Carbon Capture & Storage (CCS) Forum 2018

4–8 June 2018, San Michele, Italy

Summary Report

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1 CCS Forum 2018

The first CCS Forum was held in London over three days, 10–12 Feb 2016. It hosted delegates from academia, industry, and government to discuss the future of CCS and, in particular, to identify the key research challenges to be addressed in the near-to-medium term. Over the course of the three days, the applications of CO_2 capture technologies to the power and industrial sectors were discussed in detail, as was the subsequent geological storage of the CO_2. In addition to the utilisation of the CO_2 in enhanced hydrocarbon recovery, the mineral carbonation of industrial wastes and also the potential for the further conversion of CO_2 into chemicals was discussed. Furthermore, the role of policy measures to enable the deployment of CO_2 to the power and industry sectors was discussed. The key outputs of this meeting was:

- CCS Forum Report (published through IChemE): provides detailed insights into the critical challenges that need to be addressed for CCS development [1].
- Review and perspective paper "Carbon capture and storage (CCS): the way forward", published in Energy & Environmental Science [2], which provides a state-of-the-art update.

A second CCS Forum was held 3–8 June 2018 in San Michele, Italy. This meeting hosted international delegates from academia, industry and government, representing institutions in the UK, US, the Netherlands, Australia, Norway, Switzerland, France, Germany, Canada and Austria. The ambition for CCS Forum 2018 was to curate a highly interactive meeting of a select group of CCS thought leaders. Distinct to a typical conference with speakers and an audience, specific delegates contributed to individual sessions with a short talk, additionally every delegate was actively invited to contribute a presentation to sessions if they wished to do so. A core aim of this series is to curate a community of experts, and encourage international collaboration.

Figure 1: The CCS Forum, 3 - 8 June 2018, San Michele, Calabria, Italy.

Based on discussions during the 2018 CCS Forum, this summary report outlines the key research priorities for CCS, exploring challenges that need to be addressed from a technical, economic, commercial and political perspective.

2 The role of CCS in a transitioning energy system

Energy systems optimisation modelling of the US by Vibrant Clean Energy (VCE) demonstrates that an 80% reduction in CO_2 emissions is possible. However, to achieve such a scenario, the modelling assumes "titanic" societal and political changes, also technical constraints are relaxed. For example, build rate constraints of technology and infrastructure is relaxed, assumes no overshooting of the temperature and extensive interconnecting transmission of electricity across all areas of the country (e.g., few isolated areas).

Ideally, an energy system needs a portfolio of technologies (as illustrated by Figure 2. However, no technology is indispensable (i.e., none are absolutely needed). All technologies are desirable for different reasons (e.g., provides certain services, low cost). There is a moral imperative to mitigate climate change in the most cost effective and efficient way possible. The role of carbon capture, utilisation and storage (CCUS) needs to adapt and find its place in the evolving energy sector (*e.g.*, the phasing out of fossil fuel-fired power plants). The shift away from applications in the power sector creates opportunities for CCS in industrial decarbonisation and removal of atmospheric CO_2 (*i.e.*, negative CO_2 emissions).

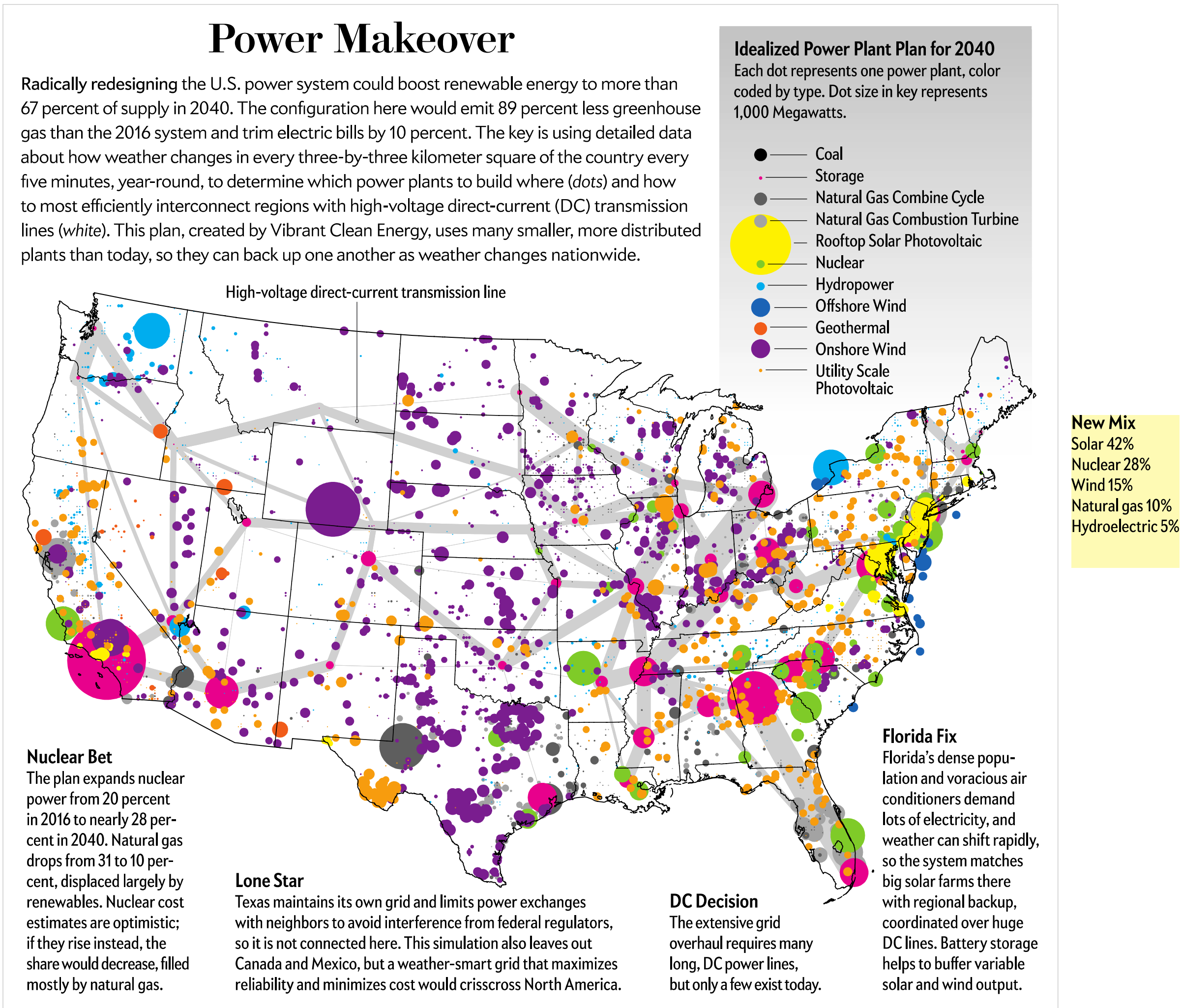

Figure 2: Idealised U.S. power system for 2040. This box was published in the article by Fairley (2018) [3]. Map by Christopher Clack, Vibrant Clean Energy.

System modelling and optimization provide important insights and enables “myth busting". For example, one common myth challenged in the modelling work by VCE is that nuclear can be flexible (common practice in some countries such as France. Furthermore, intermittent renewable energy (*e.g.*, wind and solar) can provide adequate power and other required services. Subsequently, low cost renewable energy is in strong competition with CCS in the electricity system. Although insights can be useful, reality may not follow the global optimum, *e.g.*, due to political and societal reasons. Mutual agreement on detailed modelling assumptions is difficult to achieve. Additionally, it is important to recognise that output results of models are specific for the data inputs used and region the model is specifically designed for.

3 Accelerating CCS deployment: key priorities

There is a suite of technologies for the capture, transport, storage and utilisation of CO_2 at different levels of technology readiness level, as shown by Figure 3. Some of these technologies have reached (or are close to reaching) the commercial phase of development. There are now 37 major large-scale CCS projects worldwide, many of which are in operation phase. However, deployment of large-scale project has been slow.

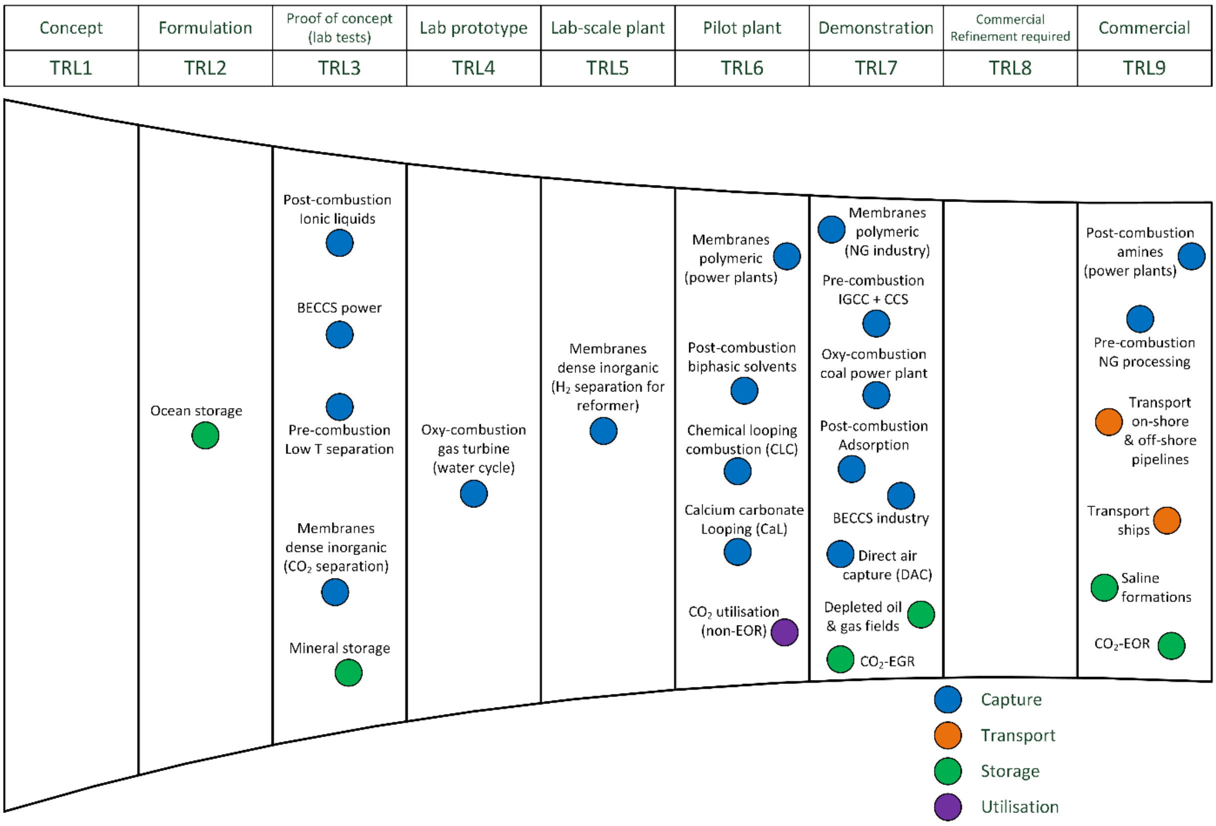

Figure 3: Progress of development of CCS technologies in terms of technology readiness level (TRL), figure sourced from Bui et al. (2018) [2].

To accelerate CCS deployment, we have identified the following key research priorities:

1. There is a need to foster data/databanks sharing to help accelerate technology development and improve bankability of CCS projects. Additionally, failed attempts should be published to avoid repetition of mistakes. Also, there is a need for transparency in reporting of technology performance data to enable fair comparison of technologies.

2. External collaboration and partnerships should be promoted. Information and study outputs need to be shared in such a way that will actually reach industry and decision makers (*i.e.*, not research articles).
3. Balancing of IP protection and knowledge sharing is necessary for cooperative problem solving.
4. We have to accelerate codes and standards to enable faster technology deployment.
5. Innovative policy is useful as long as it translates into value for both industry and society.
6. Current discussions are too focussed on the technical detail (*e.g.*, cost/tonne, efficiency), technology developers need to also demonstrate the societal value of CCS/CCUS.
7. Demonstration should be priority and need to show that CCUS is: (i) "clean" and there are no emissions of any pollutant such as SO_X, NO_X, nitrosamines, (ii) scalable (*e.g.*, > 500 Mt level), and (iii) brings clear impact to people's lives.

4 Scaling down CCS

Table 1: Overview of approaches used to scale down CCS with an outline of the benefits and challenges.

Needs	**Approaches**	**Benefits**	**Challenges**
- Smaller power applications - Industrial sources - Utilisation sinks - BECCS - DAC	- Modularisation - Advanced manufacturing - Standardisation - Process intensification - Mass manufacturing - Continue pursuing appropriate existing technologies	- High value market access - De-risk piloting and lower capital (at small scale) - Economies of number - Matching energy demand with supply, *e.g.*, thermal integration with renewable sources - More opportunity for learning by doing - Opportunity for faster evolution and disruption - Potential increase in public acceptance - "Distributed Infrastructure" - Failure impact low	- Transport scale down - Source-sink mismatch - Market size - High impact on climate change requires high deployment - More likely to observe some technical failure

Novel approaches to scaling down CCS take advantage of economies of mass manufacturing and process intensification. Modularity, mass/additive manufacturing, and innovative design show particular promise and can open up new opportunities to scale down CCS, reducing the overall system costs. Some important opportunities that have been identified include:

1. Strategic technology design has strong potential for small-scale, remote and off-shore applications. The scale of CO_2 emission sources is matched with the appropriate capture technology (e.g., membrane → adsorption → absorption).
2. Down-scaling of specific elements in the CCS chain provides opportunities for improved system design and further cost reduction, *e.g.*, down-scaled oxy-combustion boiler combined with large-scale ASU.
3. Scale down of CO_2 transport is also possible via ship, train and truck.

4. Adsorption processes are promising candidates for downscaling of CCS. The advantage of adsorption technology is being able to scale processes up/down while still maintaining the same performance level. Adsorption technology development needs to focus on the combination of material development and process design/optimisation.
5. Biology is modular in nature. New opportunities in scaling biotechnology is currently being, e.g., printed reactor made of living organisms. These novel bio-reactor systems have the potential to improve cost and efficiency of small-scale CCUS systems.

However, the major challenge for this strategy is that storage on small scale is unlikely to happen. There is a need to consolidate capture and couple appropriately scaled transportation when dealing with small emission sources.

5 Atmospheric CO_2 removal

Atmospheric CO_2 removal, *i.e.*, negative CO_2 emissions technologies (NETs), will have an important role in achieving climate change mitigation targets, particularly in scenarios meeting the COP21 1.5°C target [4]. The role of NET will become increasingly significant if climate change targets become more stringent. The two key technologies are bioenergy with CCS (BECCS) and direct air capture (DAC).

5.1 Direct air capture (DAC)

Of these, DAC is easier to regulate but some misconceptions need to be clarified. There is growing evidence that DAC can work at a relatively low cost (at least in the lower range of cost estimates, *e.g.*, Keith *et al.* (2018) [5]), but the only viable business model remains DAC to fuels (e.g., Air to Fuels™ technology). DAC plants cannot simply be put anywhere, they need to be near the source of energy used for regeneration. Furthermore, the type of energy source and the carbon accounting of the whole cycle impacts the cost of net CO_2 removal, hence the importance of terminology – carbon removal vs. carbon avoided – can drastically impact costs.

5.2 Bioenergy with CCS (BECCS)

In order to avoid competition for land used for agriculture, many have proposed the use of marginal land for the farming of biomass for BECCS. However, there is no agreement on whether biomass can actually be grown on marginal land. The main concerns about the use of marginal land include:

- Accessibility to marginal land, *e.g.*, small pockets dispersed across a large area).
- Productivity–may require soil preparation before the land is suitable for growth.
- Supply reliability, *e.g.*, low availability during years of low productivity, difficult to plan operations around variable fuel supply.

It is possible to make BECCS work. We need to ensure low carbon breakeven time, sustainable feedstock and that there is a net energy production. Additionally, regulation, monitoring and certification systems are needed to help ensure that BECCS is sustainable (*i.e.*, net negative CO_2 removal). However, delays in regulation development and certification is a bottleneck for technology deployment. In addition to negative CO_2 emissions, BECCS can provide energy as a co-product. However, this is inefficient and another solution could be to combine DAC with photovoltaic systems, which may replace the need for BECCS altogether.

5.3 Important considerations for both technologies

- Regulators are not ready for "load balancing of technologies" (*e.g.*, intermittency of renewables, or variable biomass supply). Need to address this for both BECCS and DAC.

- The fair comparison of the two technologies relies on transparency and availability of performance data. Knowledge sharing is necessary.
- The portfolio of technologies that enable negative emissions is very limited, and all solutions should not be regarded as competing but as complementary.
- BECCS and DAC are not competing technologies; both rely on accessibility/availability of reliable CO_2 storage, which required a strong united front to gain social acceptability. The deployment of BECCS and DAC in parallel could enable risk sharing, thereby promoting progress of these technologies.

6 CO_2 conversion and utilisation (CCU)

There is a great variety of CCU pathways leading to different: purposes (*e.g.*, climate mitigation, carbon removal, low-cost chemicals), impacts, time scales, costs. This pathway diversity needs to be captured in the way we communicate with policy makers, particularly in the way we explain carbon removal vs. carbon avoided.

Often studies report an uncertainty range for cost and performance. However, it is unclear how useful it is to report uncertainty. It may lead decision makers to believe there is a lack of confidence in the technology. In regards to uncertainty ranges, it is important to consider and account for the following:

- Need more transparency as to the source of the "uncertainty": Is it uncertainty in performance?
- Diversity in methodologies? Pathways? Regional context?
- Where is the mean? Differentiate what is possible from what is probable.
- These ranges are still key in highlighting the gaps.

Like any product, CO_2 conversion and utilisation (CCU) needs to be marketed. The use of this terminology is very technical and the general public cannot relate to CCU. Instead, using the term "carbon recycling" may be more appealing to consumers and general public. There is a tendency to design CCU-derived products in a way that outperform products from conventional pathways, *e.g.*, low carbon cement/steel with higher material strength than traditional cement/steel. Although this may be considered positive, over-performance of products should not be used as the benchmark (i.e., unfair comparison).

There may potentially be issues with the regulation of CCU systems and products. For example, how do you make sure you are displacing the right product? The issue of permanence is very important if we are considering the technology for climate change mitigation. Although CCU does not offer permanent storage of CO_2, it could potential provide a means of setting up the infrastructure required for CCS. Thus, CCU may be regarded as an "enabler", allowing for future cost-effective deployment of CCS. There may also be opportunities to improve the economics by finding niche markets and exploring industrial symbiosis.

7 Advanced sorbents and CCS cost reduction

Although there are large-scale CCS projects in operation and under construction, we need to continue improving the economic and technical performance of CCS technologies. We need the development of second and third generation processes. The demonstration of technology, *i.e.*, "learning by doing", is essential communicate technical feasibility, thereby convincing policy makers. In designing new CCS processes, a multi-scale approach should be employed, also considering the coupling effects of multiple process parameters. Modelling advances can help accelerate the development of new technologies. For example, high-throughput modelling for material screening and reduced order modelling to decrease CPU time. The development of new technologies can have co-benefits (spill-over benefit) to multiple sectors, *e.g.*, membrane used for desalination and now finding new applications in gas separation. Design based on fundamental understanding rather than using a "shot-gun" approach is shown to be highly valuable, saving a significant amount of time, money and resources. Also, employing integrated multi-disciplinary teams can further accelerate technology development.

8 Enabling policy frameworks

The transition to a low carbon energy system is a challenging process. Based on historical data, energy transitions appear to coincide with the occurrence of catalytic events (*e.g.*, 1970s Khmer Rouge in Cambodia, Oil crises, 1990s Burst of Dot Com Bubble, 2008/09 global financial crisis). In contrast, initiatives that aim to mitigate climate change (*e.g.*, Kyoto Protocol) have had a negligible impact on CO_2 emissions, *i.e.*, "delusion is the new denialism".

The importance of cost within the energy trilemma, (costs, security, and environment) is only growing. Thus, making it difficult to justify the cost of deploying CO_2 mitigation technologies. On one hand, governments are waiting for technical innovation to decrease the cost of CCS, whereas developers of CCS projects require government to de-risk investment and drive innovation. Where crediting schemes exist, operation of the technology is required prior to accessing that scheme, such uncertainty would deter project investment. If there is no confidence in the market, will investments really happen? How do we break the circle?

The development of supportive policies can drive business. There is a need for pragmatic policy based on detailed LCA and economic analysis which allow the free-market to work. Long-term continuous political support of CCS needs to consider:

- Busting misconceptions: renewables are often used as a proxy for decarbonisation so CCS can never compete.
- "Too expensive" is subject to political priority.
- The right language. There needs to be a unified vision and compelling argument.
- NGOs can be essential allies in gaining social and political support.
- Business can lobby much more effectively than scientists.

9 Quantifying the value of CCS in today's and tomorrow's energy system

Short-sighted decarbonisation strategies (*e.g.*, deploying only wind and solar) can lead to infrastructure lock-in, potentially asset under-utilisation. Thus, understanding the true value of low-carbon energy technologies is vital to ensuring cost effective decarbonisation of future energy systems. To make cost comparisons meaningful, it is important to compile and standardise methodologies, be transparent in what assumptions are used (currency, inflation, geography) and whether a non-standardised approach was employed for analysis (*e.g.*, heat requirements).

Levelised cost of electricity (LCOE) is not a useful metric for valuing technologies. It does not take into account the value of different technology features and system dependencies. Low-carbon dispatchable technologies have high value and crucial role in full decarbonisation pathways of power systems. In particular, CCS can provide value with regards to power system resilience and operability. It is important to recognise that only a combination of technologies will allow to achieve CO_2 emission reduction goals. “We're not selling CCS. We need to be selling a carbon-free stable grid.” However, policy and decision makers are looking for tangible benefits rather than technical detail, *e.g.*, GDP and employment benefits. Thus, the offer of such services (*e.g.*, firm capacity, system resilience) do not convince/compel policy makers, but monetising these services could help support CCS.

10 References

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