, and that CCS deployment will create and preserve jobs. Ministers should also recognize the contribution that CCS can provide in terms of energy security. These will all form part of the narrative that will help shape the future progress of CCS.

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Messages and Recommendations from the CSLF Technical Group

Following are key messages and recommendations, organized by topic, from Technical Group meetings and events since the 2013 CSLF Ministerial meeting.

A. Needs of Emerging Economy Countries.

- CCS, as part of a suite of low carbon options, is becoming a national priority area for emerging economy countries. While development of regulatory frameworks and other policy-related issues are necessary, and allocation of resources remains a challenge to emerging economies, building and sustaining CCS technical capabilities in these countries is critical to global CCS deployment. Capacity building activities such as the CSLF are beneficial and should be expanded.
- Even though there are many similarities in the needs of emerging economy countries, each country has a specific set of circumstances in terms of national priorities, and this results in different strategies for developing and implementing CCS and low emission technologies.

Recommendations:

a) Engage in additional technical capacity building activities in emerging economy countries. This is a necessary precursor before large-scale CCS can be accomplished in those countries.
b) Provide assistance as necessary for emerging economy countries in developing CO_2 storage atlases and in creating strategies for making CCS possible.

B. CO_2 Utilization, EOR.

- There are no specific technological barriers or challenges *per se* in transitioning and converting a pure CO_2-EOR operation into a CO_2 storage operation but there are legal, regulatory and economic differences between the two.
- A challenge for EOR operations which may convert to CO_2 storage operations include the lack of baseline data for monitoring, and monitoring requirements for CCS which are broader and more encompassing than for EOR.
- The main reason Enhanced Oil Recovery (EOR) is not applied on a large scale outside the United States and Canada is the unavailability of high-purity CO_2 in the amounts and at the cost needed for this technology to be deployed on a large scale.
- The absence of infrastructure for capture and transport of the CO_2 from the sources to oil fields suitable for EOR is also a key reason for the lack of large scale deployment of EOR.

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<u>Recommendation</u>:

a) Address the need for clarification of the policy and regulatory framework for CO_2 storage in oil reservoirs, including incidental and transitioned storage CO_2-EOR operations. The framework should address long-term liability, monitoring requirements, and jurisdictional responsibility.

C. CO_2 Utilization, non-EOR.

- EOR is the most near-term, commercial CO_2 utilization option. However, a number of non-EOR CO_2 utilization options are available which can serve as mechanisms for early and affordable deployment and commercialization of CCS. These options are at varying degrees of commercial readiness and technical maturity and their contribution to avoided CO_2 emissions needs to be better understood.

<u>Recommendations</u>:

a) For mature non-EOR CO_2 utilization options, efforts should be on demonstration projects and on the use of non-traditional feedstocks or polygeneration concepts.

b) Efforts that are focused on hydrocarbon recovery other than EOR should focus on field tests.

c) Efforts that are in early R&D or pilot-scale stages should focus on addressing key techno-economic challenges, independent tests to verify the performance, and support of small and/or pilot-scale tests of first generation technologies and designs.

d) More detailed technical, economic, and environmental analyses as well as technology qualifications should be conducted on options that are in early R&D or pilot-scale stages.

D. Offshore Sub-Seabed Storage of CO_2.

- Offshore sub-seabed geologic storage of CO_2 provides key advantages over onshore geologic storage: clearer stakeholder management, usually only a single owner/manager of both mineral and surface rights to the site; , and lower risks for potential disruption of existing land-based industries and resources .
- Offshore sub-seabed geologic storage also presents some challenges, including elevated costs of operation compared to onshore geologic storage, the necessity of protection of coexisting economic and environment interests such as commercial fisheries and sensitive ecosystems, and in general a more difficult overall accessibility for sub-seabed storage sites.

<u>Recommendations</u>:

a) A systematic evaluation and assessment of the offshore global storage capacity is necessary. An increased level of knowledge sharing and discussion should be implemented among the international community to outline the potential for international collaboration in offshore storage.

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b) Optimization of current offshore storage transport practices and infrastructure is important in terms of reducing cost and supporting deployment. Early pilot-scale and demonstration projects can play a critical role in transport infrastructure development.

c) Offshore CO_2-EOR is a potential mechanism to catalyze offshore storage opportunities and infrastructure networks. However, absent this mechanism, financial incentives for (offshore) CCS projects are needed to increase the speed of development of offshore CCS.

d) Additional R&D is needed to understand CO_2 storage in the sub-seabed environment. This includes the development of predictive modeling capabilities to further increase knowledge and understanding of the marine environment, and development of effective monitoring technologies to validate and quantify sub-seabed CO_2 storage. This includes advances in real-time data retrieval and processing.

E. Reducing the Cost of CO_2 Capture.

- Capture and compression of CO_2 accounts for approx. 80% of the total cost of CCS, and a wide range of next-generation technologies are under development to reduce this cost.
- Technology qualification through pilot- and demonstration-scale testing is critical to address technical, economic and environmental issues, but is time consuming and challenging. Computer simulations and modeling can help to reduce the duration of the overall development cycle, but cannot be a substitute for the experience and knowledge gained through real-world testing.

Recommendations:

a) Development and innovation is important but must establish clearly defined targets and metrics to help drive sound R&D, pilot- and demonstration-scale project investment decisions.

b) Sharing of knowledge, best practices and comparative tests should be encouraged. These are tools which will drive further technology development and scale-up.

c) There must be continued and sustained support not just for capture R&D but for CCS as a whole, including pilots and demonstration projects. Continuity of support is critical, particularly for demonstration projects which are large, complex, multi-year endeavors requiring significant financial, human, and technical resources.

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Progress on CCS Deployment: An Update from the IEA Working Party on Fossil Fuels

Important progress on the development and demonstration of CCS technologies has been achieved over the past two years, most notably with the first demonstration of carbon capture applied to the full output from a commercial-scale coal-fired power generation unit. Looking forward, there are several large-scale demonstration projects in development globally that are scheduled to start in the next two years.

In 2015, the science underpinning CCS technology developments was reviewed in a Special Issue of the *International Journal of Greenhouse Gas Control*. This international, peer-reviewed journal provided updates on technical advances made since publication of the 2005 IPCC Special Report on CCS. The takeaway message from the Special Issue was that:

> "The *capture and geological storage of CO_2 is truly ready for large scale deployment to mitigate climate change. There are several demonstrations of this already at large scale and several others will join in the near future. The cost of avoided CO_2 from the full CCS chain, once corrected to account for inherent variations in the market of power equipment, will go down as leading technologies are deployed. Emerging technologies are also being demonstrated at increasing scales, offering opportunities for more substantial reductions in cost and energy penalties. In short, the science and the technologies supporting CCS as a climate change mitigation tool have experienced a great advance in the last 10 years, consolidating and expanding the knowledge base to estimate more accurately the impacts, risks and cost associated with large CCS projects.*"

Large-Scale CCS Projects

Commissioned in 2014, the first CCS demonstration in the power sector was the 120 MW **Boundary Dam Unit 3 CCS Project** in Saskatchewan, Canada. Utilising amine-based capture technology, results obtained from the first year of operation show that the capture unit and power plant can function together effectively, producing up to 1 million tonnes per year of high purity CO_2. The captured CO_2 is either sold and transported by pipeline to nearby oil fields and used for enhanced oil recovery (EOR), or stored in a saline aquifer. Initial results indicate that the plant is operating at a higher efficiency than originally expected. Furthermore, the operators feel confident the costs of a similar CCS plant based on amine technology could be reduced by 20-30%, just based on the lessons learned during the retrofit.

The **Air Products Industrial CCS Project** was commissioned in early 2014 as the United States' first industrial CCS project. As a first-of-its-kind operating at such a large scale, CO_2 is separated from the flue gas of a steam methane reforming plant producing hydrogen for use in a local refinery. Over 1 million tonnes of CO_2 have since been supplied for EOR operations in Texas.

In 2015, commissioning of Brazil's **Lula Oil Field CCS Project** saw the world's first offshore, deepwater CO_2-EOR project enter operation. The project uses a novel membrane system to strip CO_2 from natural gas before reinjecting it for EOR. The capture and reinjection operations both take place on a floating platform some 300 km off the coast, with a water depth of 2 000 metres.

Experience gained during construction and operation of demonstration plants, and from rigorous monitoring of the CO_2 stored, is essential to the future of CCS. Large-scale application of CCS increases confidence in the technology, as well as helping to develop and refine it, reducing costs for future projects. The next 18 months will see a number of new projects commissioned, including:

- **Quest CCS Project**. This first-of-a-kind project in Canada's oil sands sector is due to start up in November 2015. More than 1 million tonnes per year of CO_2 will be captured from Shell's

Scotford Upgrader near Fort Saskatchewan, Alberta, using an amine-based capture technology. The CO_2 will be transported via an 80-km pipeline to a storage site where it will be injected and permanently stored in a saline aquifer more than 2 km underground.

- **Kemper County Energy Facility**. Mississippi Power's CCS project is due to begin commercial operation in 2016. The 582 MW integrated gasification combined cycle (IGCC) unit, with its pre-combustion CO_2 capture facility, is under construction. The IGCC technology is designed to be particularly effective with low rank coals, which makes this a particularly important demonstration, as low rank coals constitute a significant portion of the world's coal resource. Not only is the plant co-located with a coal mine, but also located close to mature Mississippi oil fields, where captured CO_2 will be used for CO_2-EOR.
- **Gorgon CO_2 Injection Project**. Natural gas produced from the Greater Gorgon Fields, located some 130-200 km offshore Western Australia, contains up to 14% CO_2. Amine-based capture technology will be used to strip CO_2 from the gas. The captured CO_2 will be stored in a geological formation at a depth of approximately 2.3 km beneath the surface, rather than releasing it to the atmosphere as has been traditional practice from similar projects. The project represents a threefold scale up of Norway's Sleipner project and, after it enters operation in 2016 will be the biggest CO_2 storage project of its kind in the world.
- **Petra Nova CCS Project**. In a joint venture between NRG and JX Nippon Oil & Gas Exploration, CO_2 from a 240 MW slipstream of WA Parish's 610 MW coal-fired power plant will be captured using amine-based technology. The project, which becomes operational in late-2016, represents the next phase of scale-up after the Boundary Dam Unit 3 CCS Project. The captured CO_2 will be used to enhance production at mature oil fields in the Gulf Coast region.
- **Abu Dhabi CCS Project**. In 2016, the first large-scale demonstration of CCS in the steel sector will take place in the United Arab Emirates. The CO_2 will be compressed, dehydrated and then pumped through 50 km of pipeline before being injected to enhance oil recovery from an onshore field.

Moving Forward: Innovating Technology and Policy

Complementing progress on numerous large-scale projects is the continued advancement of **next generation CCS technologies**, a number of which are moving through the bench-scale R&D phase and entering pilot-scale testing. These technologies address all parts of the CCS chain—more efficient and lower cost CO_2 capture, less energy intensive CO_2 compression, more effective CO_2 transport, more attractive options to utilise CO_2 and more characterisation of underground repositories for geological storage of CO_2.

While CCS deployment has been slower than anticipated, the need for the technology as a global mitigation option has not receded. Indeed, many energy and climate studies continue to attribute an important role for CCS in a low-carbon energy future.

CCS has made progress in recent years, not only with major demonstrations of the technology now evident in both power and industry sectors, but also with regulatory frameworks necessary to ensure safety of storage. Yet, more is needed. While the technology has been proven, the **policy framework and business case** for wide deployment is not present. CCS is well understood but, at the same time, its value is not fully recognised. Recognition among countries of the importance of CCS must be matched by **policies that incentivise deployment**. Only by assertively striving for such an approach will CCS truly become an option to address the challenges associated with climate change mitigation.

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Zero emissions platform

CCS and the Electricity Market

Modelling the lowest-cost route to decarbonising European power

European Technology Platform for Zero Emission Fossil Fuel Power Plants

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Executive summary

- **ZEP's model shows the lowest-cost route to decarbonising European power**

In order to identify how low-carbon technologies can reduce European power emissions most cost-effectively in the horizon to 2050, the Zero Emissions Platform (ZEP) has developed a model based on an existing model from the Norwegian University of Science and Technology (NTNU) and linked it to the Global Change Assessment Model (GCAM).

ZEP's model is designed to select the lowest-cost investments to meet expected electricity demand, while replacing plants that exceed a defined lifetime – country by country. It is unique in that it not only takes into account optimised operating costs hour-by-hour, but also has a dispatch model for renewable power based on capacity factors and historic weather data.

- **Baseline modelling highlights the critical role of CCS as early as 2030**

Cases studied in the baseline modelling show that the wide and progressive use of lignite, coal, gas and biomass with CO_2 Capture and Storage (CCS) between 2030 and 2050 – combined with a large expansion in hydro, wind and solar – is the lowest-cost route to achieving an 80% absolute[1] reduction in emissions from power. This is documented in ZEP's report, "*CO_2 Capture and Storage (CCS) – Recommendations for transitional measures to drive deployment in Europe*", published in November 2013.[2]

- **CCS is needed to meet electricity demand *and* climate targets – cost-effectively**

Having such a powerful model available, ZEP decided to undertake further modelling in response to questions from the European Commission and other stakeholders:

1. *If CCS is excluded altogether, what is the impact on costs and emission reductions?*
   If CCS is not available to the model and limits[3] on onshore wind and solar photovoltaics (PV) from the original modelling are maintained, electricity demand is not met after 2045 because the model's 80% emission reduction target cannot be achieved without CCS. Blackouts are a possible consequence.

2. *What if the cost of solar in 2050 is also much lower than originally estimated?*
   If the cost of solar is drastically reduced from 1,000 to 200 $€_{(2010)}$/kW installed in 2050 – requiring a major technology breakthrough compared to today – demand is still not met after 2045 and the cost to Europe is 20-50% higher than with CCS.

3. *What if the limits on solar and wind are also relaxed?*
   To see if the above results were robust, limits on the amount of onshore wind and PV were also relaxed – including cases with no limits whatsoever. The latter results in 600 GW of PV and 1,000 GW of wind in 2050 with the original PV cost; up to 1,500 GW of PV and 640 GW of wind with the low PV cost. This represents up to 200,000 5 MW-class wind turbines and up to 10,000 km^2 of Europe's surface covered with PV. Even if this was practically possible, the cost is 35-45% higher than equivalent cases with CCS.

4. *What is the impact of electricity storage on costs?*
   If the model is allowed to select electricity storage to help integrate the renewables, this only has a limited effect (from 2040 onwards) and plays a small role in reducing costs.

- **Conclusion: without CCS, the cost of decarbonising European power is 20-50% higher by 2050**

Even when the limits on PV and wind are relaxed and the cost of PV is significantly reduced, CCS still plays a critical role in the generation mix, reducing the cumulative cost of European power by 20-50% by 2050. This represents some €2-4 trillion – a substantial amount compared to, for example, the ~€150 billion annual electricity expenses incurred by European industry.

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[1] i.e. relative to 2010 levels

[2] See www.zeroemissionsplatform.eu/library/publication/240-me2.html for full details of model equations, cost parameters and results

[3] A total of 250 GW of solar PV and 270 GW of onshore wind in Europe in 2050

1 Background

ZEP's model shows the lowest-cost route to decarbonising European power

In order to identify how low-carbon technologies can reduce European power emissions most cost-effectively in the horizon to 2050, ZEP has developed a model[2] based on an existing model from the NTNU and linked it to the GCAM. It is designed to select the lowest-cost investments to meet expected electricity demand, while replacing plants that exceed a defined lifetime – country by country. It is also unique in that it not only takes into account optimised operating costs hour-by-hour, but also has a dispatch model for renewable power based on capacity factors and historic weather data.

Baseline modelling highlights the critical role of CCS as early as 2030

Cases studied in the baseline modelling show that the wide and progressive use of lignite, coal, gas and biomass with CCS between 2030 and 2050 – combined with hydro, wind and solar – is the lowest-cost route to reducing emissions from electricity generation, driven by the EU ETS.

Given the assumptions made, the model suggests that a CO_2 price ramp rising from its current low levels through to 35-40 €(2010)/tonne in 2030 is sufficient for CCS to be deployed, taking into account cost learning curves. This means that the average emissions intensity for Europe will drop from 420 g CO_2/kWh to 60 g CO_2/kWh in 2050. When considering the increase in electricity consumption, this corresponds to an absolute reduction of ~80% in CO_2 emissions.

These results are fully documented in ZEP's 2013 report: "*CO_2 capture and Storage (CCS) – Recommendations for transitional measures to drive deployment in Europe*".[2]

ZEP undertakes further calculations in response to stakeholder requests

Having such a powerful model available, ZEP decided to carry out further simulations in response to requests from the European Commission and other key stakeholders:

- A number of scenarios were simulated where CCS was excluded in order to see the impact on both emissions and cost.
- Costs for solar PV were originally assumed to drop from 1,900 €/kW in 2010 to 1,000 €/kW in 2050. An extremely aggressive cost reduction to 200 €/kW (that cannot be anticipated with today's technology trends, requiring a new innovation leap) was also simulated to see the impact.
- Limits for onshore wind and PV in the original report were based on projections in the various European countries. These limits were also revised (see Chapter 2).
- Finally, an electricity storage model was added: although pumped hydro storage was present in the original simulations, possible new installation sites were limited. The storage model is described by three variables:
    1. The cost of power components (generator, hydro runner, compressor etc.) at 600 €/kW
    2. The cost of energy storage (caverns, thermal stores etc.) at 60 €/kWh
    3. A round-trip efficiency of 75%.

  The model is free to choose power and energy independently. It appears that a typical ratio of energy to power is 7 hours, which gives 1,000 €/kW for installation costs (600 €/kW + 7 h x 60 €/kWh), or 140 €/kWh for overall storage costs. The latter value is in line with long-term targets for batteries and is ~20% of today's cost level.

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2 Testing a variety of assumptions

Relaxing the limits on onshore wind and solar PV

The model needs realistic limits for the deployment of each technology – especially those that require a substantial amount of land area due to their low energy density. However, it was observed that the limits in the original ZEP report[2] were very tight for some countries – in particular, those on PV installations appeared unequal across Europe.

In Germany, for example, a limit of 70 GW was assumed which, given a panel efficiency of 15%, corresponds to 0.15% of the country's total surface area. Considering that Germany has a comparably high population density, a similar coverage should be possible for other countries as well.

It was therefore decided to set the limit for PV at 0.15% of each country's surface area, which corresponds to a total of 1,000 GW for Europe (the limit in the original report was 250 GW). Figure 1 compares the original and revised limits.

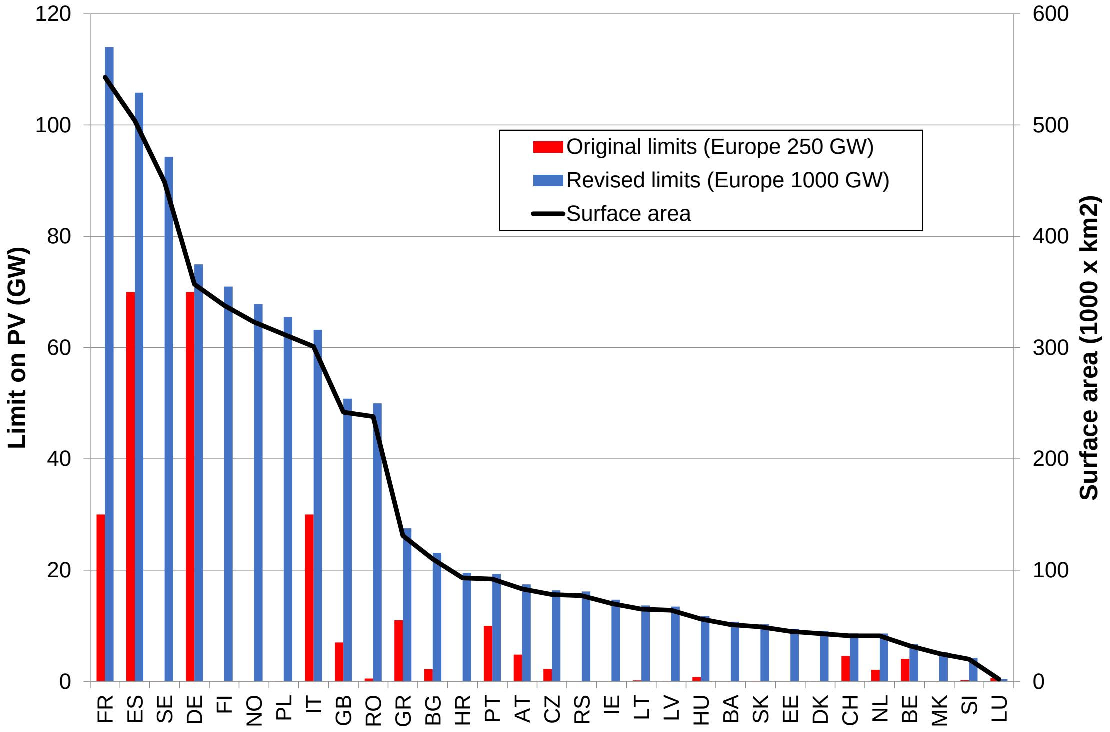

Figure 1: Original and revised limits on PV installations in European countries

A similar argument can be made for onshore wind: a modern 6 MW wind turbine occupies ~1 km^2 of land, in the sense that no housing or other turbines can be within this area. Taking again the example of Germany, the limit for onshore wind was set at 60 GW, which corresponds to 10,000 km^2 or 3% of the country's surface area. As before, the same coverage was therefore used for all European countries. Figure 2 below compares the original and revised limits.

It must be emphasised that these are only technical limits based on a simple argument of land usage. The model is free not to build onshore wind in eastern European countries with poor wind resources, or not to deploy PV in northern European countries with low solar irradiation.

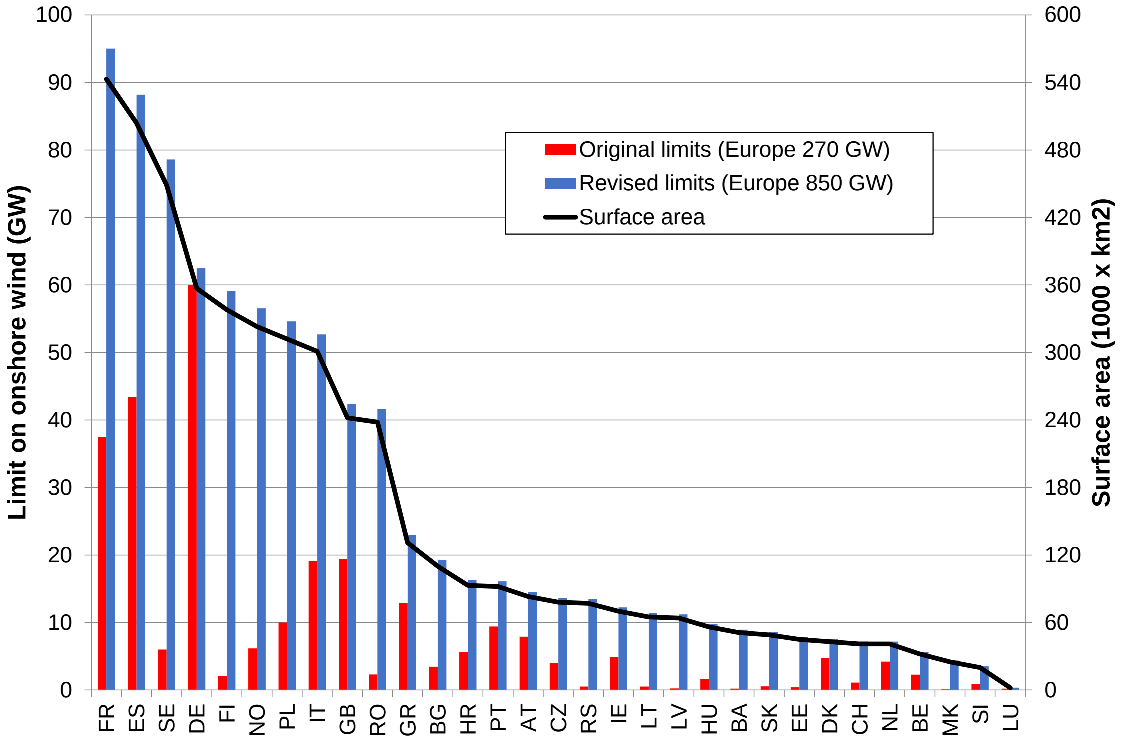

Figure 2: Original and revised limits on onshore wind installations in European countries

Assuming a significantly lower cost for solar PV in 2050

The simulations are based on cost assumptions for the period 2010 to 2050. Given the maturity that established technologies, such as thermal power plants and wind turbines, have reached following an organic growth from the early 1990s, the projection of costs should be reasonably accurate.

PV has paved the way for a more distributed generation. There has been a collapse in module prices that was greater than anticipated. Considering that PV belongs more to the world of semi-conductors than to that of steel and glass fibre, further substantial cost reductions can be expected. Of course this will only be true for the core modules; nevertheless one has to assume that roof-mounted PV, as we know it today, will be substituted by integrated PV, e.g. on windows or directly on walls.

The original ZEP report[2] assumed a cost reduction from 1,900 €/kW in 2010 to 1,000 €/kW in 2050. In order to challenge this assumption, simulations were performed assuming a reduction to 200 €/kW. Figures 3 and 4 summarise the most important cost elements, namely investment and fixed operating & maintenance costs. Figure 5 shows the assumptions for fuel and CO_2 prices from the original ZEP report.

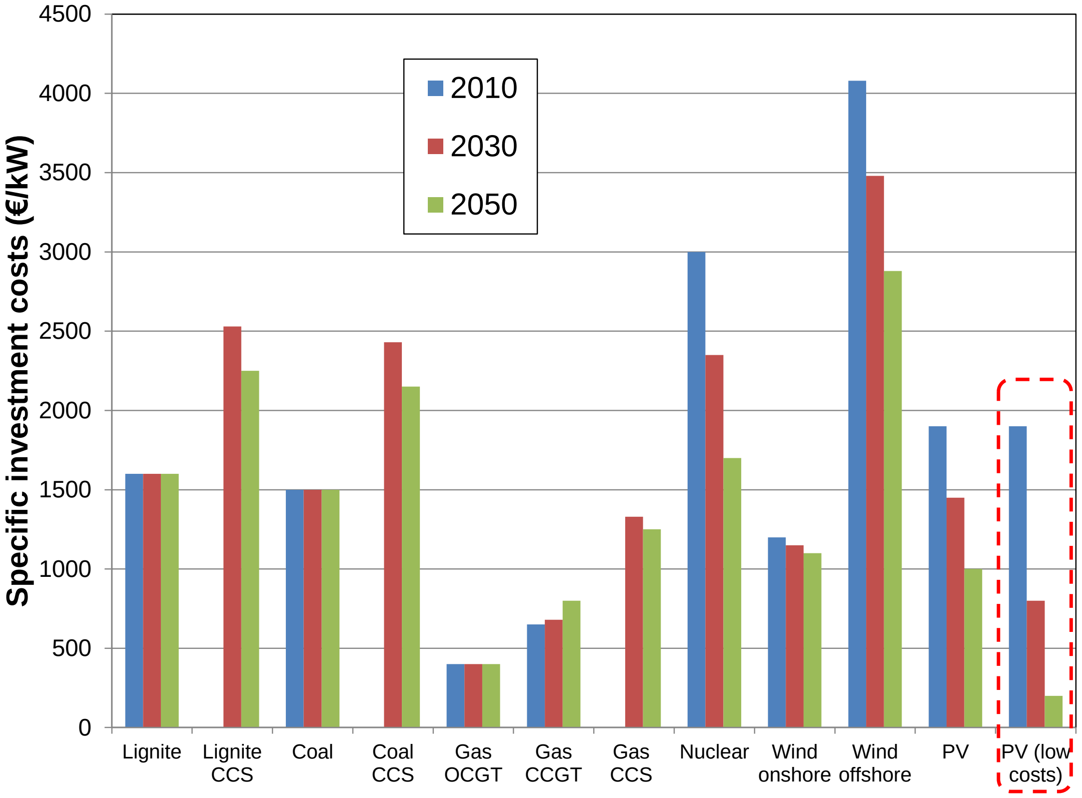

Figure 3: Cost assumptions for the main technologies, including low PV cost scenario

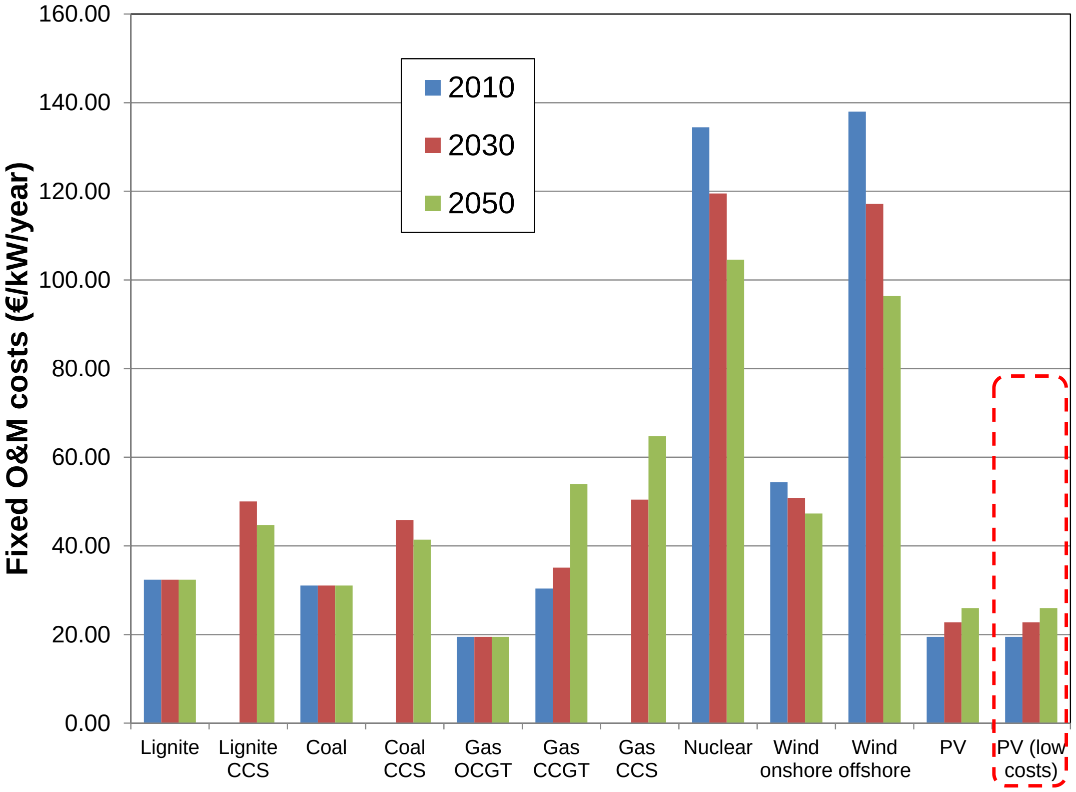

Figure 4: Cost assumptions for the main technologies, including low PV cost scenario

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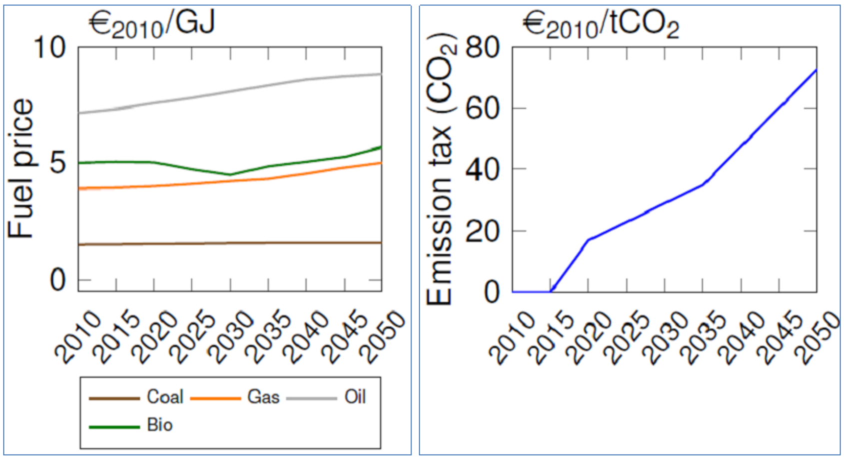

Figure 5: Fuel and CO_2 prices for the GCAM 450 ppm scenario

Modelling a range of scenarios, including electricity storage

Six different scenarios were built, resulting from a combination of different limits on PV and onshore wind, and different costs for PV. These were defined as follows:

- *High constrained*: limits on onshore wind as per the original report (270 GW in Europe). Limits on PV were revised to 1,000 GW (the original limit of 250 GW was considered too restrictive).
- *Weak constrained*: limits on onshore wind were revised to 850 GW in Europe. Limits on PV were revised to 1,000 GW.
- *No limits*: a hypothetical scenario to see the reaction of the model.

PV costs were:

- *High*: 1,000 €/kW in 2050
- *Low*: 200 €/kW in 2050

This gives scenarios 1 to 6:

	PV High	PV Low
High constrained	1	2
Weak constrained	3	4
No limits	5	6

Each scenario had the same three variants:

- Variant A – With CCS and electricity storage
- Variant B – No CCS, no electricity storage
- Variant C – No CCS, with electricity storage

A comparison of Variant A and Variants B and C highlights the impact the lack of support measures for CCS may have on future generation costs. The difference between Variant B and C shows the potential value of electricity storage.

All non-CCS variants were subject to an important constraint: as the deployment of CCS leads to a massive reduction in specific[4] CO_2 emissions, the model enforced the same Europe-wide reduction for cases *without* CCS. This enables the cost of different variants to be comparable based on an *equal* impact on climate change.

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[4] Specific emissions = emissions divided by demand

Ensuring a fair comparison of possible trajectories

Simulations were carried out in 5-year periods from 2010 to 2050. The model delivers various types of results, including for each period:

- Investment costs (€bn)
- Annual operation costs (€bn/y), consisting of variable and fixed operation & maintenance costs, fuel costs, emission unit allowances (EUAs) and CO_2 transport and storage
- Annual electricity demand and production (TWh/y)
- Amount of released and stored CO_2 (M tonnes/year).

The simulations offered a fair comparison of the different trajectories, i.e. mainly CCS-dominated vs. renewable-dominated. This was achieved on the basis of two types of charts:

1. A temporal trajectory of cumulated costs produced by totalling operation costs and investment costs. In order to account for the expected interest yield, investment costs were multiplied by a factor of 2.5 – see Figure 6. (The annuity factor for an expected interest rate of 9% and a typical lifetime of 25 years is 10%. Paying 10% of the investment for 25 years leads to a factor of 2.5.)
2. A temporal trajectory of the cost of electricity was determined with the aforementioned assumptions (interest rate 9%, 25 year lifetime, 10% annuity factor).

The other parameter is specific CO_2 emissions in kg_{CO2}/MWh – the figures in Chapter 3 plot cumulated costs and LCOE vs. specific CO_2 emissions.

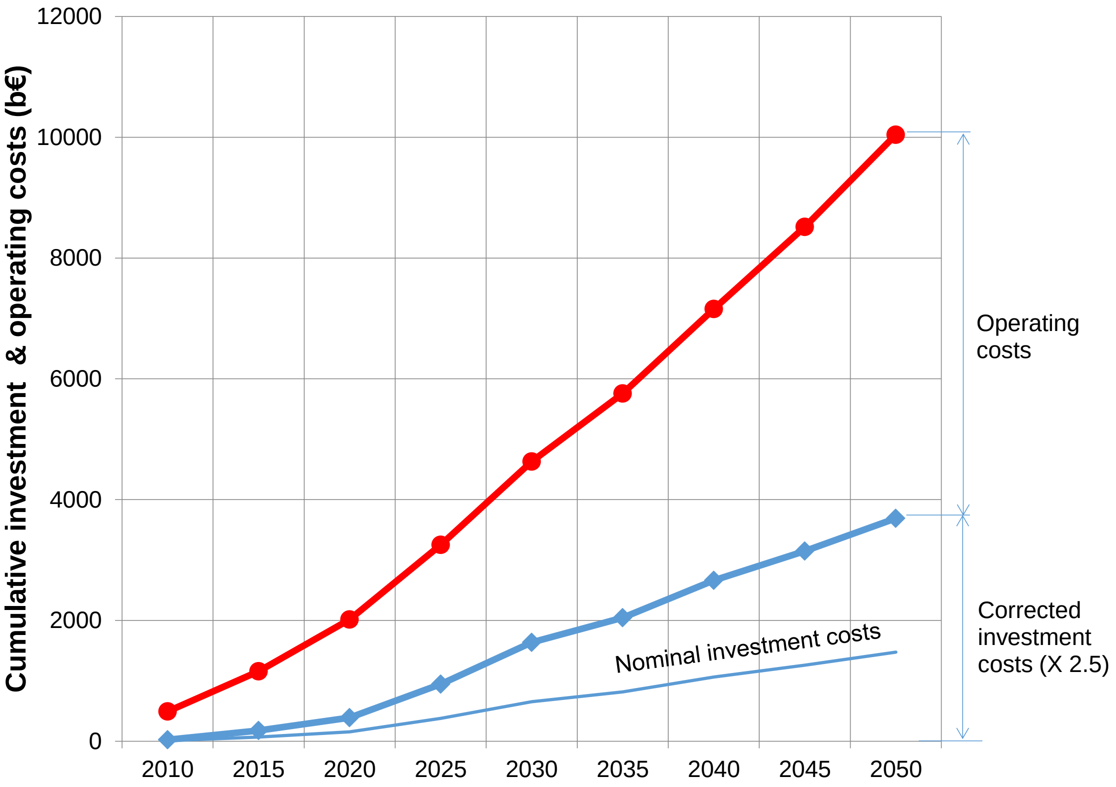

Figure 6: Trajectory of cumulative investment and operating costs for the period 2010 to 2050

3 The results

Without CCS, the cost of decarbonising European power is 20-50% higher by 2050

The following figures show the results of the six scenarios. These demonstrate that:

- All constrained scenarios without CCS (1-4) lead to crises where demand cannot be met in 2050. This is driven by the model's attempt to reach the same high level of emission reduction that can be achieved with CCS. In every case, renewable capacity is used up to its constrained level and blackouts are a possible consequence.
- For all scenarios, the CCS option clearly offers the lowest-cost route to reducing CO_2 emissions. Until 2030, the CCS and no-CCS cases are similar and emission reductions are mostly achieved by switching to highly efficient, gas-fired combined cycle power plants. After 2030, however, a massive investment in PV and wind capacity takes place for the no-CCS scenarios that leads to higher costs than investment in CCS. This can be seen in both the cumulative costs (top graphs) and in the relative LCOE (bottom graphs).
- Electricity storage only has a limited effect towards the end of the time horizon, i.e. from 2040 onwards. It is more present in cases where PV plays an important role. This is most likely an artefact related to the fact that the model considers only single days throughout a year, when the time scales of wind energy fluctuations go beyond one day. These require a longer-term storage that is beyond the scope of the model.

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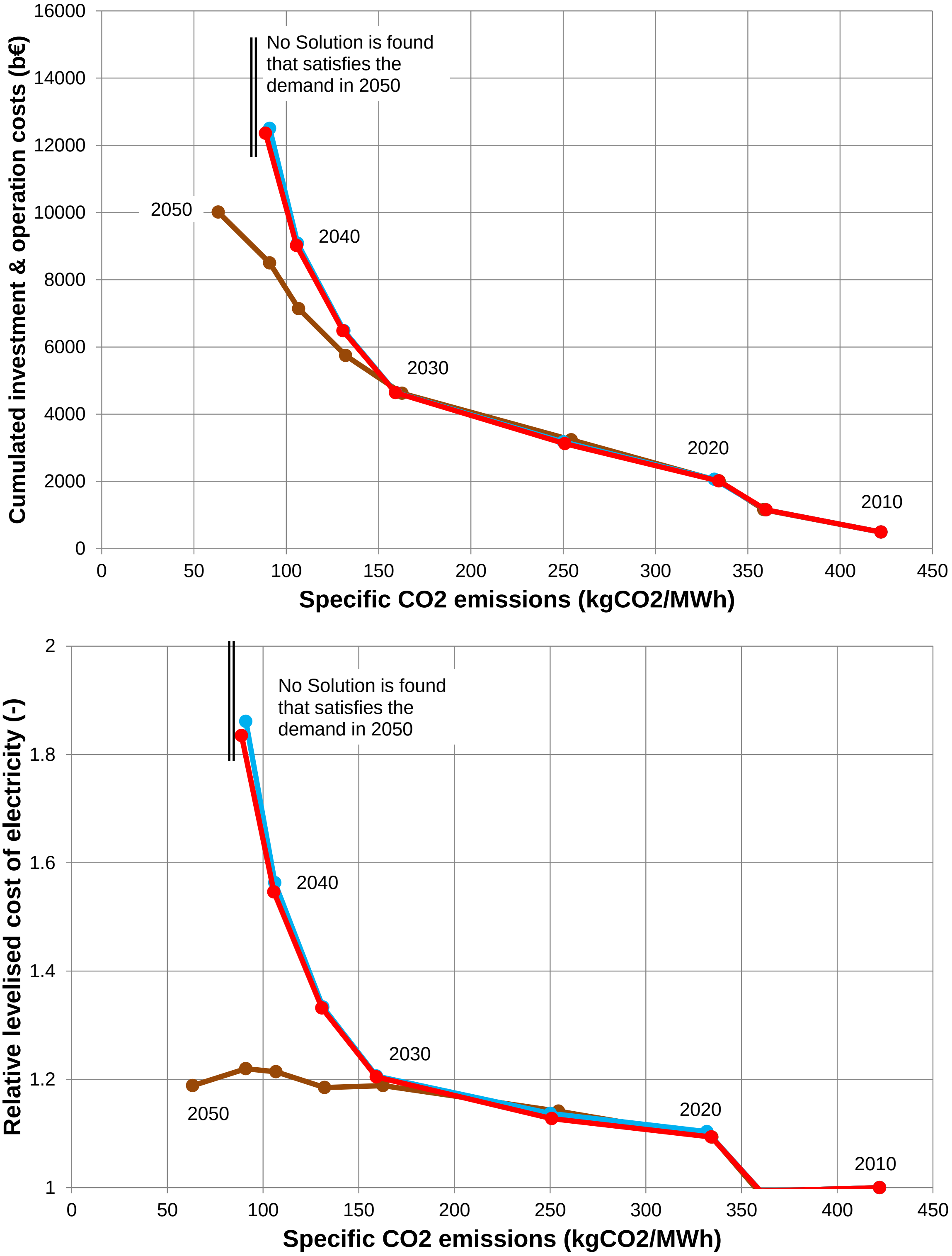

Figure 7: Scenario 1: high constrained, high PV costs: ▬ CCS, with electricity storage; ▬ no CCS, no electricity storage; ▬ no CCS, with electricity storage

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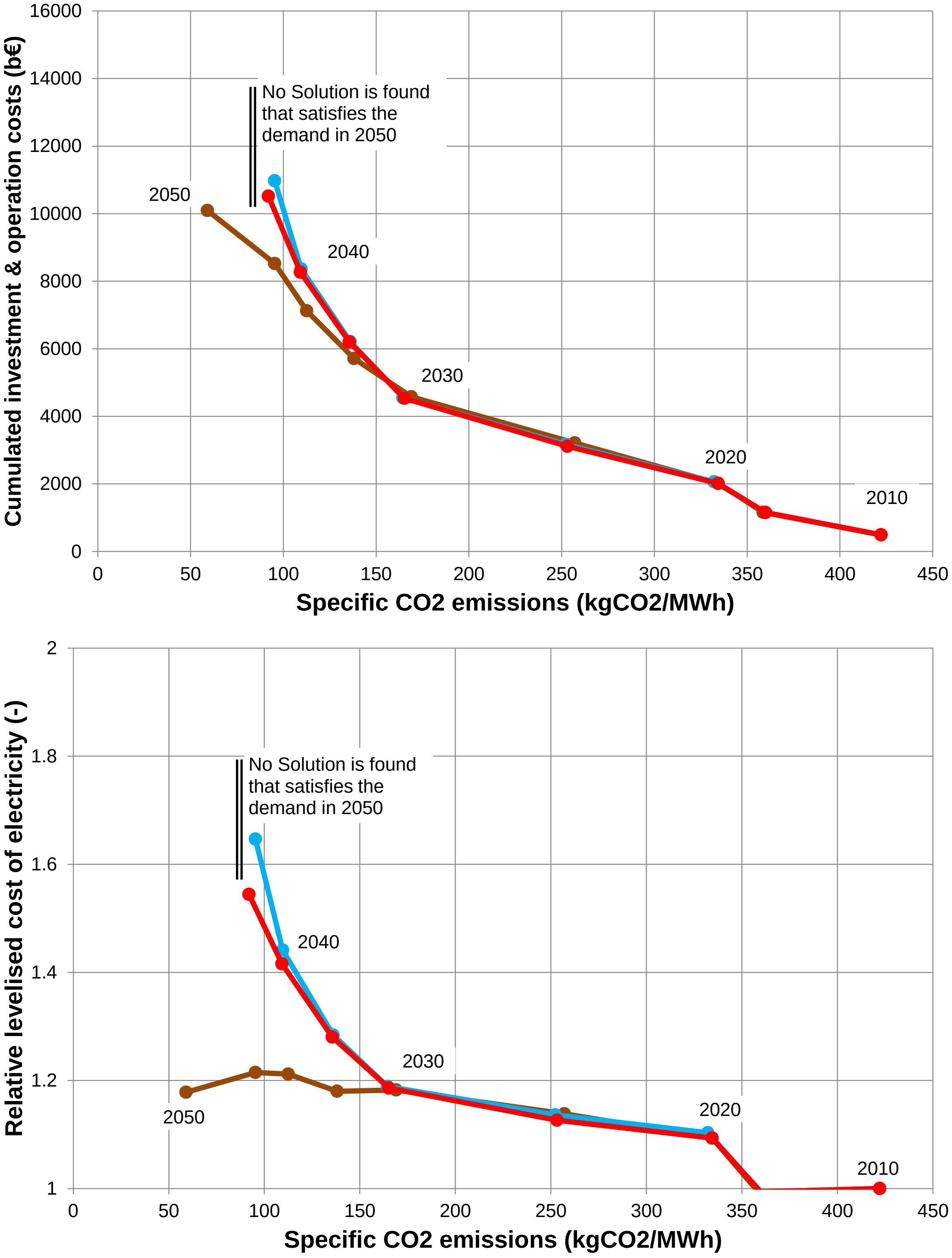
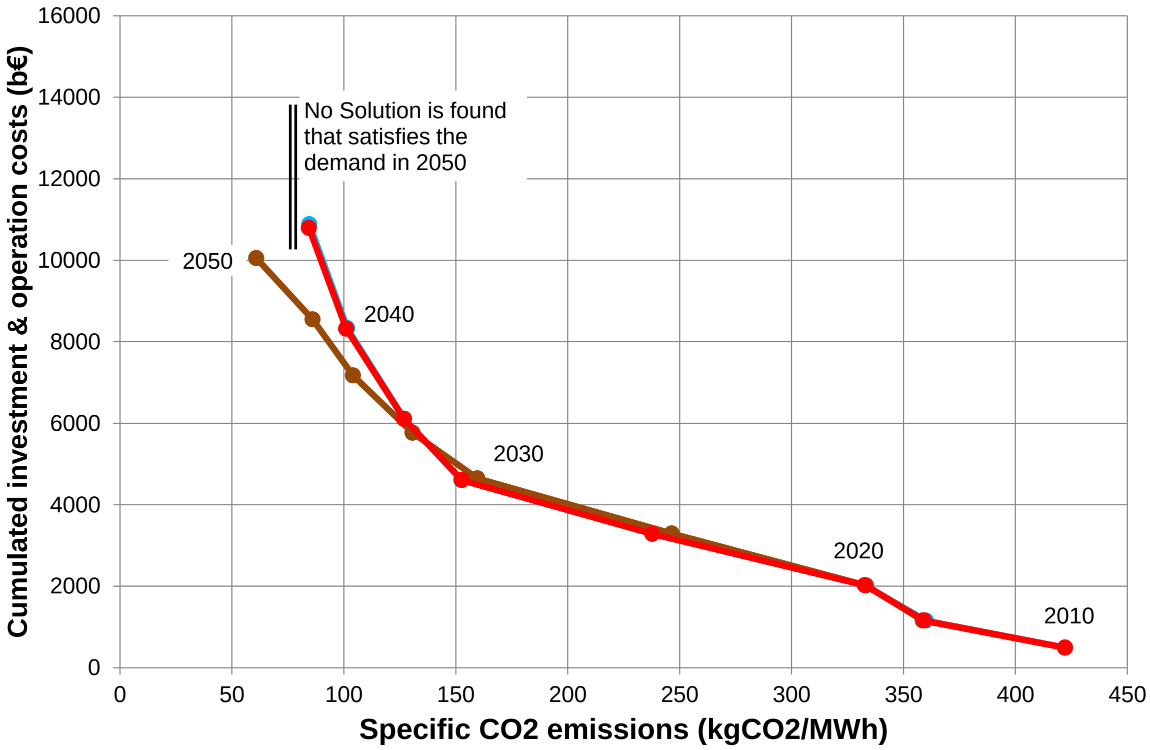


Figure 8: Scenario 2: high constrained, low PV costs: ▬ CCS, with electricity storage; ▬ no CCS, no electricity storage; ▬ no CCS, with electricity storage



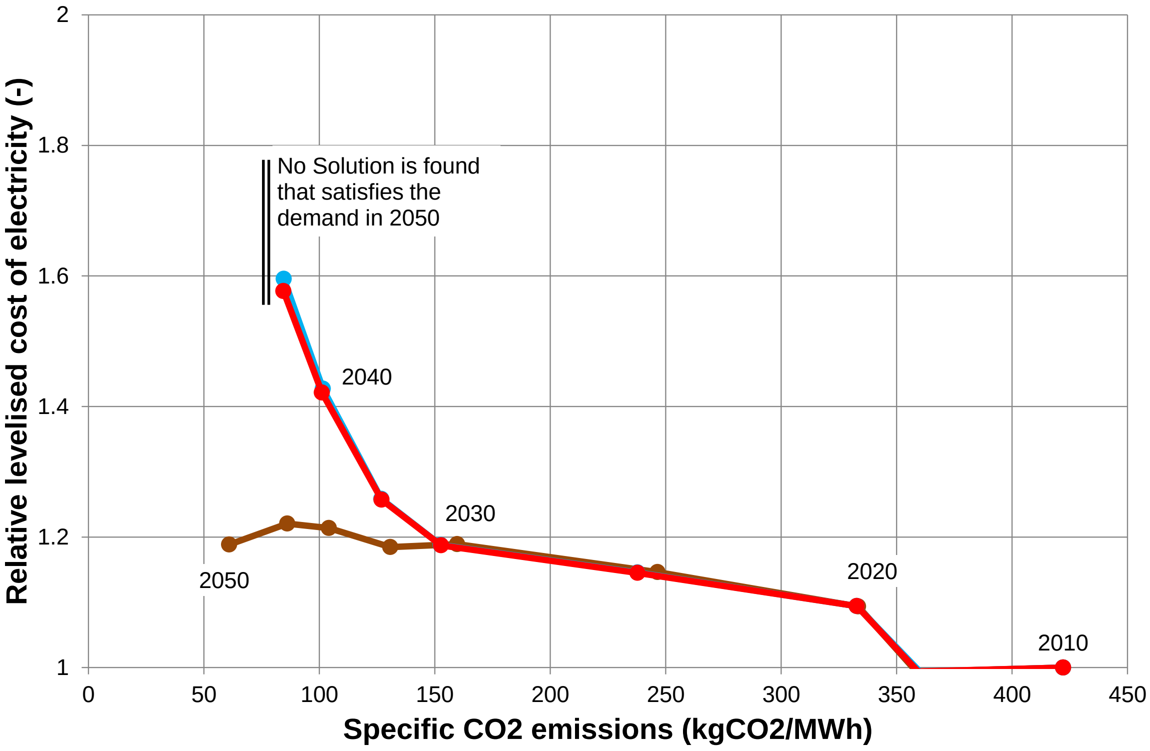


Figure 9: Scenario 3: weak constrained, high PV costs: ▬ *CCS, with electricity storage;* ▬ *no CCS, no electricity storage*; ▬ *no CCS, with electricity storage*

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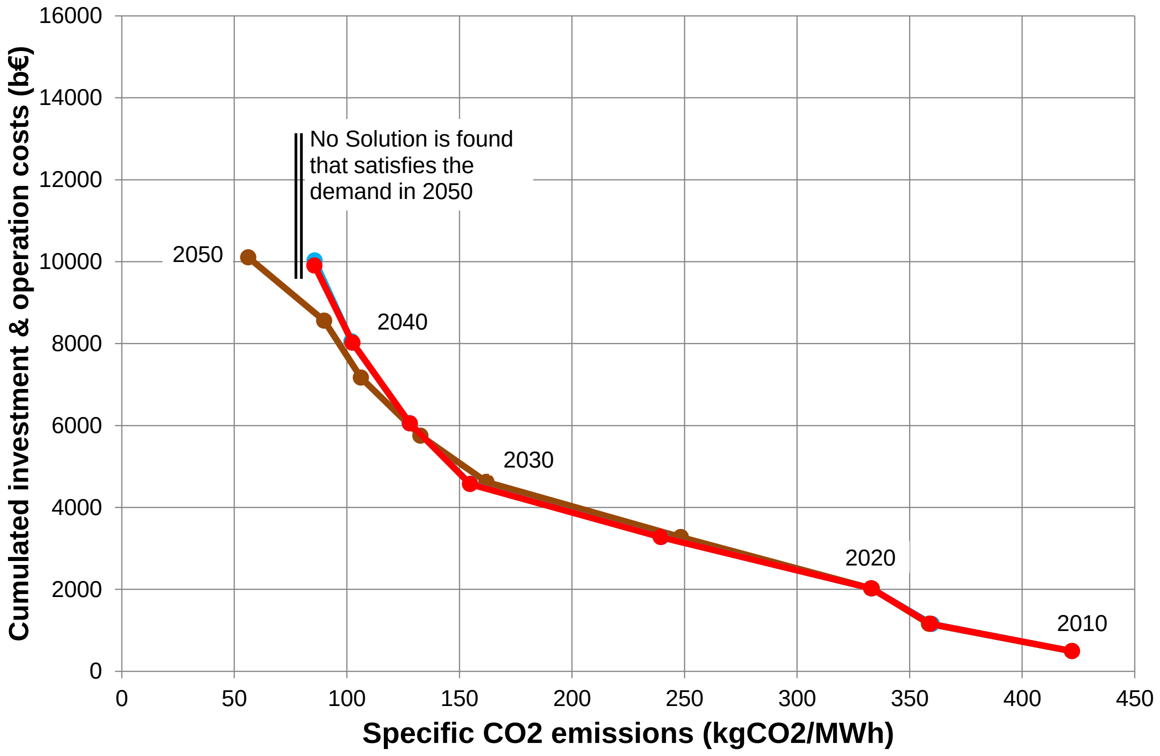

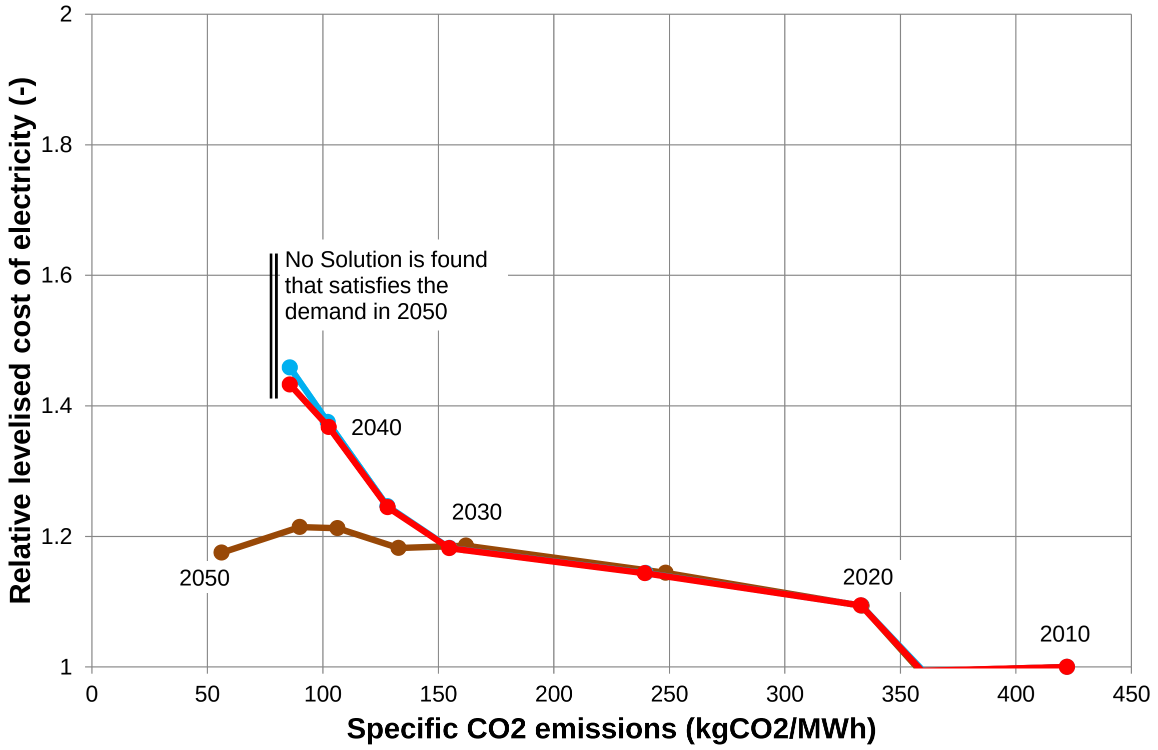

Figure 10: Scenario 4: weak constrained, low PV costs: ▬ CCS, with electricity storage; ▬ no CCS, no electricity storage; ▬ no CCS, with electricity storage

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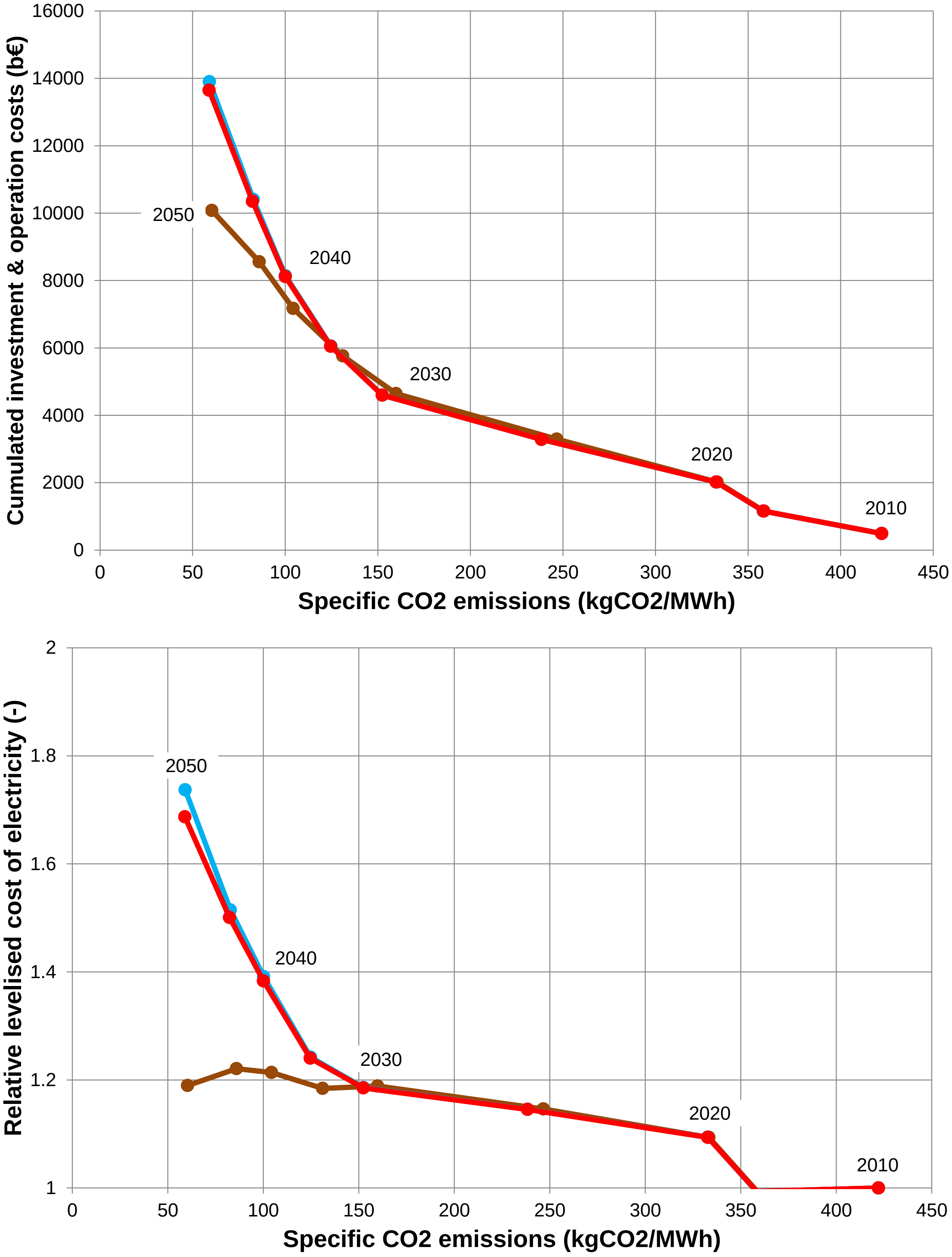

Figure 11: Scenario 5: no limits, high PV costs: ▬ *CCS, with electricity storage,* ▬ *no CCS, no electricity storage*, ▬ *no CCS, with electricity storage*

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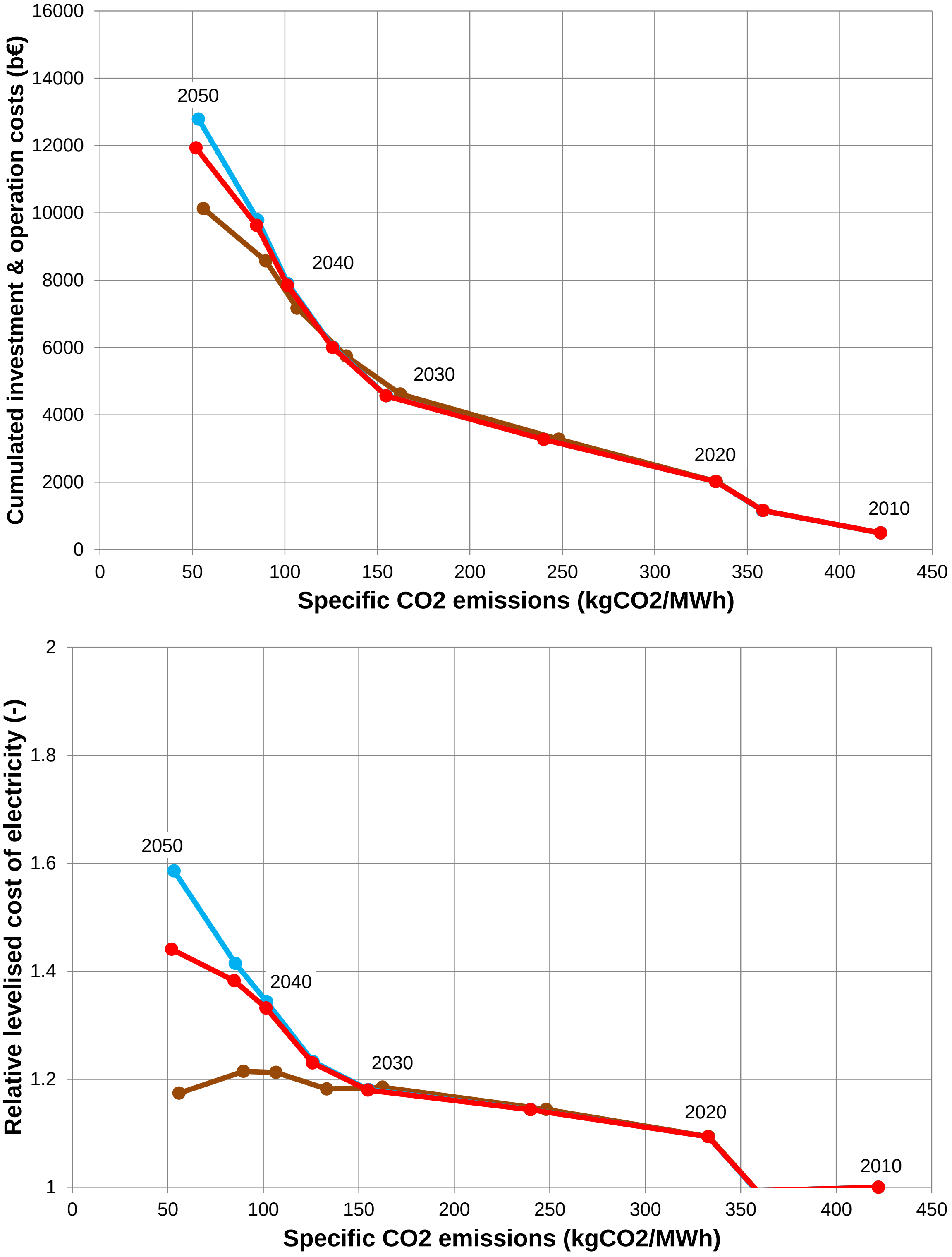

Figure 12: Scenario 6: no limits, low PV costs: ▬ CCS, with electricity storage; ▬ no CCS, no electricity storage; ▬ *no CCS, with electricity storage*

Breakdown by European country

The CCS cases are mainly driven towards CO_2 reductions by the increasing CO_2 price. The no-CCS cases are forced to follow the same trajectory of CO_2 reductions in order to make them comparable to the CCS case. None, however, considers European countries on an individual basis: the model chooses freely how to realise CO_2 reductions in order to minimise the overall costs for Europe.

The consequences are shown in Figure 13. Based on Scenario 5, this demonstrates the emission intensity in each European country in 2010 and 2050, both for the “with CCS” case and the “no-CCS, with electricity storage” case. This shows that all countries start from different emission intensities and that they reach different levels in 2050.

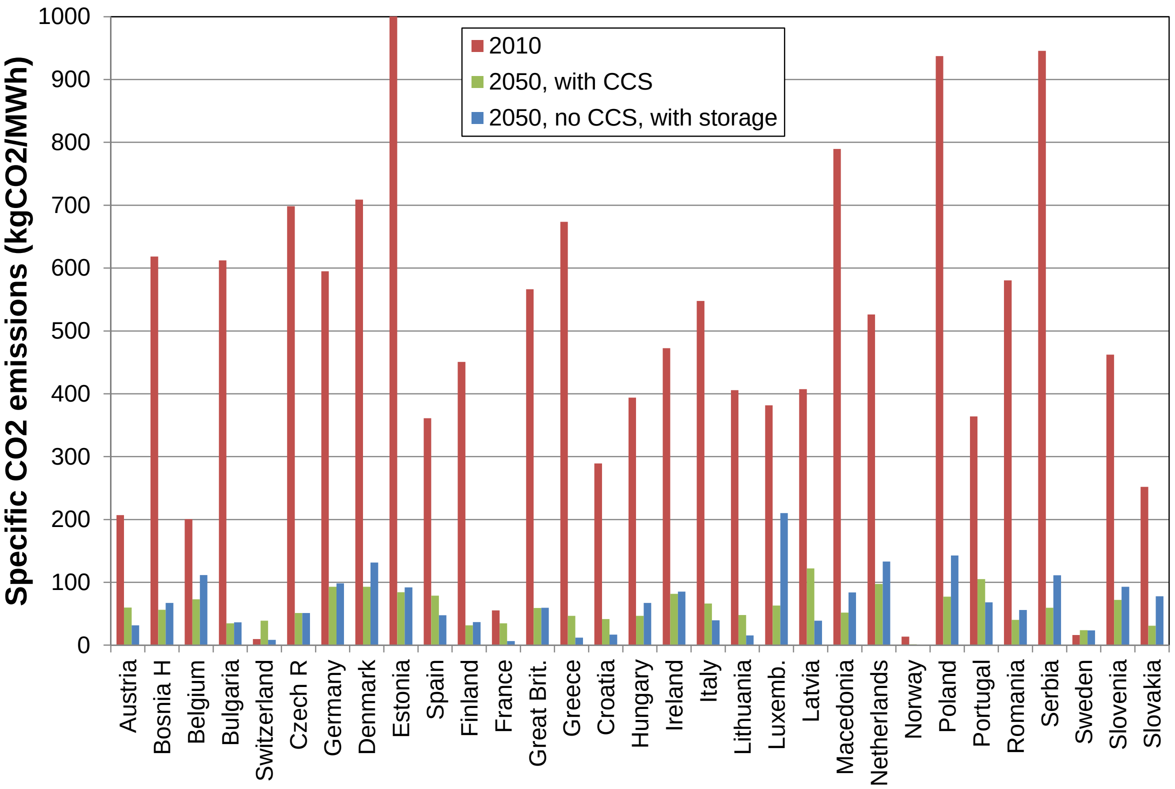

Figure 13: CO_2 emissions by country in 2010 and 2050 (Scenario 5 – no limits, high PV costs)

Figure 14 below shows the relative CO_2 reduction from 2010 to 2050. Again, countries vary in their contribution to the overall Europe-wide reduction. For some countries, such a reduction is meaningless because they start from very low emissions levels (e.g. France, Switzerland, Norway etc).

In order to achieve an equal reduction for all countries, an additional simulation was run where *every* country had to reduce absolute CO_2 emissions by 80% in 2050 (countries which started from very low levels were exempted from this rule). Figure 15 below shows the reductions for the different countries. When compared to Figure 14, the scatter has strongly reduced and all countries meet the 80% reduction target.

Finally, a comparison was made of electricity generation costs in 2050 for Europe-wide cases and those with country-specific emission limits. A moderate increase of 3% and 4.5% was found for the “with CCS” and the “no CCS, with electricity storage” cases, respectively. The cost optimal solution for Europe as a whole therefore implies different emission reductions for each country – costs increase when emission reductions are forced to be equal for all countries.

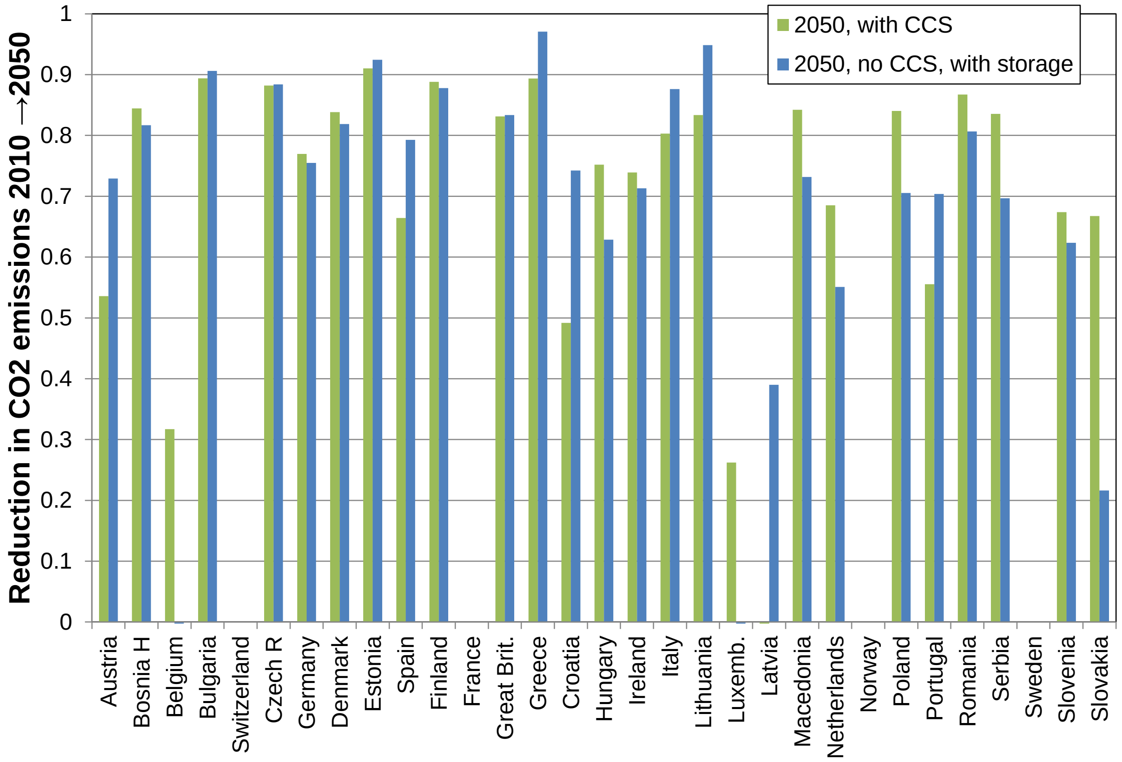

Figure 14: Reduction in absolute CO_2 emissions from 2010 to 2050; 80% target prescribed for Europe overall ("No CCS, with electricity storage" case follows emission reduction achievable in CCS case)

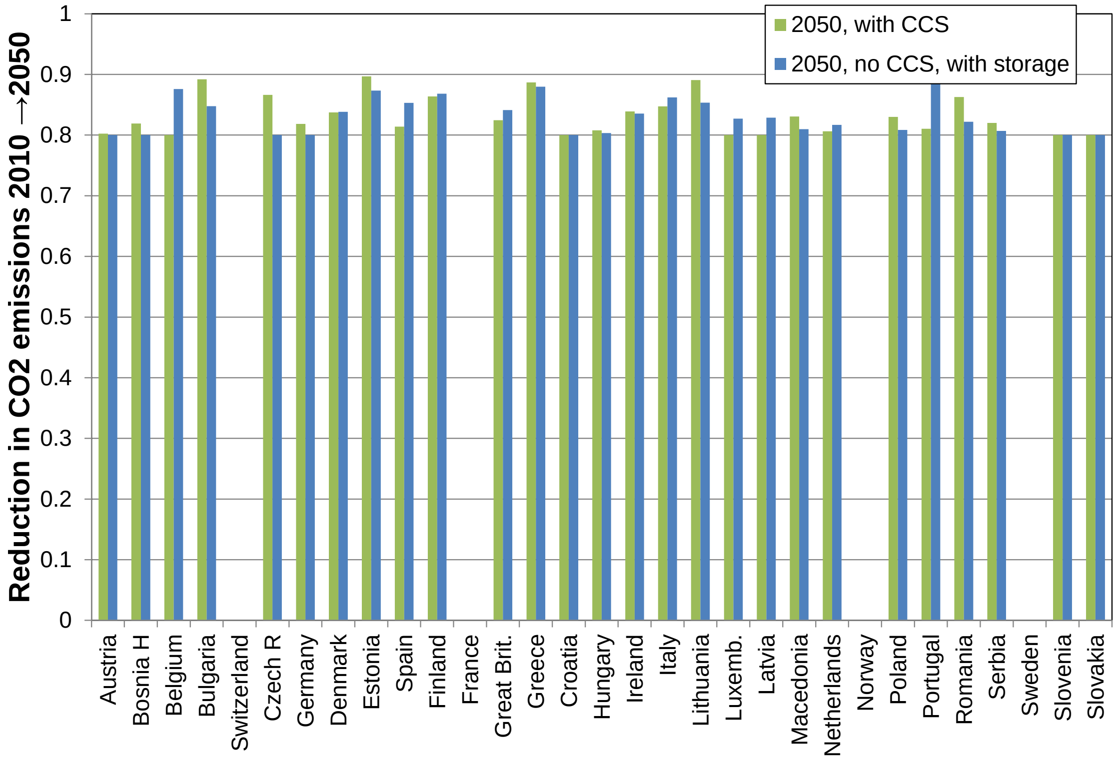

Figure 15: Reduction in absolute CO_2 emissions from 2010 to 2050; 80% target prescribed for each individual country

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Key conclusions

- If CCS is excluded from the model altogether, and limits on onshore wind and solar PV from the original modelling are maintained, electricity demand in Europe is not met after 2045 because the model’s 80% emission reduction target cannot be achieved without CCS.

- Even if the cost of PV is reduced to 200 €$_{(2010)}$/kW installed in 2050 – requiring a significant technology breakthrough compared to today – demand is still not met after 2045 and the cost of electricity is 20-50% higher than cases with CCS (see Figure 16).

- If there are no limits on wind and solar PV whatsoever, this results in 600 GW of PV and 1,000 GW of wind in 2050 for the original (1,000 €$_{(2010)}$/kW PV costs in 2050) scenario; up to 1,500 GW of PV and 640 GW of wind in 2050 for the low PV cost scenario. This represents 100,000-200,000 5 MW-class wind turbines and up to 10,000 km^2 of Europe’s surface covered by PV. Even if this was practically possible, the cost to Europe is 35-45% higher than equivalent cases with CCS (see Figure 16).

- Even if electricity storage is selected to help integrate the renewables, it only has a limited effect from 2040 onwards and plays a small role in reducing costs.

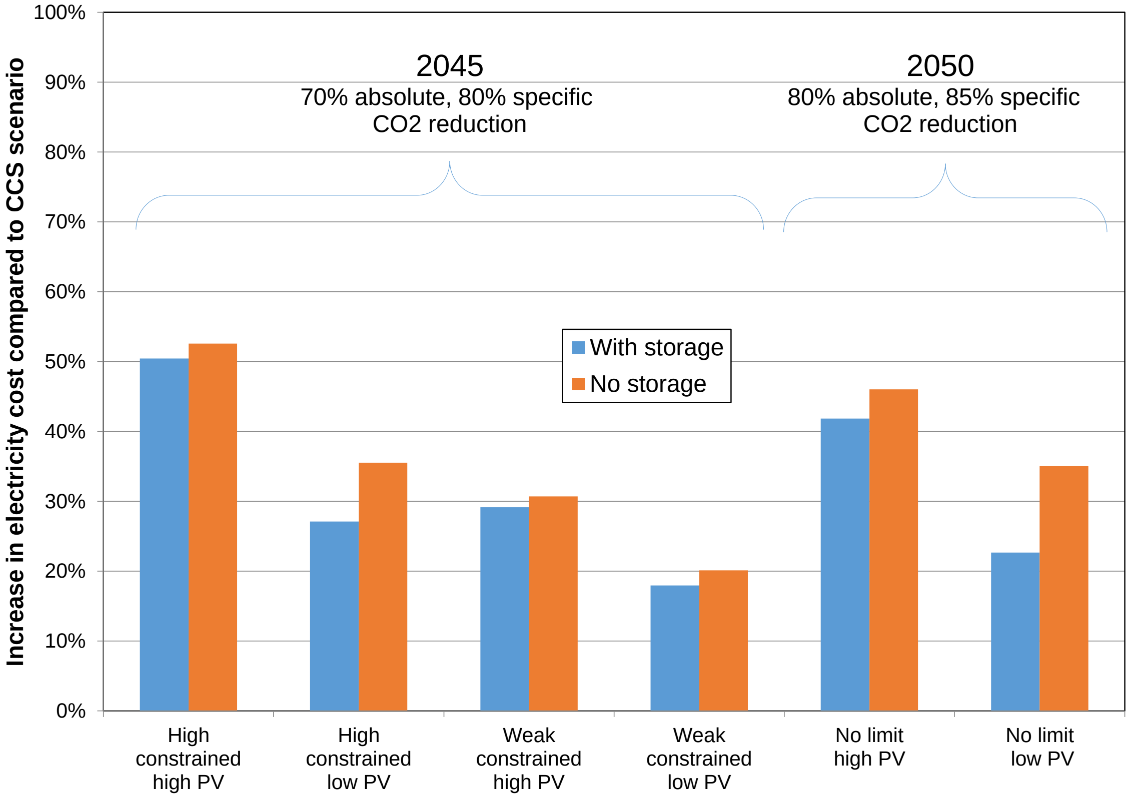

Figure 16: Increase in electricity costs from CCS to non-CCS variants in 2045/2050

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Annex I: Members of the ZEP Temporary Working Group Market Economics

Name	Country	Organisation
Daniele Agostini	Italy	ENEL S.p.A.
Heinz Bergmann	Germany	RWE
Paula Coussy	France	IFP Énergies nouvelles
Gianfranco Guidati	Switzerland	Alstom
Christina Hatzilau	Greece	National Technical University of Athens (NTUA)
Jonas Helseth	Belgium	Bellona Europa
Emmanuel Kakaras	Greece	Centre for Research and Technology Hellas (CERTH)
Juliette Langlais	Belgium	Alstom
Goran Lindgren	Sweden	Vattenfall
Wilfried Maas	The Netherlands	Shell
Giulio Montemauri	Italy	ENEL S.p.A.
Anca Popescu	Romania	ISPE
Hermione St. Leger	UK	St. Leger Communications Ltd.
Christian Skar	Norway	Norwegian University of Science and Technology (NTNU)
Charles Soothill	Switzerland	Alstom and Chair of ZEP TWG ME; Vice-Chair of ZEP Advisory Council
Graeme Sweeney	UK	Chairman of ZEP
Kazimierz Szynol	Poland	PKE S.A.
Bill Thompson	UK	BP
Asgeir Tomasgard	Norway	Norwegian University of Science and Technology (NTNU)
Marc Trotignon	France	EdF
Keith Whiriskey	Belgium	Bellona Europa
Karl-Josef Wolf	Germany	RWE

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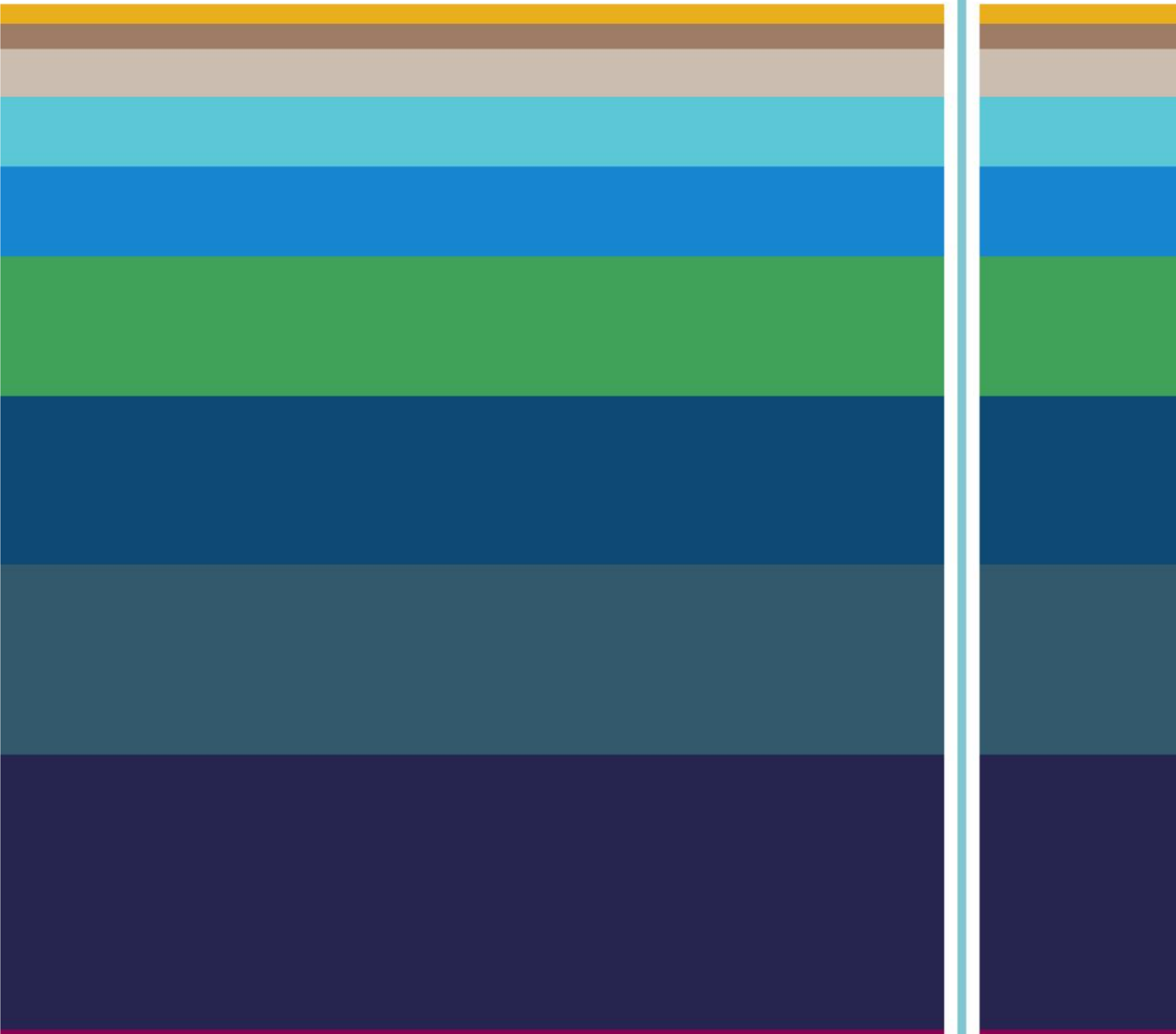
Zep
Zero emissions platform



October 2014

www.zeroemissionsplatform.eu

European Technology Platform for Zero Emission Fossil Fuel Power Plants

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UK Electricity Market Reform

The main objectives of the UK's Electricity Market Reform Programme introduced in 2012 are to

- **Ensure a secure electricity supply** by providing a diverse range of energy sources, including renewables, nuclear, CCS equipped plant, unabated gas and demand side approaches; and ensuring we have sufficient reliable capacity.
- **Ensure sufficient investment in sustainable low-carbon technologies** to put us on a path consistent with our EU 2020 renewables targets and our longer term target to reduce carbon emissions by at least 80% of 1990 levels by 2050.
- **Maximise benefits and minimise costs** to the economy as a whole and to taxpayers and consumers - maintaining affordable electricity bills while delivering the investment.

The key elements of EMR include:

- A mechanism to support investment in low-carbon generation: the Feed-in Tariffs with Contracts for Difference (CfD);
- A security of supply support mechanism, in the form of a Capacity Market; and
- The institutional arrangements to support these reforms.

These mechanisms are supported by:

- The Carbon Price Floor – a tax underpinning the EU Emissions Trading System;
- An Emissions Performance Standard
- Electricity Demand Reduction;
- Market liquidity support measures and market access for independent generators; and
- Effective transitional arrangements.

How the CfD works –

(1) The strike price

Generators with a CfD will sell their electricity into the market in the normal way. The CfD pays the difference between the market price for electricity and an estimate of the long term price needed to bring forward investment in a given technology (the 'strike price').

This means that when a generator sells its power, if the market price is lower than needed to reward investment, the CfD pays a 'top-up'. However, if the market price is higher than needed to reward investment, the contract obliges the generator to pay the difference back.

In this way, CfDs stabilise returns for generators at a fixed level, over the duration of the contract. This removes the generator's long term exposure to electricity price volatility, substantially reducing the commercial risks faced by these projects. As commercial risks are lower under the CfD, this lowers the cost of raising finance, and, ultimately, encourages investment in low-carbon generation at least cost to consumers.

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Figure 1: How the market reforms instruments will be administered

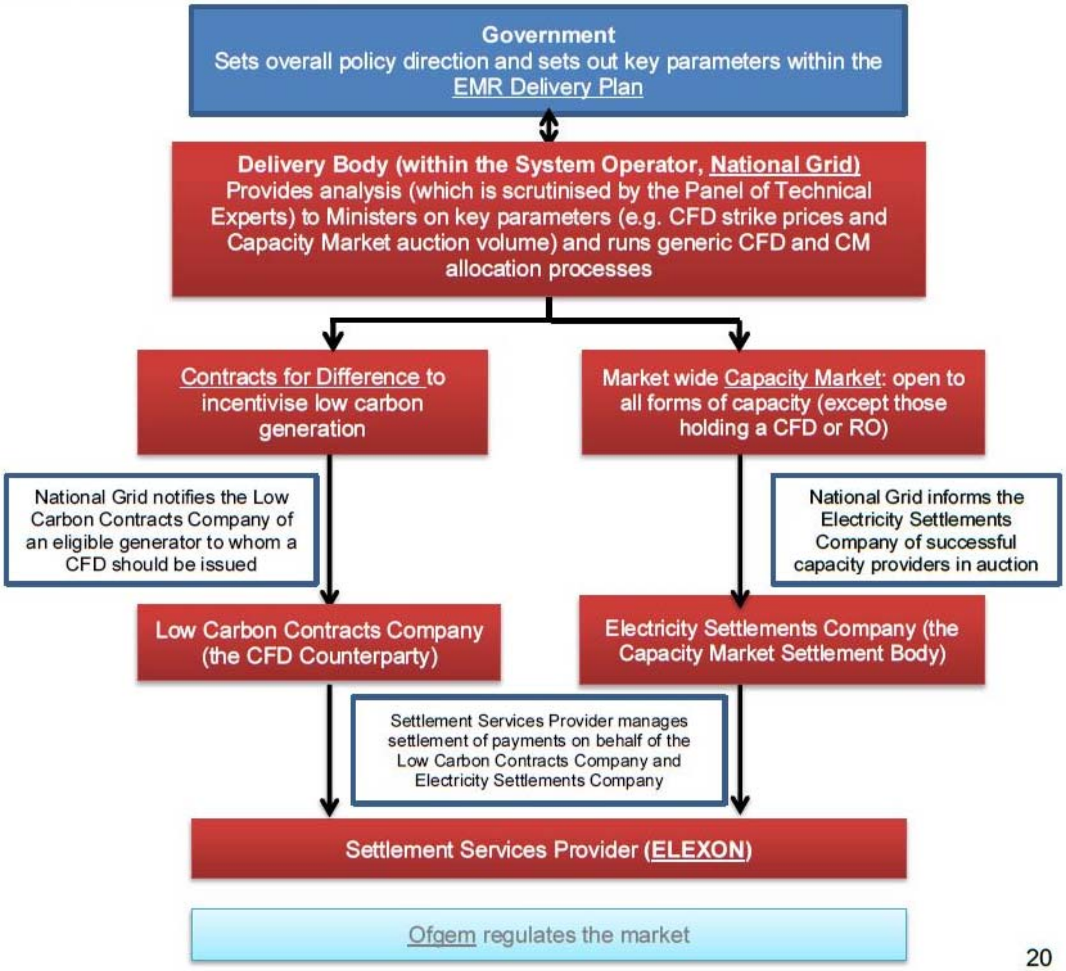
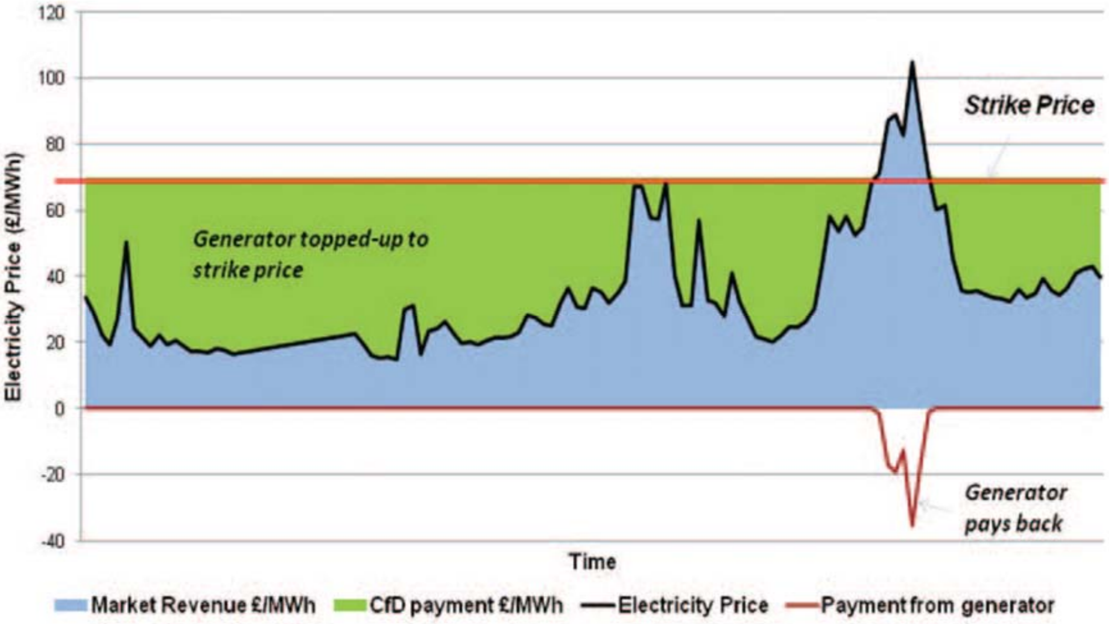


Figure 2: Illustration of the operation of a Feed-in Tariff with Contracts for Difference



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The CfDs take the form of long-term, private law contracts, providing generators with a clear set of rights and obligations, and recourse to arbitration processes to resolve disputes. This structure supports investor confidence in the arrangements and reduces the risk that the support payments might be reduced or removed in future; further reducing risk to investing and therefore costs to consumers.

(2) The Levy Control Framework

The Levy Control Framework (LCF) allows the Government to control public expenditure paid for through consumers' energy bills, and reflects the importance the Government places on monitoring and controlling spending on levy schemes that are funded in this way. The LCF sets annual limits on the overall costs of all DECC's low carbon electricity levy-funded policies until 2020/21The annual cap in 2020/21 has been set at £7.6 billion, a level which will enable us to meet our low carbon and renewables ambitions.

(3) CfD allocations and auctions

We intend to allocate CfDs to a broad range of low-carbon technologies. The CfD will be largely standardised across technologies. This provides a stable basis for investment, simplifies the process for allocating CfDs, and makes it easier to compare costs of different technologies. The standardisation of CfDs will also support the move to technology-neutral auctions in the longer term.

However, initially there will be a degree of variation in CfDs. First, there will be different generic CfD designs for low-carbon generation that is intermittent and baseload, reflecting the different ways that these plant operate. In addition, there may be some variation for some projects or technology types to recognise the different risk profiles of some projects or technologies. Any variations agreed will have to represent value for money and be consistent with state aid rules.

CfDs were initially allocated directly to projects, with the levels of support (i.e. the strike prices) set by Government. We intend to move towards more competitive forms of allocation for all technologies as soon as practicable. Competition in the allocation process allows prices to be set by the market, rather than by Government, and further reduces costs to consumers. We anticipate that the conditions for moving to technology-specific competitions for some renewables could be present as early as 2017 and it is possible that we could move to technology-neutral processes in the 2020s. The move towards more competitive forms of allocation will vary between technologies. Our long-term vision for the electricity market (and for CCS specifically) is for Government to play a decreasing role over time, and to transition to a market where low-carbon technologies compete fairly on price.

The EMR programme is already starting to deliver investment in electricity infrastructure – demonstrating industry confidence in the arrangements being set up. Eight renewable electricity projects were awarded Investment Contracts (an early form of CfD) under the FID Enabling for Renewables process in April 2014. These projects could add a further 4.5GW of electricity capacity to the UK's generation mix, providing up to £12 billion of private sector investment by 2020, and supporting 8,500 jobs.

Figure 3: The four stages of EMR (including estimated timings)

Stage 1 To 2017	Stage 2 2017 – 2020s	Stage 3 2020s	Stage 4 late 2020s/beyond
CfDs will run alongside the Renewables Obligation. Established technologies will enter a competitive auction to set the strike prices. Less established technologies are likely to receive support at the administrative strike price (unless the CFD budget constraint is reached, then those technologies would have to compete with each other on price).	Technologies mature (but at different rates) and some are able to enter competitive, technology-specific auctions.	Continued maturity of technologies and movement towards technology neutral auctions. Demand side response, additional storage and interconnection, and well-functioning energy markets across the EU, will play an increasingly large role in managing supply and demand.	Technologies are mature enough and the carbon price is high and sustainable enough to allow all generators to compete without intervention.

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Key Messages from the CSLF "Lessons Learned from Large-Scale CCS" Workshop

Background

The CSLF Technical Group has organized a continuing series of Technology Workshops. The most recent one, themed on "Lessons Learned from Large-Scale CCS" was held in June 2015 and featured presentations from representatives of eight commercial-scale projects. This document summarizes the takeaways and key messages from that Workshop.

Session 1: Siting and Construction

A. Site Selection and Overall Project Viability

- Economic drivers that affect CCS project siting include the availability of nearby indigenous fuels, opportunities for polygeneration of potentially saleable byproducts, and proximity of existing pipeline infrastructure. It has been shown to be possible to structure a project such that sales of byproducts are the major source of revenue. However, any project that includes sales of CO_2 for EOR must be sited in relatively close proximity to an existing CO_2 pipeline due to the high cost of pipeline construction.

- For non-EOR projects, understanding the regional geology will greatly aid CO_2 storage site selection and characterization. Comprehensive modeling and injectivity test programs should not be considered a luxury.

- Stakeholder engagement is crucial for success, as storage sites and pipelines may be near populated areas. Spending the time and resources to develop an effective outreach plan, making use of credible consultants, will pay dividends in the long run. A good public outreach program focuses on education, and openness is essential. A badly-handled public outreach program can doom a project.

B. Project Design

- CO_2 capture rate will impact overall project economics. This may result in a need for compromise on what is possible vs. what is do-able.

- First-of-a-kind (FOAK) projects are not designed for financial efficiency, they are designed to demonstrate the integration of CCS technology components at large scale. To reduce the risk of integration in FOAK projects, there are typically large safety factors in design and a significant on-site presence by technology providers, both of which drive up project costs. A major objective of FOAK projects is for the learnings to enable a significant reduction in the risk of integration so that future large-scale projects can be designed more efficiently and less expensively.

- For CCS at power projects, it is essential that the CO_2 capture plant be designed to maximize its flexibility in terms of capture rate, as the power plant may not be operated in baseload mode.

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- Focus on overall integration and interfaces between components. There will usually be opportunities for incremental cost savings, such as utilizing waste heat for drying the power plant fuel supply.

C. Permitting

- The permitting process for CO_2 storage will almost always take longer than planned. This is a relatively new regulatory area, and the relevant authorities are often on a steep learning curve.

- The overall storage plan will need to include an extensive and adaptive Measuring, Monitoring and Verification (MMV) program. Do not even begin the permitting process until the MMV plan is fully developed.

- There will be a continuing need for data, and having an environmental baseline will be very helpful toward the overall permitting process.

D. Construction

- A larger footprint for the plant will make construction easier and faster, which may result lower construction costs. But this will also result in greater materials costs.

- Expect the unexpected. Do not underestimate the complexity and the infrastructure requirements of the project.

- There will always be unanticipated FOAK plant issues. Be ready to adapt and learn.

Session 2: Operations

A. Clarity of Mission

- Have agreed aims and objectives, and regularly review progress against these goals.

- Focus on long-term sustainable commercial operations and improving the business case for the project. This will make future projects of this kind easier to do.

- Avoid getting too obsessed with technology. The project will enhance the overall knowledge base without needing to “push the envelope” on the limits of the technology components.

B. Transitioning into the Operational Phase

- Use of retrofitted new technology in an older plant will inevitably be challenging. There will be a need for experienced process engineers.

- Uncertainty can be a good thing. Recognizing and understanding real-world deviations from CO_2 storage models will in the end improve those models.

- Stuff happens. Expect the unexpected, and always have a “Plan B”.

- Above all, have realistic expectations from FOAK projects. The next-generation projects are the ones that will change the world.

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C. MMV and Data Management

- The more comprehensive the MMV, the better. A good MMV program is key for completing technical risk assessments and developing mitigation strategies.
- A comprehensive MMV program will generate large amounts of data. Working with these quantities of data requires appropriate management systems.
- Exercise caution regarding interpretation and release of data. Peer reviews should first be considered.
- Large-scale CCS projects are intended to enhance the overall knowledge base, but not at the expense of protection of intellectual property (IP). A proper balance between knowledge sharing and IP management requires procedures which allow sharing of information and experiences without revealing proprietary information.

D. Communications

- The project won't be a success unless people believe it is a success. Therefore, continuing external communications with stakeholders should be a key part of the project plan.
- Social acceptance is a goal for any CCS project. To be successful in that regard, people need to understand how the project works so there will be a need for experienced public outreach professionals.
- Good relations with abutting landowners and nearby population centers will pay dividends. Once in a while there may be an unexpected event of some kind and it is highly desirable that these people be supportive of the project.
- The single greatest benefit from FOAK large-scale CCS projects is the knowledge gained (in all aspects of the project) that will allow future projects to be less costly and problematic to implement. Sharing lessons learned in international conferences and forums should therefore be a priority.

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Summary of CSLF Policy Group Activities

CSLF Committee Work Plans
At the last CSLF Ministerial Meeting in November 2013 in Washington, D.C., the CSLF Ministers charged the Policy Group to establish an exploratory committee to discuss policy issues concerning actions where international collaboration can globally advance carbon capture and storage (CCS). After numerous discussions, the exploratory committee recommended four topics of interest: communications, global collaboration on large-scale CCS projects, financing for CCS projects, and supporting development of 2nd and 3rd generational CCS technologies. These four key action areas were reported back to the larger Policy Group, complete with a country lead for each key action. Over the past two years, each committee developed and is implementing a work plan around each major action.

1. **Communications:** Since the CSLF is the only ministerial body focused solely on CCS, it is well-positioned to communicate with Ministers. Messages should include timely topics (e.g. induced seismicity), be harmonized and closely coordinated with other organizations such as the International Energy Agency and the Global CCS Institute, and be more frequent than the CSLF Ministerial Meetings held every two years. Thus, the CSLF has investigated the potential to communicate key CCS messages directly in a number of other Ministerial-level meetings, such as the Clean Energy Ministerial and the United Nations Framework Convention on Climate Change. Key messages have included the need for CCS to be viewed on a “level playing field,” for CCS to receive “policy parity,” and that CCS will be needed in non-power sector applications such as the cement and steel industries. To help prepare a communications strategy to distribute key CCS messages, the CSLF has recently engaged a communications expert. [Lead: Saudi Arabia, with support from the International Energy Agency and the Global CCS Institute]

2. **Global Collaboration on Large-Scale CCS Projects:** The CSLF is well-positioned to facilitate global collaboration efforts for large- scale CCS projects, whether as new greenfield projects or by adding additional functionality and value to existing or planned commercial projects. Furthermore, as many of the recently deployed large-scale CCS projects are focused on storage via enhanced oil recovery (EOR), the needs of large saline formation storage has remained underserved. To facilitate these efforts, the United States and China announced the formation and joint leadership of the Large-Scale Saline Storage Test Network. This Network will serve two purposes: 1) facilitate collaborative testing of advanced technologies at large- scale saline storage sites, and 2) form a global network of large-scale injection sites that can share best practices, operational experience, and key learnings. As a first step in this effort, the United States Department of Energy (DOE) and the Shell Quest project have collaborated over the past year on identifying opportunities to field test advanced technologies funded through the DOE at the Quest site in Alberta, Canada. Today, DOE and Shell are pleased to announce the first project that will be field tested at the Quest site. [Lead: China and the United States]

3. **Financing for CCS Projects:** The Financing for CCS Projects committee hosted a series of workshops and discussions on the business case for CCS, including discussions of what business-to-business connections and government-to-government actions the CSLF should facilitate. These workshops demonstrated that there is growing interest in CCS, but that government assistance is still essential. These workshops also concluded that lessons learned from existing projects have important

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impact, and that stable government systems and supporting CCS policy, legal and regulatory frameworks are requisite for projects to succeed. Another important outcome from the workshops has been increased dialogue between the CCS community and financial institutions, resulting in increased understanding of the issues and risks associated with financing CCS projects. Outcomes and recommendations from these workshops were captured and disseminated to maximize value. [Lead: France]

4. **Supporting Development of 2nd and 3rd Generational CCS Technologies:** At the 5th CSLF Ministerial Meeting in 2013, it was determined that efforts should be taken to better understand the role and enabling mechanisms of 2nd and 3rd generation technologies for achieving widespread CCS deployment. This was considered as a priority for action as the cost of CCS is a significant barrier to its widespread deployment, with carbon capture accounting for the majority of this cost. To that end, a joint Policy Group-Technical Group Task Force co-chaired by Canada and Norway was formed, which identified emerging technologies for carbon capture and testing facilities through a technical literature review, and assessed policy and funding mechanisms through interviews with CCS stakeholders. A set of recommendations for Ministerial consideration have been put forth based on the Task Force's analysis. The recommendations call for the CSLF to continue to enhance collective efforts among governments, technology developers and adopters, and academia / researchers by enhancing networks, sharing best practices, and fostering research cooperation and exchanges. Complementing this work, a proposal for a CSLF website mapping was also discussed to help facilitate opportunities for evaluation and testing of emerging technology leaders as a means to accelerate their commercial adoption. [Lead: Canada and Norway]

CSLF Capacity Building Program

The CSLF continues its efforts under the CSLF Capacity Building Program, which was approved by the CSLF Policy Group and endorsed by the CSLF Ministers in 2009. The Program strives to assist all CSLF Members to develop the information, tools, skills, expertise, and institutions required to implement CCS demonstrations and then move rapidly into commercial operation. The Program Plan further defines four program initiatives:

- Disseminate practical information
- Build capacity in emerging economies
- Assist government and regulatory agencies
- Build academic and research institutions for CCS

Each of the capacity building projects undertaken by the CSLF addresses one or more of these program initiatives. To date, a total of fourteen capacity building projects in five countries have been approved and either have been, or will be, conducted by the CSLF. While projects may be held in a specific country, workshops and other events are open to participants from all CSLF Members. In August 2015, the CSLF sent a new request for additional project proposals for funding under the CSLF Capacity Building Program, and CSLF emerging economy members have been encouraged to submit proposals.

For additional information on the CSLF Capacity Building Program, please see the CSLF Capacity Building Program Summary elsewhere in this documents book.

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CCS in the Academic Community Task Force

The CCS in the Academic Community Task Force was formed in June 2009 with the mission to identify and engage academic programs on CCS throughout the world. Accomplishments to date include a worldwide mapping and gap analysis of CCS post-graduate academic courses. At the 2015 CSLF Mid-Year Meeting, the Task Force was re-established with a new organizational structure and focus to advance CSLF objectives via academic CCS research programs, international collaborations, research exchanges, networks and summer schools. With more proactive engagement among the CCS academic community, the CSLF can facilitate and align international research collaborations with CSLF priority areas and leverage funding opportunities that advance the CSLF mission. The Task Force agreed to: conduct an initial baseline survey of current CCS academic research and training programs and academic champions among Task Force members; assess funding commitments and mechanisms; determine opportunities to leverage resources from programs such as the CSLF Capacity Development Fund; assess resources need to strengthen and catalyze Academic Task Force activities, and prepare a Task Force report with a plan of action for the 6th CSLF Ministerial Meeting.

For additional information on the CCS in the Academic Community Task Force, please see the CCS in the Academic Community Task Force Summary elsewhere ein this documents book.

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FUND MANAGER

GLOBAL CCS INSTITUTE

CARBON SEQUESTRATION LEADERSHIP FORUM

CAPACITY BUILDING FUND

Capacity building facilitates a country's journey towards large-scale CCS deployment. On-the-ground projects are the end-goal of CCS deployment, but these do not happen without the right 'know-how'.

The CSLF Capacity Building Fund was established to assist CSLF members, with an emphasis on emerging economy members, to develop the tools, skills, expertise and institutions required to implement CCS demonstration projects and then move towards commercial operation.

This goal was underpinned by five guiding principles:

- Use a country-led process in which each country defines its own needs
- Share information and tools, create skills and expertise and build institutions
- Tailor capacity building to the individual needs of each Member
- Take advantage of existing resources and avoid duplication
- To the extent possible, work with partners and leverage resources.

A total of US$2,965,143 was contributed by donors to establish the Capacity Building Fund. Original donors to the Fund were Canada, Norway, United Kingdom and the Global CCS Institute.

It can be seen in Table 1 that US$1,657,950 of this has been utilised to support 12 projects.

The Global CCS Institute took on the role of CSLF Capacity Building Fund Manager in early 2015. The program has since been reinvigorated with two significant projects in China commenced. New project proposals are being developed by CSLF Member countries, which will be considered by the Governing Council for funding approval.

The Global CCS Institute continues to coordinate with other capacity building providers, such as the World Bank and the Asian Development Bank, to ensure capacity building activities across organisations complement, not duplicate, each other.

Feedback from recipients about Fund-supported activities can be found over the page. They touch on how specific Fund-supported activities have helped them to tap into information and develop tools to facilitate CCS progress.

Table 1: Summary of capacity building projects completed and in progress

PROJECT		DESCRIPTION	FUNDING
Projects implemented			
Training program: Mineral coal combustion and gasification process	Brazil	Three training courses delivered. The first was an introductory CCS course; the second focused on up-skilling five technicians in the use of Aspen Plus software to simulate carbon capture systems and facilitate economic analysis; the third training course focused on post-combustion sorbents	US$302,450
Training program: CCS in the offshore environment	Brazil	Training program aimed at the oil and gas sector regarding the implementation of CCS, and enhanced oil/gas recovery in the offshore environment	US$161,000
Public engagement workshops	Brazil	Two basic courses and two advanced courses introduced CCS to a broad stakeholder community, focusing on technical aspects, environmental and regulatory issues	US$213,000
CO_2 storage in the Clean Development Mechanism	Brazil	This workshop focused on CCS Clean Development Mechanism opportunities for Portuguese language country stakeholders	US$10,000
Chinese language website on CCUS technologies	China	Development of CCUS website, and translation of website and CCS reports into Chinese to share international knowledge with Chinese stakeholders	US$110,000
Legal and regulatory workshop	China	This workshop shared international experience on legal and regulatory issues with Chinese stakeholders	US$76,000
CCS demonstration workshop	China	This workshop shared international experience of CCS demonstration projects with Chinese stakeholders	US$76,000
Introduction of CCS into the academic sector	Mexico	Series of four workshops aimed at professors and graduate students to generate interest in CCS in academia	US$93,500
Sponsorship of CCS Week	South Africa	CCS Week was aimed at disseminating information about international CCS R&D and to showcase CCS activities currently underway in South Africa	US$86,000
Report on the 'Impacts of CCS on South African national priorities other than climate change'	South Africa	This report analysed the impact of CCS development on national priorities such as job creation and security, poverty alleviation, promoting health, training and innovation	US$80,000
Projects in Progress			
Exploring CCUS Legal and Regulatory Framework in China	China	Series of workshops, stakeholder engagement and a report exploring legal and regulatory issues and recommendations for CCUS in China	US$250,000
CCS Financing Roadmap for China	China	Series of workshops, stakeholder engagement, analysis and final report on CCS Financing Roadmap for China	US$200,000

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Feedback from South Africa

Tony Surridge, Head of South African Centre for Carbon Capture & Storage, talks about the South African CCS Week:

The 2011 CCS Week involved an open conference as well as open specialised workshops. The CCS Week was opened by the Director General of the Department, indicating government support for the CCS work in South Africa. Also, participation by Botswana indicated potential for cooperation – A Botswana CCS Delegation visited South Africa during 2015 to further that cooperation.

Presentations from the Decatur and Otway Projects gave practical inputs to the development of South Africa's Pilot CO2 Storage Project. Discussions regarding legal and regulatory frameworks inputted to the development of such by the Department of Energy. Outputs of the public engagement discussions inputted to the development of a Public Engagement Programme for the development of CCS in South Africa, especially the Pilot Project.

The Risk Assessment discussions were the first detailed addressing of CCS risk in South Africa and led to the development of a risk profile.

The outputs of the Conferences/Workshops are fed directly into the improvement of the CCS work as one of the eight Flagship Programmes of the 'National Climate Change Response Strategy White Paper'.

Tony Surridge addressing CCS Week attendees

CCS Week participants

Feedback from Brazil

Rodrigo Sebastian Iglesias, Associate Professor, Engineering Faculty and Institute of Petroleum and Natural Resources, from the Pontifícia Universidade Católica do Rio Grande do Sul talks about the Brazil CCS public engagement workshops:

The funding was used to sponsor the costs for a series of short courses on CCS in Brazil, to help raise awareness. The courses were directed at a broader public audience including academia (university graduate and undergraduate students), the industrial sector, NGOs and government agencies.

We enjoyed the organization and realization of these courses as an opportunity to bring together a group of people interested in the field, while interacting with some of the CCS experts that participated as lecturers. We felt that both participants and speakers were very satisfied with the courses, attending most of the lectures even if the agenda was intense and the courses were free of charge.

Each course gave us an opportunity to further improve the program, identifying the topics that were more relevant and interesting for the audience, and those that were not. Apart from the experience gained in the organization of this type of event, we have developed a comprehensive program, materials and activities that can be used for CCS introductory courses, and we intend to use this in future events and/or university extension or post-graduation courses.

Workshop delegates

Workshop participants visit the Institute of Petroleum and Natural Resources labs

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Accelerating the Adoption of 2nd and 3rd Generation Carbon Capture Technologies

Background

At the November 2013 CSLF Ministerial Meeting in Washington D.C., the Exploratory Committee of the CSLF Policy Group stated that one of the four main thematic focal points for the upcoming 6th CSLF Ministerial Meeting was to be "Supporting Development of 2nd and 3rd Generation Carbon Capture Technologies". To that end, a joint Policy Group-Technical Group Task Force co-chaired by Canada and Norway was formed to:

- Identify 2nd and 3rd generation technologies for carbon capture and testing facilities;
- Assess policy and funding mechanisms; and
- Propose areas of follow-up for the CSLF to facilitate the acceleration of 2nd and 3rd generation carbon capture technologies.

What are 2nd and 3rd Generation Technologies?

- *2nd generation technologies* include technology components currently in R&D that will be validated and ready for demonstration in the 2020–2025 timeframe.
- *3rd generation technologies* include technology components that are in the early stage of development or are conceptual. They have the potential for performance and cost improvements beyond those expected from 2nd generation technologies and are expected for demonstration in the 2030–2035 time period.

The term "emerging technologies" will be used to refer to both 2nd and 3rd generation carbon capture technologies.

Results of Task Force Research

Approximately 30 groupings of emerging technologies have been identified from the technical literature review. Most are 3rd generation, i.e. unlikely to be commercialized for large scale implementation before 2030. A minority is classified as 2nd generation, i.e. likely to be ready for large scale implementation between 2020 and 2025. The study has also identified 11 test facilities that may be used to speed up the development of emerging technologies. The majority of the identified test facilities are designed for post-combustion capture of CO_2.

Interviews were conducted with key CSLF stakeholders to identify impeding barriers and assess existing or potential mechanisms to accelerate research, development, and deployment (RD&D) of emerging technologies. The table below summarizes the barriers and corresponding mechanisms, based on the stakeholder interviews.

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Barriers	**High priority mechanisms**
Lack of a market	• Carbon pricing
High costs	• Government funding programs • Tax incentives for research and development • Operational support programs • Test centers / test facilities • Cooperation and knowledge-sharing networks
Technical and operational challenges	• Government funding programs • Operational support programs • Test centers / facilities • Cooperation and knowledge-sharing networks
Insufficient test sites in key geographies/sectors	• Test centers / test facilities
Storage availability and lack of clear regulations	• Cooperation and knowledge-sharing networks

Recommendations for Ministerial Consideration

- Given the priorities and findings that emerged from the research of the Task Force, and in light of the capacity of the CSLF, it is recommended that the CSLF continue to enhance *collective efforts* to accelerate the development of emerging technologies among governments, technology developers and adopters, and academia / researchers by:
    - ✓ Maintaining a global inventory of test facilities, including availability, capacities, and capabilities (different sizes, scales, fuels);
    - ✓ Implementing mechanisms that allow developers of emerging technologies and operators of test facilities to cooperate in mutually beneficial and cost-effective ways;
    - ✓ Enhancing networks to cover additional regions, sectors, and levels of scale. This should be based on the successful models of the ITCN[1] and the European network ECCSEL[2];
    - ✓ Assessing cooperative opportunities, similar to the EU twinning approach[3], among other CSLF member countries to enhance the global knowledge base and cooperation in emerging technologies;

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[1] ITCN, the International CCS Test Centre Network, is fostering knowledge-sharing among carbon capture test facilities around the world to accelerate the commercialization of technology. Its membership includes test facilities in Canada, Germany, Norway, the UK, and the U.S.

[2] ECCSEL, the European Carbon Dioxide Capture and Storage Laboratory Infrastructure, is opening access for researchers to a top quality European research infrastructure devoted to 2nd and 3rd generation CCS technologies, through a consortium of selected Centres of Excellence on CCS research from 9 countries across Europe.

[3] The EU twinning approach fosters bilateral cooperation between next generation carbon capture R&D projects. It has been implemented through a European Commission (EC) call for twinning between EC-funded and Australian projects, and will be repeated with South Korea.

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- ✓ Fostering the sharing of best practices in funding emerging technologies, with the potential of documenting best practices in developing priority funding areas;
- ✓ Contributing to the development of a consistent terminology for emerging technologies and project maturity levels and supporting efforts being made by the ISO, the ITCN and others to derive consistent performance evaluation methods; and
- ✓ Enhancing opportunities for researchers and developers to participate in extended visits, training opportunities, and staff exchanges, supported by the CSLF Academic Community Task Force.

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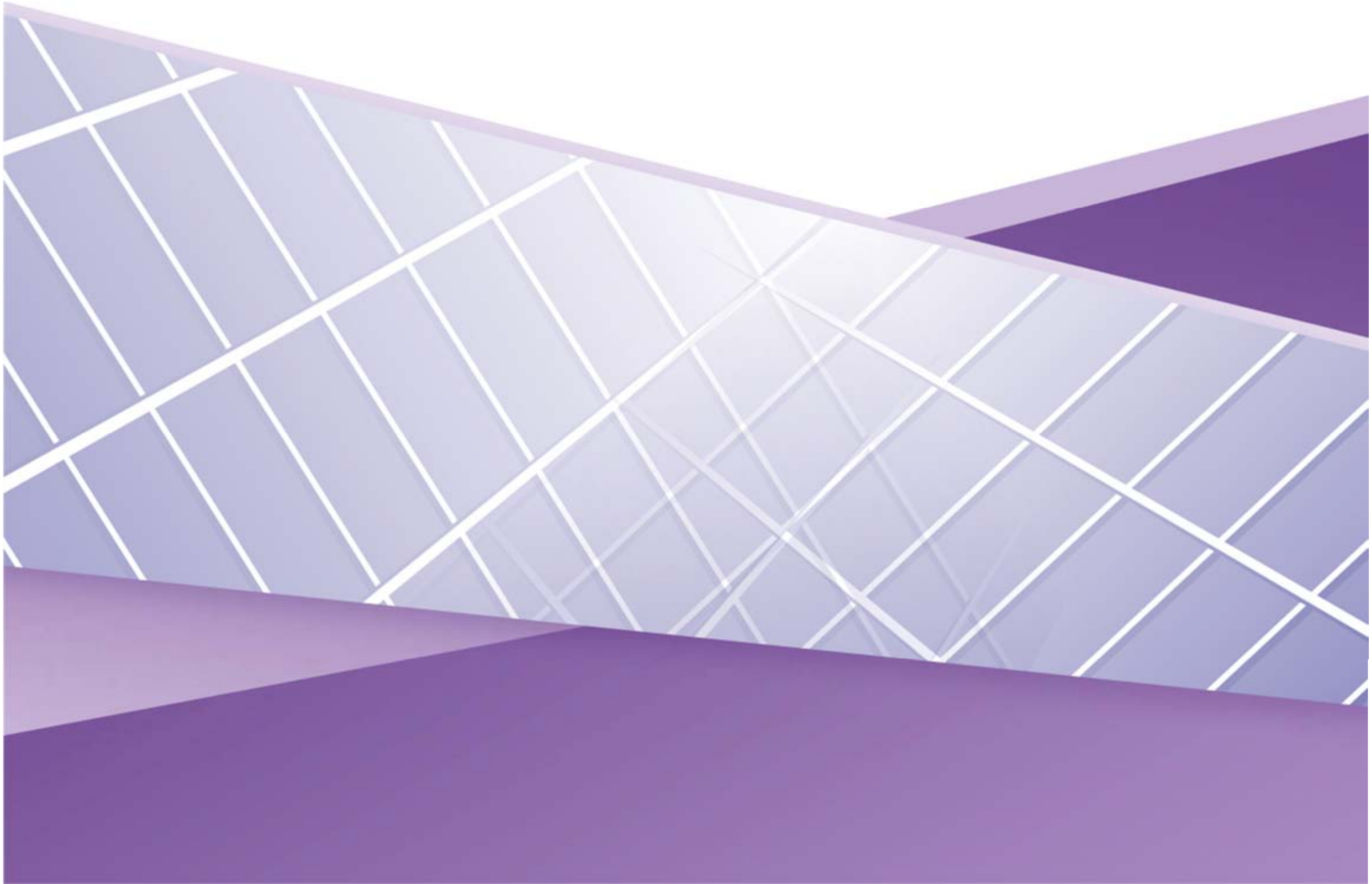
CCS IN THE ACADEMIC COMMUNITY TASK FORCE
CARBON SEQUESTRATION LEADERSHIP FORUM

Background and Key Highlights of Plan of Action

October 2015



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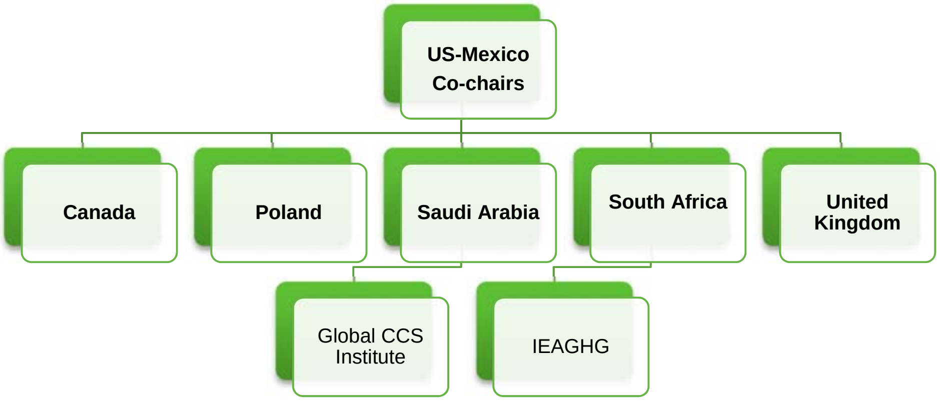
Introduction

The academic community plays a vital role to advance carbon capture and storage (CCS) technologies through research, development, and demonstration (RD&D), as well as through policy guidance and a wide range of educational programs that support development of the next generation of scientists, engineers and policymakers. Governments can strongly influence the extent to which the academic community is engaged in CCS. Thus, the Carbon Sequestration Leadership Forum (CSLF) is in a unique position to catalyze, grow and strengthen the academic community's contribution to achieving CSLF goals.

The mission of the *CCS in the Academic Community Task Force* (Academic Task Force), originally established in 2008, is to identify and engage academic programs on CCS throughout the world to help support the mission and path forward for the CSLF. Early accomplishments of the Task Force included a mapping and gap analysis of CCS post-graduate academic courses worldwide and links to the CSLF Capacity Building Task Force.

Although in recent years this Task Force has been dormant, at the CSLF Mid-Year Policy Committee Meeting in Regina, Saskatchewan, Canada in June 2015, it was re-established with a new organizational structure (Figure 1) and focus– to foster and support the CSLF mission and objectives via academic CCS research programs, international collaborations, research exchanges, networks, and summer schools. With more proactive engagement among the CCS academic community, the CSLF can facilitate international research collaborations in priority areas and leverage funding opportunities that advance the CSLF mission.

CSLF CCS in the Academic Community Task Force Members (June 2015)



Specifically, in re-establishing the Academic Task Force, its members agreed to take the following steps:

- Conduct a baseline survey of current CCS academic research programs, international collaborations, student exchanges, summer schools, and networks.
- Assess current funding commitments and mechanisms in CSLF member countries to support and enhance international CCS academic collaborations.

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- Determine funding opportunities available from capacity development programs such as the World Bank CCS Trust Fund, Asian Development Bank CCS Trust Fund, CSLF Capacity Development Fund and other sources.

- Assess resource needs to strengthen and catalyze Academic Task Force activities and determine opportunities to leverage available funding.

- Outline a plan of action for the Academic Task Force to help achieve CSLF goals.

In response to the above agenda set forward by the new Task Force, this report provides an initial baseline survey of existing mechanisms for international CCS academic collaborations, key research groups, summer schools, and networks for Academic Task Force members. The report also includes key CCS academic contacts for Task Force members, and presents a Plan of Action to strengthen Academic Task Force activities, as summarized below. This report will soon be expanded to include all CSLF member countries.

Plan of Action: Key Highlights

- Secure endorsement from Ministers at the CSLF Ministerial Meeting in Saudi Arabia in November 2015 on the importance of the CCS academic community to help meet CSLF goals, and the new structure of the CCS in the Academic Task Force.

- Secure endorsement from Ministers at the November CSLF Ministerial Meeting to provide support for the Academic Task Force to host a planning workshop for the CCS academic community some time in the first half of 2016, possibly in conjunction with the mid-year CSLF meeting. This Academic Task Force workshop will bring together academic representatives from the Task Force member countries, as well as other CSLF member states. The major objectives of the workshop are to:

    - Identify and document current academic community research linkages with CSLF Technical Group and Policy Group priorities;

    - Determine where and how the CSLF can help leverage international collaborations, student exchanges, summer schools, networks and funding opportunities to further CSLF goals;

    - Establish Academic Task Force membership across the global academic community, and

    - Prepare an Action Plan for moving forward, to be presented at the CSLF 2016 Mid-Year Meeting.

Required support for this workshop includes basic travel expenses for up to 20 academic participants from CSLF member countries (and potential member countries) who would not otherwise be able to attend.

- In addition to the above, the Task Force will undertake the following activities:

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- Complete baseline survey for all CSLF Member Countries; where there is no current activity, determine possible mechanisms and opportunities.

- Assess current CCS internship opportunities with governments and industry and how they may be expanded among CSLF member countries and linked to study-abroad programs.

- Assess the availability of on-line CCS certification programs and CSLF member interest in providing such programs via the Academic Task Force.

- Provide an on-line platform within the CSLF web site to include Academic Task Force information.

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Short Summaries of Projects featured in Ministerial Conference Opening Plenary Session Roundtable

- SaskPower Boundary Dam Project
- Illinois Industrial CCS Project in the United States
- Uthmaniyah CO_2-EOR Project in Saudi Arabia
- Rotterdam Storage and Capture Demonstration Project (ROAD) in the Netherlands

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OVERVIEW OF SASKPOWER’S CARBON CAPTURE & STORAGE INITIATIVES

OVERVIEW OF THE BOUNDARY DAM CCS PROJECT

The Boundary Dam Carbon Capture and Storage (CCS) Project is SaskPower’s flagship CCS initiative. The Boundary Dam CCS Project completely rebuilt a coal-fired generation unit with carbon capture technology, resulting in low-emission power generation. In the fall of 2014, the project came online as the ***World's First Post-Combustion Coal-Fired CCS Project.*** This project transformed the aging Unit #3 at Boundary Dam Power Station near Estevan, Saskatchewan into a reliable, long-term producer of 120 megawatts (MW) of base-load electricity, capable of reducing greenhouse gas emissions by up to one million tonnes of carbon dioxide (CO_2) each year.

The captured CO_2 is sold and transported by pipeline to nearby oil fields in southern Saskatchewan where it is used for enhanced oil recovery. Injected CO_2 is continuously used within the oil reservoir, where it is stored permanently once depleted. CO2 not used for enhanced oil recovery will be permanently and safely stored, 3.2 KM underground at SaskPower’s Carbon Storage and Research Centre, hosting the Aquistore project. In addition to CO_2, SaskPower sells other products captured from the project. The entire sulphur dioxide (SO_2) that is captured is converted to sulphuric acid and sold for industrial use. Fly ash, another product of coal combustion, is sold for use in ready-mix concrete, pre-cast structures and concrete products.

SaskPower proceeded with CCS on coal to ensure a diversified portfolio for power generation in Saskatchewan. Additionally, the price of fuel for natural gas is unpredictable. Comparably, coal is reliable, abundant and affordable as a fuel source.

SaskPower’s total investment for the Boundary Dam carbon CCS Project was $1.23B CAD. The federal government contributed an additional $240M CAD grant, for a total of $1.467B CAD.

SASKATCHEWAN AS AN EPICENTRE OF CCS EXPERTISE

Saskatchewan has quickly developed as a world leader in the area of carbon capture and storage. For nearly 15 years, we have been safely storing over 25 million tonnes of CO_2 underground through the process of enhanced oil recovery as part of the **IEAGHG Weyburn-Midale Project.**

At the **Boundary Dam CCS Project,** SaskPower has successfully captured over 400,000 tonnes of CO_2 since it became operational in October 2015. At full capacity, it will be able to capture 90% of the CO_2 from Unit #3.

SaskPower’s Carbon Storage and Research Centre also hosts **Aquistore**, an independent CO_2 storage and monitoring project which demonstrates that storing CO_2 deep underground is a safe, workable solution to reduce GHG emissions.

In June 2015, SaskPower held a grand opening for our world-leading **Carbon Capture Test Facility (CCTF)**. This facility provides robust evaluation of carbon capture technologies and is designed to accommodate a wide range of carbon capture solvents and equipment. It was developed in collaboration with Mitsubishi Hitachi Power Systems, who are operating the facility as our initial vendor until late 2016. This facility is truly unique due to its close proximity to a working commercial-scale CCS project at Boundary Dam.

SaskPower has also developed a state-of-the-art **Amine Chemical Laboratory**, providing new means of analyzing the environmental impact of carbon capture processes.

Operational data and experience being collected at the Boundary Dam CCS Project is critical to decisions that will be made by SaskPower in terms of continued CCS development. **Units #4 and 5 at Boundary Dam** are nearing the regulatory requirement to either retire or retrofit coal-fired plants with CCS technology. The outcomes and learnings of Unit #3 are critical to allow SaskPower to accurately forecast if it is feasible to retrofit those two units with carbon capture technology as well.

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The Illinois ICCS Project: CO_2 Capture from Biofuels Production and Storage into the Mt. Simon Sandstone

Goals/Objectives

The overall project objective is to develop and demonstrate an integrated system of CO2 processing and transport from Archer Daniels Midland's (ADM) Decatur IL ethanol plant to the Mt. Simon Sandstone Formation (saline reservoir) for geologic sequestration.

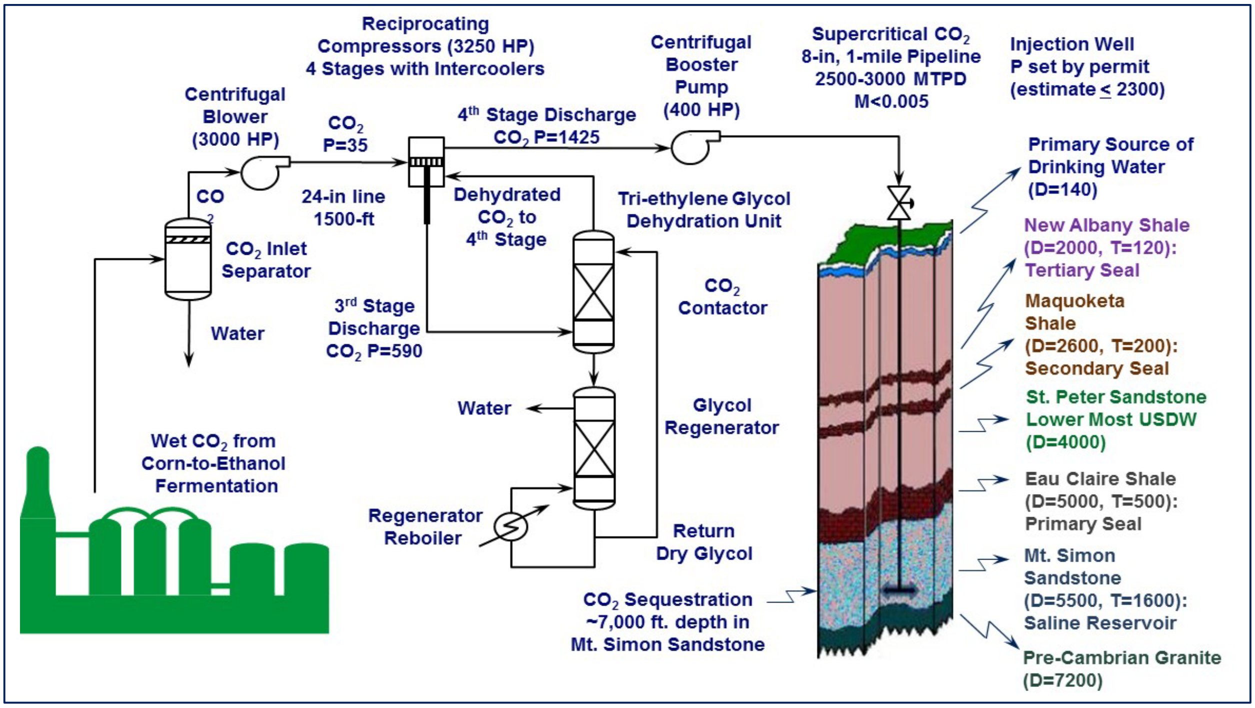
Project Scope

The Illinois ICCS project will demonstrate an integrated system for collecting CO_2 from an ethanol production plant and geologically storing it (deep underground storage) in a sandstone reservoir. The CO_2 produced is a byproduct from processing corn into fuel-grade ethanol at the ADM ethanol plant in Decatur, Illinois. Because all of the collected CO_2 is produced from biologic fermentation, a significant feature of the Illinois ICCS project is its "negative carbon footprint," meaning that the storage results in a net reduction of atmospheric CO_2.

The CO_2 will be sequestered in the Mt. Simon Sandstone, a prolific saline reservoir in the Illinois Basin with the capacity to store billions of tons of CO_2. Saline reservoirs are layers of porous rock that are saturated with brine (a concentrated salt solution). Mt. Simon Sandstone is a clean sedimentary rock dominated by silicate minerals and lacking significant amounts of clay minerals (which typically clog pores and reduce porosity), resulting in highly favorable porosity and permeability features for CO_2 storage. Supercritical CO_2 fluid will be injected into the saline reservoir at a depth of approximately 7,000 feet at a site adjacent to the ADM ethanol plant. Nearly 50 years of successful natural gas storage in the Mt. Simon Sandstone indicates that this saline reservoir and overlying seals should effectively contain sequestered CO_2.

The project scope includes the design, construction, demonstration, and integrated operation of CO_2 compression, dehydration, and injection facilities, and Monitoring, Verification, and Accounting (MVA) of the stored CO_2. More specifically:

- Design, construction, and operation of a new collection, compression, and dehydration facility capable of delivering up to 2,000 metric tons of CO_2 per day to the injection site.
- Integration of the new facility with an existing 1,000 metric tons per day CO_2 compression and dehydration facility to achieve a total injection capacity of up to 3,000 metric tons of CO_2 per day.
- Implementation and validation of deep subsurface and near-surface MVA plans.
- Demonstration of the cost advantages and economic viability of implementing CCS at ethanol production facilities.



Carbon Dioxide Compression, Dehydration, and Transmission

The CO_2 will be collected at atmospheric pressure from ADM's ethanol fermentation train and will be compressed and dehydrated to deliver supercritical CO_2 to the injection wellhead for storage. In this process the CO_2 will be initially compressed using a 3000 hp blower and sent to a dehydration and compression facility. The CO_2 will be compressed and dehydrated at that facility to 1425 psia using 3250 hp, 4-stage reciprocating compressors and a tri-ethylene glycol dehydration system. Next the gas is further compressed up to 2300 psia using a 400 hp centrifugal booster pump and transported through a 2 km 8-inch pipeline to the injection wellhead.

MVA of the Stored CO_2

The Illinois ICCS project will implement a robust MVA plan to monitor CO_2 migration and to protect groundwater sources. The MVA efforts will employ methods to provide an accurate accounting of the stored CO_2 and a high level of confidence that it will remain permanently stored deep underground. The MVA plan includes near surface and deep subsurface activities. Near surface monitoring includes aerial infrared imagery to monitor vegetative stress, an electrical resistivity survey of the soil to identify the geophysical nature of the near surface bedrocks, soil CO_2 flux to monitor changes in CO_2 concentrations, and shallow groundwater sampling for geochemical analysis. Deep subsurface monitoring includes geophysical (seismic) surveys and passive seismic surveys in the above cap rock seal locations and geophysical surveys, geochemical sampling, and pressure and temperature monitoring in the injection zone. A monitoring well (approximately 7200 ft. depth) and a geophysical well (approximately 3500 ft. depth) will be drilled for deep subsurface monitoring through direct and indirect measurements of the storage reservoir conditions. A baseline 3-D surface seismic study was conducted in February 2011. A geophysical analysis of the 3-D seismic data did not indicate any geologic faults in the cap rock seal at the proposed ICCS injection site. A lack of geologic faults offers greater certainty that the injected CO_2 will be strategraphically trapped in the Mt. Simon Sandstone. Other trapping mechanisms such as solubility trapping (dissolution of CO_2 in the brine solution) and residual trapping (CO_2 held in the pores) could also securely retain approximately 50% of the injected CO_2 in the sandstone.

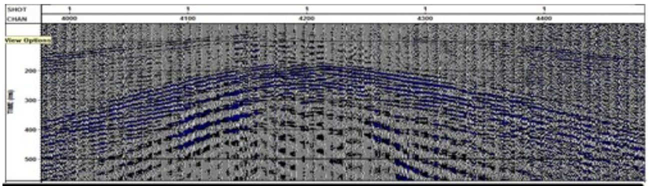
Current Status

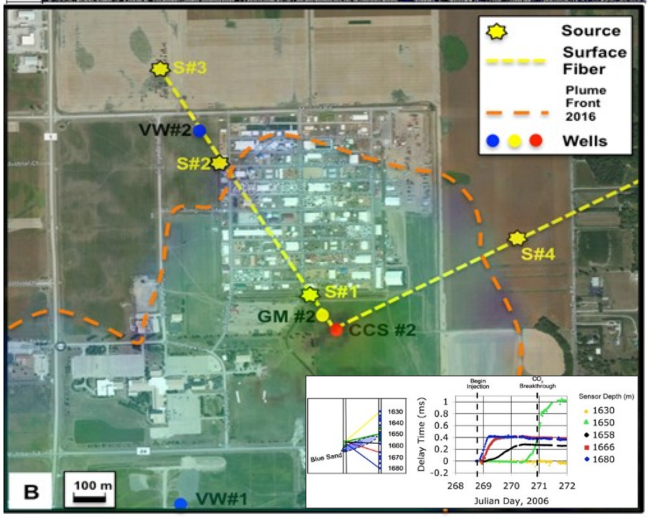
The project has completed all major construction activities and is undergoing unit commissioning. All well completion reports have been submitted to the EPA for review and authorization for injection. Operation is expected to begin in the first quarter of 2016.

Decatur, Illinois is home to two other DOE-sponsored CCS projects:

Illinois Basin-Decatur Project (IBDP) led by ISGS under the Midwest Geological Sequestration Consortium (MGSC) Regional Carbon Sequestration Program. In November 2014, this large scale injection test completed the project goal of injecting 1,000,000 metric tons of CO_2 over three years. The project is currently in the post injection monitoring period.

Intelligent Monitoring System (IMS) led by ADM: This project's goal is to develop and validate software tools that advance CCS-specific IMS by enabling access, integration, and analysis of real-time surface and subsurface data for decision-making and process automation. This project will demonstrate integration of data acquisition, process monitoring, and data analysis system components to validate feasibility of real-world application to CCS.





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Uthmaniyah CO2-EOR and CCS Demonstration Project

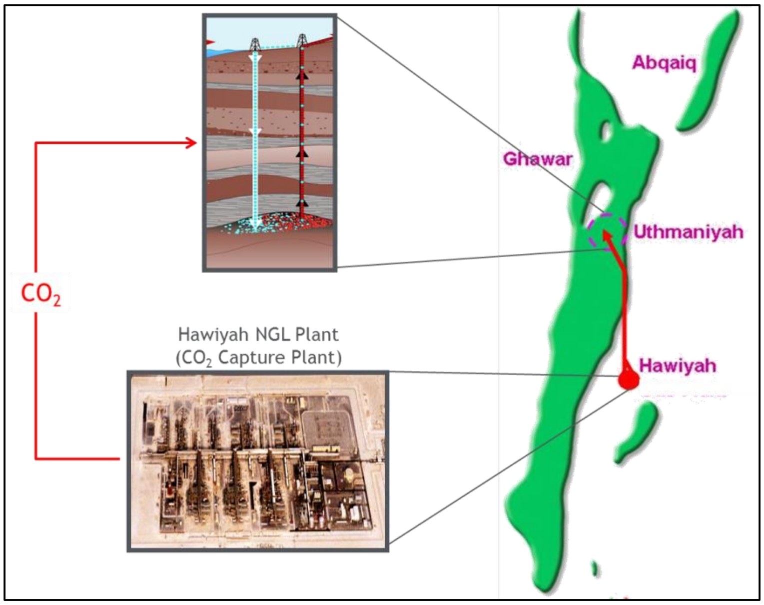
Summary: October 2015

On June 30, Saudi Aramco launched the Kingdom's first carbon capture and sequestration (CCS) and CO2 Enhanced Oil Recovery (EOR) project at Uthmaniyah. The project is the first of its kind in the Middle East in terms of scale and operation. It involves capturing about 40 million standard cubic feet per day (MMscf/d), approximately 800,000 tons of CO2 per year that would have been ordinarily emitted into the atmosphere, compressing the CO2 and piping it across 85 km and injecting it into a nearly watered-out zone of Uthmaniyah field – part of the giant Ghawar field.

The CO2 is injected in a WAG (water-alternating-gas) mode. The key objectives of the project are to test enhance oil recovery (estimated to be 7 - 9% beyond waterflooding) and permanently sequester about 40% of the injected CO2. For this reason, the project is considered a win-win technological solution – sequester CO2 and enhance oil recovery. The project is part of Saudi Aramco's corporate Carbon Management strategy and technology road map. Implementation of the project demonstrates that the company is part of the solution to proactively address global environmental challenges and reduce its carbon footprint.

The project consists of two major components based on major infrastructure locations:

1. Capture – Surface capture facilities of CO2 including dehydration and compression.
2. Injection – Injection wells and production facilities.



Locations of CO2 capture facilities and CO2-EOR demonstration project

This includes four injectors, four producers, and two observation wells for monitoring and surveillance. All wells were specifically drilled for the CCS-EOR project. They are all equipped with downhole monitoring sensors, real-time flow measurement devices, automated and remotely-controlled choke valves to provide full surveillance of reservoir parameters and to ensure full accessibility and control over the project area.

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The project deployed several novel technologies; some for the first time in the world, and others are first in the Middle East region. These include vertical compression technology for the CO2 compressor, 4D seismic for reservoir monitoring, novel tracers for saturation monitoring, borehole gravimetry, electromagnetic surveys, etc. For its potential to offer knowledge sharing, planning and road-mapping, and for its nature of research, development and demonstration (RDD), the project has been recently, in October 2015, awarded the “EOR Project of the Year” by Oil and Gas Middle East. The project is also internationally recognized by the Carbon Sequestration Leadership Forum (CSLF).

2015 Oil & Gas Middle East Award

An elaborate monitoring and surveillance (M&S) program has been developed for the pilot project to obtain data and evaluate its performance for the next 3 – 5 years. The main objectives of the (M&S) program include the understanding of CO2 migration within the reservoir, assessing CO2 potential for oil recovery and storage, and building public confidence in the first CO2 sequestration project, not just in the Kingdom, but throughout the GCC region.

Over the next three to five years, the demonstration project will be evaluated and lessons learned from this project will be utilized at other facilities and oil fields around the Kingdom, and shared with others in the greater Middle East region and worldwide.

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road
CCS

ROAD – Rotterdam Capture and Storage Demonstration Project

ROAD is the Rotterdam Opslag and Afvang Demonstratieproject (Rotterdam Capture and Storage Demonstration Project) and is one of the largest, integrated Carbon Capture and Storage (CCS) demonstration projects in the world. ROAD is being developed by Maasvlakte CCS Project C.V., a joint venture of E.ON Benelux and ENGIE Energie Nederland (known as GDF SUEZ Energie Nederland N.V. prior to April 2015). ROAD aims to capture CO_2 from the flue gases of Maasvlakte Power Plant 3 (MPP3) using post combustion capture technology. The captured CO_2 will be transported through a pipeline and injected into a gas field under the North Sea.

Project Objectives

The main objective of ROAD is to demonstrate the technical and economic feasibility of a large-scale, integrated CCS chain deployed on power generation. To date, post-combustion CCS has been applied to a 110 MWe facility in Canada in the power industry. Further large-scale demonstration projects are needed to show that CCS is an efficient and effective CO_2 abatement technology.

With the knowledge, experience and innovations gained by projects like ROAD, CCS could be deployed on a larger and broader scale: not only on power plants, but also within the energy intensive industries. CCS is one of the transition technologies expected to make a substantial contribution to achieving the climate objectives. It has to play a pivotal role in all credible scenarios towards a decarbonized energy supply.

The ROAD project is co-financed by the European Commission (EC) within the framework of the European Energy Programme for Recovery (EEPR) and the Government of the Netherlands. The grants amount to € 180 million from the EC and € 150 million (of which € 75 million conditional upon operational performances in the period 2015-2019) from the government of the Netherlands. In addition, the Global CCS Institute is knowledge sharing partner of ROAD and has given a financial support of AUD$ 6.2 million to the project.

Integrated CCS Chain

ROAD applies post combustion technology to capture the CO_2 from the flue gases of a new 1,069 MWe coal-fired power plant (Maasvlakte Power Plant 3, "MPP3") in the port and industrial area of Rotterdam. The capture unit has a capacity of 250 MWe equivalent. During the demonstration phase of the project, approximately 1.1 megatons of CO_2 per year will be captured from the new Maasvlakte Power Plant 3 (MPP3) located in the port of Rotterdam. The capture installation is planned to be operational 2019 – three years after the Financial Investment Decision (FID) has been taken.

From the capture unit the CO_2 will be compressed and transported through a pipeline: 5 kilometers over land and about 20 kilometers across the seabed to the P18-A platform in the North Sea. The pipeline has a transport capacity of around 5 million tonnes per year. It is designed for a maximum pressure of 140 bar and a maximum temperature of 80 °C.

ROAD plans to store the captured CO_2 in depleted gas reservoirs under the North Sea. These gas reservoirs are located in block P18 of the Dutch continental shelf, approximately 20 kilometers off the coast. The depleted gas reservoirs (P18-2; P18-4; P18-6) are at a depth of around 3,500 meters under the seabed of the North Sea. In the first phase CO_2 will be injected into depleted gas reservoir P18-4. The estimated storage capacity of reservoir P18-4 is approximately 8 million tonnes.

CCS Demonstration and Knowledge Sharing

ROAD is a CCS demonstration project intended to facilitate the generation and dissemination of new technical, legal, economic, organizational and societal knowledge and experience. ROAD will share this knowledge and experience through the European CCS Demonstration Project Network (www.CCSnetwork.eu) with governments, companies and knowledge institutions. Furthermore, ROAD has drafted a series of reports for the Global CCS Institute and delivered a large number of presentations and articles for various conferences and

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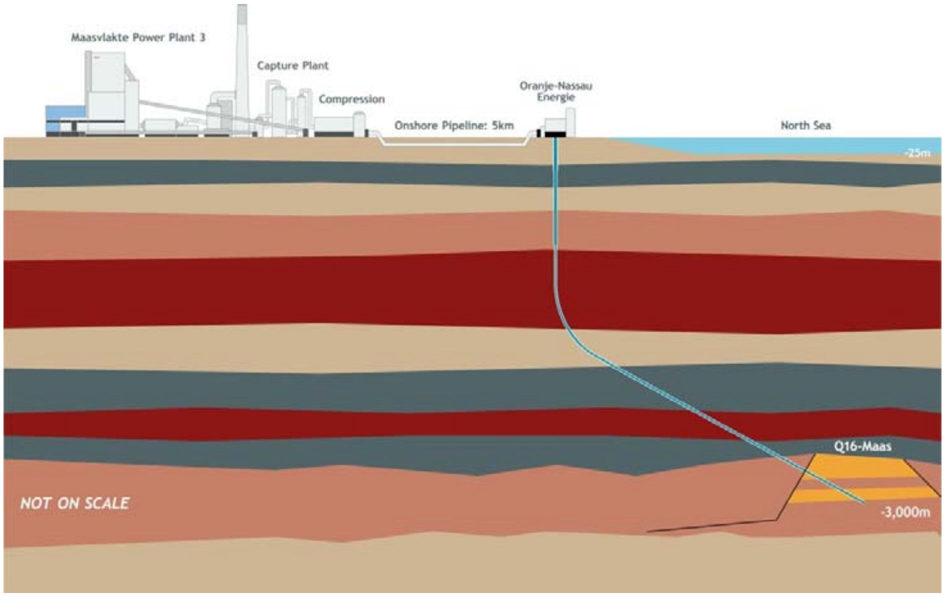
publications. In this way, ROAD can make a significant contribution to the commercial introduction of CCS and ultimately to the worldwide reduction of CO_2 emissions.



Project Status Quo

Since the first half year of 2012, the ROAD project has been slowed down because of the financial gap caused by structural low carbon prices (EU ETS). Although the project had already made substantial progress and reached several essential milestones (e.g. engineering, permitting, contracting) no Financial Investment Decision (FID) was taken due to a lack of sufficient funding.

Consequently, ROAD decided to review its positioning, after consulting the EC and in close co-ordination with other key stakeholders. The objective of this review was to find alternative funding sources, improve the project economics and to explore a phased project approach.

This review has resulted in a number of alternative project scenarios. Currently, ROAD is focusing on a scenario, including an alternative storage location and CO_2 utilization, and is assessing its feasibility. It is expected, ROAD will finalize these feasibility studies within the next coming months. The FID is now rescheduled to Q1/Q2 of 2016.

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Shell Quest Carbon Capture and Storage Project, Alberta, Canada

THE GLOBAL STATUS OF CCS | 2015

The Global Status of CCS: 2015 is the Institute's annual publication on the progress of carbon capture and storage (CCS) globally.

You are invited to download your PDF copy of the Summary Report of this publication before it launches on 5 November 2015 by visiting:

[GLOBALCCSINSTITUTE.COM/STATUS2015]

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COP21 | PARIS, FRANCE 2015

30 November - 11 December 2015

The Institute will host a series of events during the COP21 negotiations, to advocate for the role of CCS.

How the UNFCCC architecture can help mobilise international resources and support CCS	Friday 4 December	4.30pm - 6.00pm
Global CCS Institute Members' reception	Sunday 6 December	6.00pm - 8.00pm
Financing the demonstration and deployment of CCS in developing countries	Tuesday 8 December	1.00pm - 2.30pm
Hitting 2C Means: Investing in Renewables, a storage revolution, energy efficiency and CCS	Thursday 10 December	11.30am - 1.00pm
Global CO2 geological storage mapping	Friday 11 December	11.45am - 1.15pm

For more information about the Institute's planned activities at COP21, please contact **events@globalccsinstitute.com**.

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Carbon Sequestration Leadership Forum
www.cslforum.org

CHARTER FOR THE CARBON SEQUESTRATION LEADERSHIP FORUM (CSLF)
A CARBON CAPTURE AND STORAGE TECHNOLOGY INITIATIVE

The undersigned national governmental entities (collectively the “Members”) set forth the following revised Terms of Reference for the Carbon Sequestration Leadership Forum (CSLF), a framework for international cooperation in research, development demonstration and commercialization for the separation, capture, transportation, utilization and storage of carbon dioxide. The CSLF seeks to realize the promise of carbon capture utilization and storage (CCUS) over the coming decades, ensuring it to be commercially competitive and environmentally safe.

1. Purpose of the CSLF

To accelerate the research, development, demonstration, and commercial deployment of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage or utilization; to make these technologies broadly available internationally; and to identify and address wider issues relating to CCUS. This could include promoting the appropriate technical, political, economic and regulatory environments for the research, development, demonstration, and commercial deployment of such technology.

2. Function of the CSLF

The CSLF seeks to:

2.1 Identify key obstacles to achieving improved technological capacity;

2.2 Identify potential areas of multilateral collaborations on carbon separation, capture, utilization, transport and storage technologies;

2.3 Foster collaborative research, development, and demonstration (RD&D) projects reflecting Members’ priorities;

2.4 Identify potential issues relating to the treatment of intellectual property;

2.5 Establish guidelines for the collaborations and reporting of their results;

2.6 Assess regularly the progress of collaborative RD&D projects and make recommendations on the direction of such projects;

2.7 Establish and regularly assess an inventory of the potential RD&D needs and gaps;

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2.8 Organize collaboration with the international stakeholder community, including industry, academia, financial institutions, government and non-government organizations; the CSLF is also intended to complement ongoing international cooperation;

2.9 Disseminate information and foster knowledge-sharing, in particular among members' demonstration projects;

2.10 Build the capacity of Members;

2.11 Conduct such other activities to advance achievement of the CSLF's purpose as the Members may determine;

2.12 Consult with and consider the views and needs of stakeholders in the activities of the CSLF;

2.13 Initiate and support international efforts to explain the value of CCUS, and address issues of public acceptance, legal and market frameworks and promote broad-based adoption of CCUS; and

2.14 Support international efforts to promote RD&D and capacity building projects in developing countries.

3. Organization of the CSLF

3.1 A Policy Group and a Technical Group oversee the management of the CSLF. Unless otherwise determined by consensus of the Members, each Member will make up to two appointments to the Policy Group and up to two appointments to the Technical Group.

3.2 The CSLF operates in a transparent manner. CSLF meetings are open to stakeholders who register for the meeting.

3.3 The Policy Group governs the overall framework and policies of the CSLF, periodically reviews the program of collaborative projects, and provides direction to the Secretariat. The Group should meet at least once a year, at times and places to be determined by its appointed representatives. All decisions of the Group will be made by consensus of the Members.

3.4 The Technical Group reports to the Policy Group. The Technical Group meets as often as necessary to review the progress of collaborative projects, identify promising directions for the research, and make recommendations to the Policy Group on needed actions.

3.5 The CSLF meets at such times and places as determined by the Policy Group. The Technical Group and Task Forces will meet at times that they decide in coordination with the Secretariat.

3.6 The principal coordinator of the CSLF's communications and activities is the CSLF Secretariat. The Secretariat: (1) organizes the meetings of the CSLF and its sub-groups, (2) arranges special activities such as teleconferences and workshops, (3) receives and forwards new membership requests to the Policy Group, (4)

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coordinates communications with regard to CSLF activities and their status, (5) acts as a clearing house of information for the CSLF, (6) maintains procedures for key functions that are approved by the Policy Group, and (7) performs such other tasks as the Policy Group directs. The focus of the Secretariat is administrative. The Secretariat does not act on matters of substance except as specifically instructed by the Policy Group.

3.7 The Secretariat may, as required, use the services of personnel employed by the Members and made available to the Secretariat. Unless otherwise provided in writing, such personnel are remunerated by their respective employers and will remain subject to their employers' conditions of employment.

3.8 The U.S. Department of Energy acts as the CSLF Secretariat unless otherwise decided by consensus of the Members.

3.9 Each Member individually determines the nature of its participation in the CSLF activities.

4 Membership

4.1 This Charter, which is administrative in nature, does not create any legally binding obligations between or among its Members. Each Member should conduct the activities contemplated by this Charter in accordance with the laws under which it operates and the international instruments to which its government is a party.

4.2 The CSLF is open to other national governmental entities and its membership will be decided by the Policy Group.

4.3 Technical and other experts from within and without CSLF Member organizations may participate in RD&D projects conducted under the auspices of the CSLF. These projects may be initiated either by the Policy Group or the Technical Group.

5 Funding

Unless otherwise determined by the Members, any costs arising from the activities contemplated by this Charter are to be borne by the Member that incurs them. Each Member's participation in CSLF activities is subject to the availability of funds, personnel and other resources.

6 Open Research and Intellectual Property

6.1 To the extent practicable, the RD&D fostered by the CSLF should be open and nonproprietary.

6.2 The protection and allocation of intellectual property, and the treatment of proprietary information, generated in RD&D collaborations under CSLF auspices should be defined by written implementing arrangements between the participants therein.

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7. Commencement, Modification, Withdrawal, and Discontinuation

7.1 Commencement and Modification

7.1.1 Activities under this Charter may commence on June 25, 2003. The Members may, by unanimous consent, discontinue activities under this Charter by written arrangement at any time.

7.1.2 This Charter may be modified in writing at any time by unanimous consent of all Members.

7.2 Withdrawal and Discontinuation

A Member may withdraw from membership in the CSLF by giving 90 days advance written notice to the Secretariat.

8. Counterparts

This Charter may be signed in counterpart.