Carbon Capture and Storage Forum 2018

Key research priorities and challenges for CCS

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CCS Leaders Forum 10–12 Feb 2016

Imperial College London

Location: Royal Academy of Engineering, London

Purpose:

Three day international workshop which hosts delegates from academia, industry and government to discuss the future of CCS.

Attendees:

Delegates from the US & EU, including participants from Imperial College, Cambridge, Edinburgh, Columbia, Princeton, Stanford, Berkeley, Shell, BP, Tata, Capture Power Ltd and Novacem and the UK’s DECC.

2016 CCS Forum Report

CCS Forum Report: http://www.icheme.org/~/media/Documents/icheme/Media%20centre/Misc/ccs-forum-report-full-report-july-2016.pdf

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Outcome of the 2016 CCS Forum

CCS review and perspective paper.

Provides a state-of-the-art update.

Key research challenges that need to be addressed.

Balanced perspective on scientific, policy and commercial priorities.

Energy & Environmental Science

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Carbon capture and storage (CCS): the way forward

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Source: Bui et al. (2018). Energy & Environmental Science, 11 (5), 1062-1176.

CCS Forum 2018

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Location: San Michele, Calabria, Italy

Dates: 3–8 June 2018

Format: Similar to Faraday Discussions.

Speakers allotted 15 minutes (incl. 5 min Q&A). All delegates invited to present. Panel at the end of each session to encourage discussion.

Participants: Imperial College, Cambridge, Melbourne University, PNNL, TU Delft, IIASA, Shell, Total, IEA, Carbon Engineering, Sheffield, SINTEF, Colorado School of Mines, BEIS, ETH Zürich, UK FCO and many more…

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Acknowledgement of Sponsors
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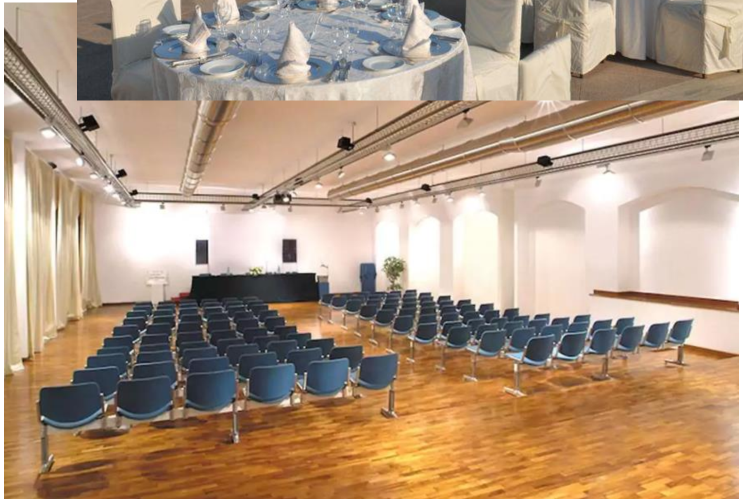
Overview of the sessions

1. Summary of EES review paper
2. Introductory Keynote: Do we really need CCS?
3. Research Priorities: Problem Statement
4. Scaling down CCS
5. Technologies for atmospheric CO_2 removal
6. CO_2 conversion and utilisation (CCU)
7. Enabling policy frameworks
8. Quantifying the value of CCS in the energy system
9. Advanced sorbents and CCS cost reduction
10. Delivering CCS projects – commercialisation challenges



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Do we really need CCS?

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Low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes

Mark Z. Jacobson, Mark A. Delucchi, Mary A. Cameron, and Bethany A. Frew

PNAS December 8, 2015 112 (49) 15060-15065; published ahead of print November 23, 2015
https://doi.org/10.1073/pnas.1510028112

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Do we really need CCS?

Do we really need CCS?

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US energy system optimisation model: 80% reduction of CO_2 emissions feasible without CCS.

Requires “titanic” societal and political changes, also technical constraints relaxed. E.g., social acceptance, no overshooting of targets, unconstrained build rates, perfect interconnection.

Need a portfolio of technologies. No technology is indispensable, all are desirable but for different reasons (i.e., different services).

CCUS needs to adapt and find its place in the evolving energy sector (*e.g.*, phase out of coal).

In the US scenario modelled, low cost renewable energy is in strong competition with CCS in the electricity system.

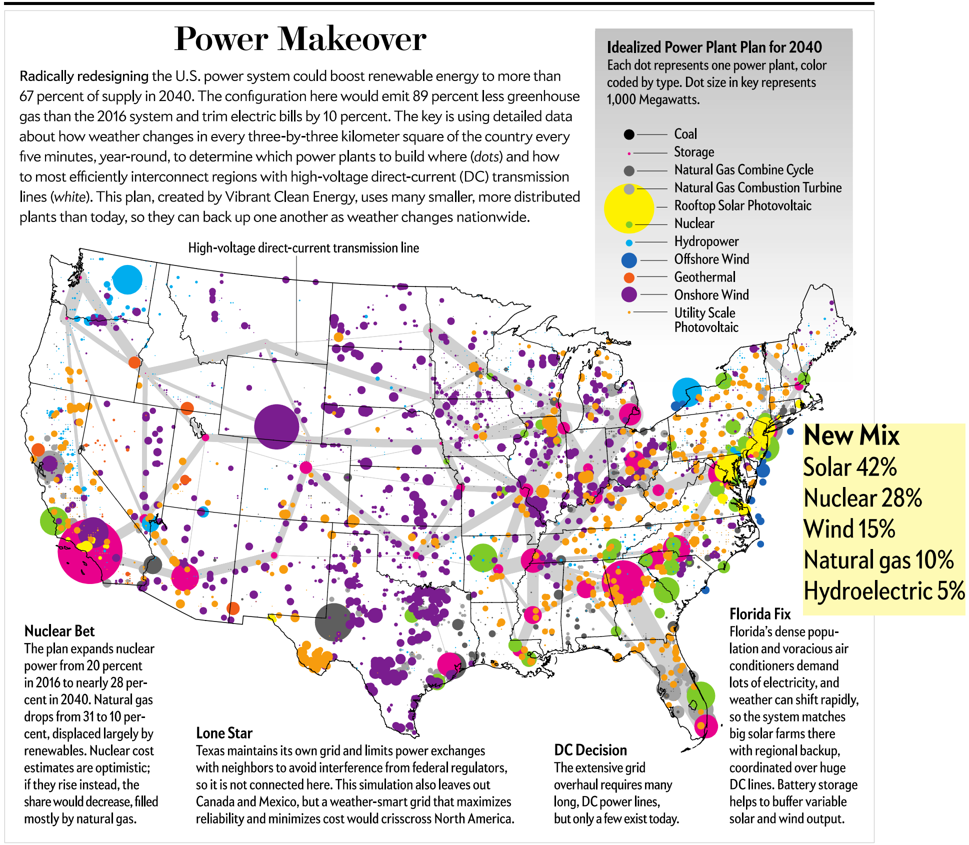

Fig: Fairley, P. (2018). Building a weather-smart grid. Scientific American, 319, 60-65.
Map by Christopher Clack, Vibrant Clean Energy (VCE)

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Do we really need CCS?

CCS focus should shift towards applications in industry and negative emissions.

System modelling and optimisation provide important insights.

Some common myths challenged:
- Nuclear can be flexible (common practice in France).
- Intermittent renewables (wind/solar) can provide adequate power and full range of services (reserve, ancillary etc.).

Although these insights are useful, reality may not follow the global optimum, *e.g.*, due to political and societal reasons.

Mutual agreement on detailed model assumptions difficult to achieve.

Results tend to be region specific and is highly dependant on data inputs – need to ensure the use of realistic data inputs.

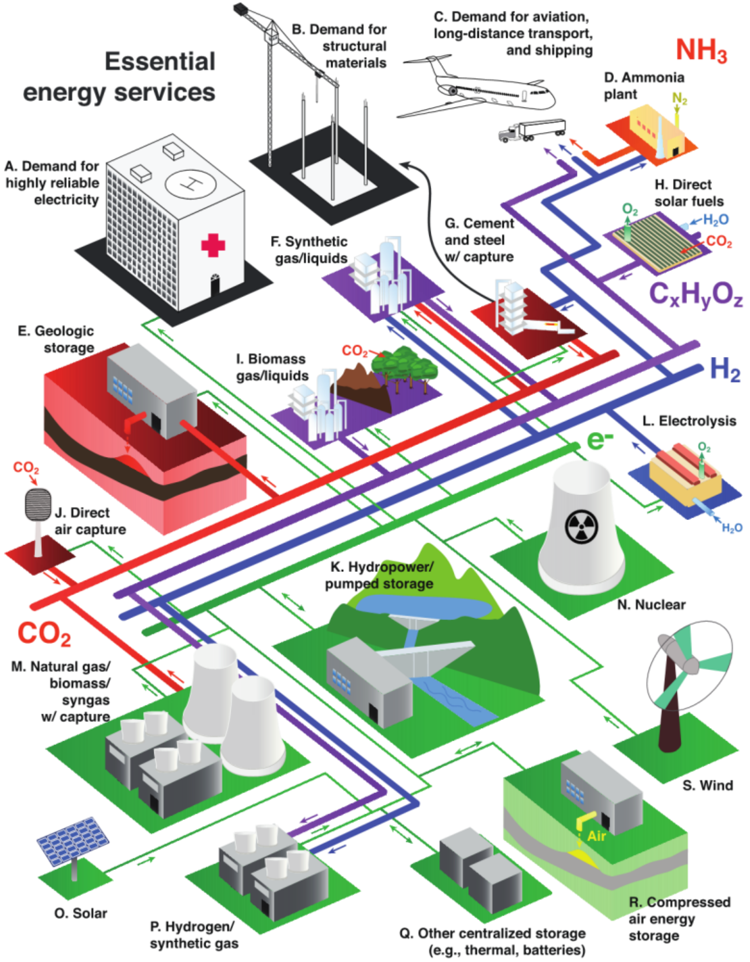

Fig: Davis, S. J., et al. (2018). Net-zero emissions energy systems. Science, 360 (6396).

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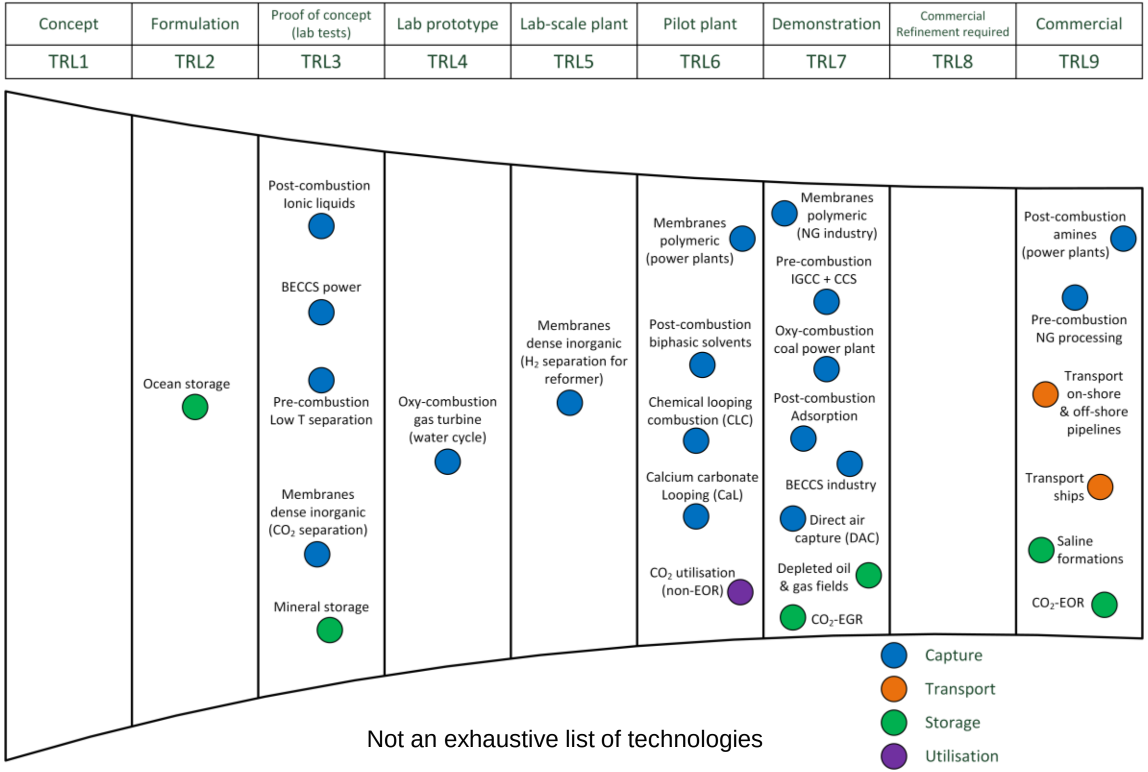
Current status of CCS development



Not an exhaustive list of technologies

There is a suite of CCS technologies for capture, transport and storage of CO_2.

Technologies advance through a series of scale-up steps (lab to commercial scale).

Congestion occurs at TRL 3, TRL 6 & TRL 7.

Development tends to be hindered due to technical challenges or insufficient funding.

Bui, M., et al. (2018). Energy & Environmental Science, 11 (5), 1062-1176.

Current status of CCS development

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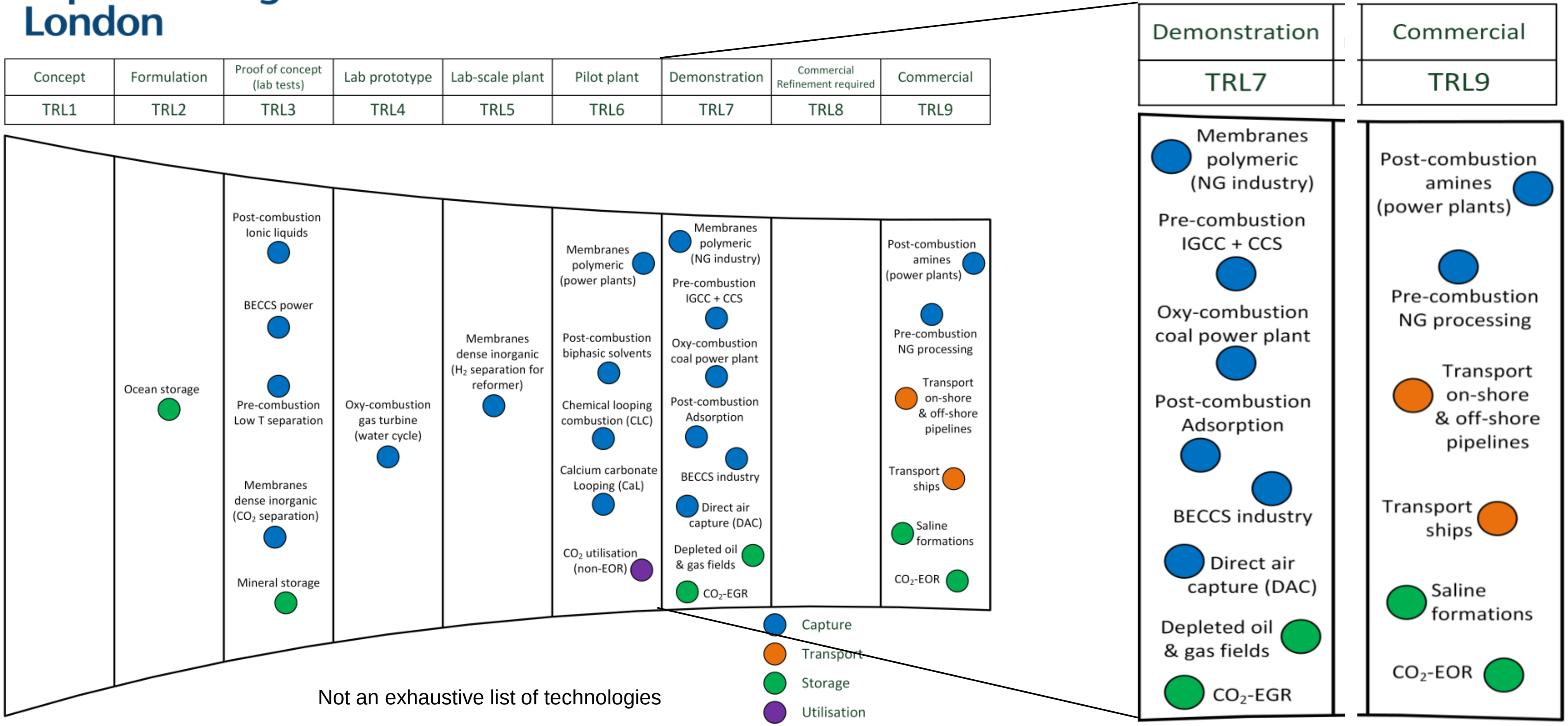

Bui, M., et al. (2018). Energy & Environmental Science, 11 (5), 1062-1176.

Global status of commercial scale CCS

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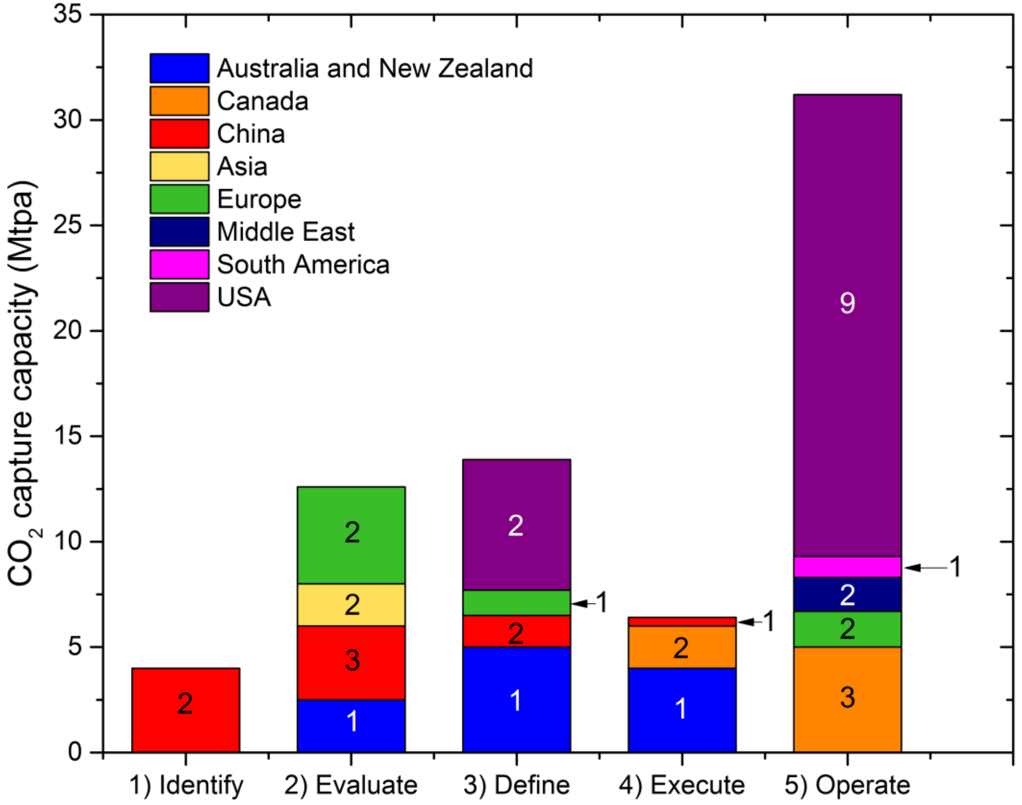
37 commercial-scale projects worldwide:

- 17 are in operation
- 4 under construction

Total capacity of CO_2 captured
= 31.2 Mtpa
(based on currently operating projects)

IPCC scenario for limiting to 2 °C requires a capture rate of 10 Gt_{CO2}/year by 2050.

Current CCS deployment rate will not reach requirements of our mitigation target. Need to accelerate…



Bui et al. (2018). Energy & Environmental Science, 11 (5), 1062-1176.

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Accelerating CCS deployment: key priorities

Foster sharing of data/databanks:

- Accelerates technology development;
- Improves bankability of CCS projects;
- Should publish failed attempts to avoid repetition of mistakes;
- Need transparency in reporting of technology performance data to enable fair comparison of technologies.

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).

External collaboration and partnerships should be promoted.

Balancing of IP protection and knowledge sharing is necessary for cooperative problem solving.

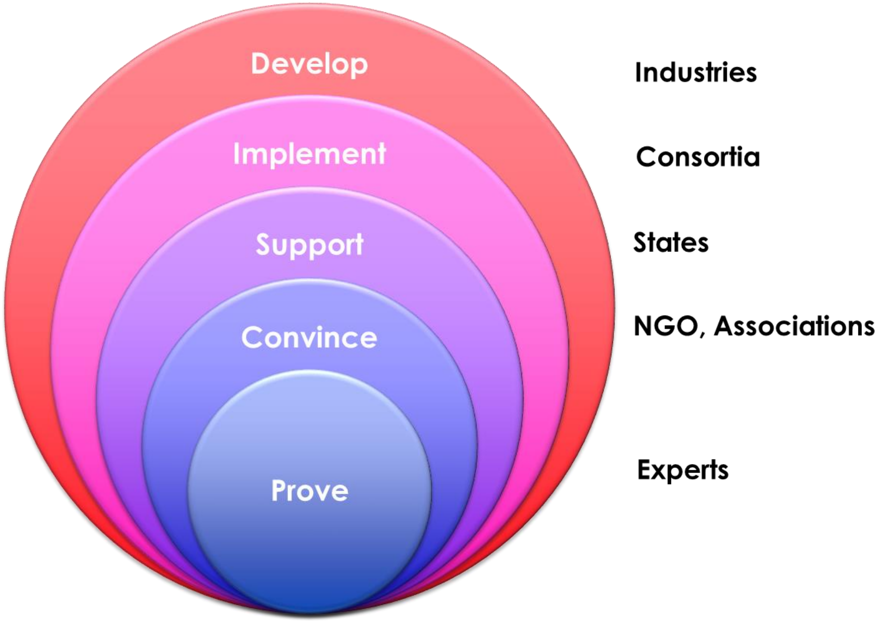

Fig: Fabrice Devaux, Total, 2018

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Accelerating CCS deployment: key priorities

We have to accelerate codes and standards to enable faster technology deployment.

Innovative policy is useful as long as it translates into value for both industry and society.

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.

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.

Northern Lights Project: Full-chain CCS demonstration in Norway

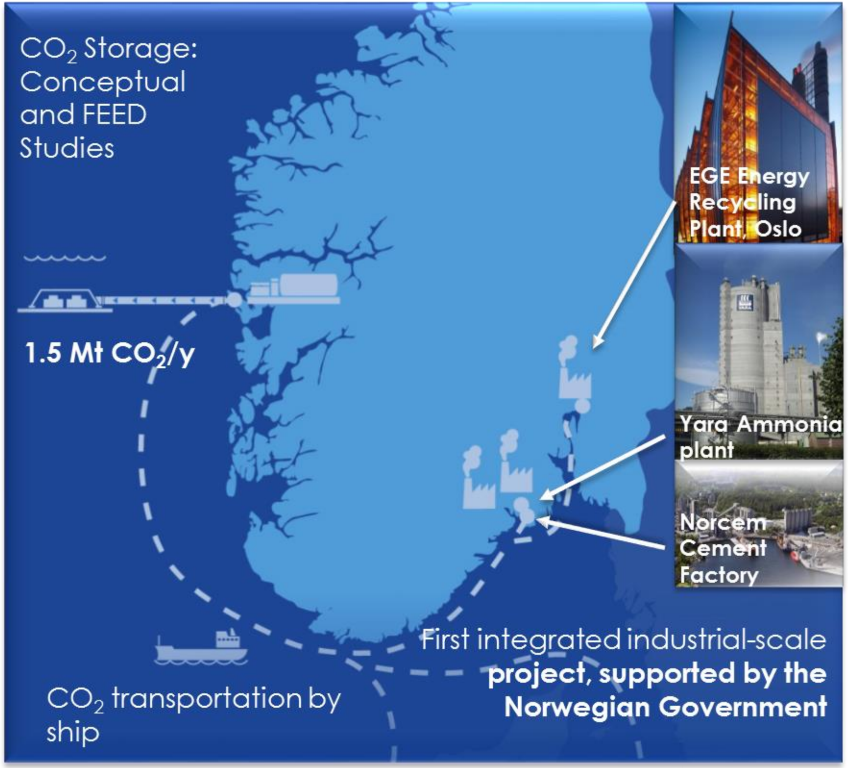

Fig: Courtesy of Fabrice Devaux, Total, 2018

Scaling down CCS technologies

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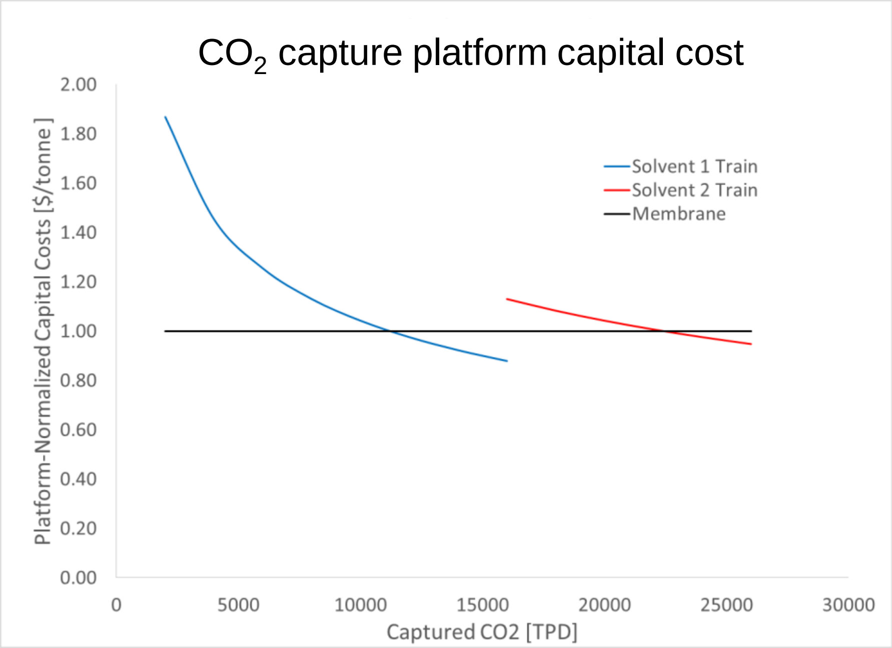
Modularity, mass/additive manufacturing, biotechnology and innovative design can open up new opportunities in scaling down CCS and reducing overall cost.

The scale of CO_2 emission sources is matched with the appropriate capture technology (*e.g.*, membrane → adsorption → absorption).

Strategic technology design has strong potential for small-scale, remote and off-shore applications.

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.

Scale down of CO_2 transport is also possible via ship, train and truck.



Solvent capital cost increases exponentially.
Membranes projected to be more modular → good for scaling

Figure by Michael Matuszewski, National Energy Technology Laboratory, 2018.

Scaling down CCS technologies

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Adsorption is a promising technology for scaling - can scale up or down while still maintaining the same performance level.

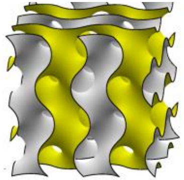
Adsorption technology development needs to focus on the combination of material development and process design/optimisation.

Biology is modular in nature. New opportunities in scaling biotechnology is currently being explored, e.g., printed reactor made of living organisms. Novel bio-reactor systems have the potential to improve cost and efficiency of small-scale CCUS.

The major challenge for this strategy is that storage on small scale is unlikely to happen.

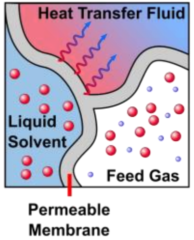
When dealing with small emission sources, there is a need to consolidate capture and couple appropriate transportation scale.

Gyroid structure



Hierarchy structure

Multifunctional Reactors



Live biology in printed reactors

Printed prototypes

Figures: Laurence Livermore National Laboratory, 2018.

Technologies for atmospheric CO_2 removal

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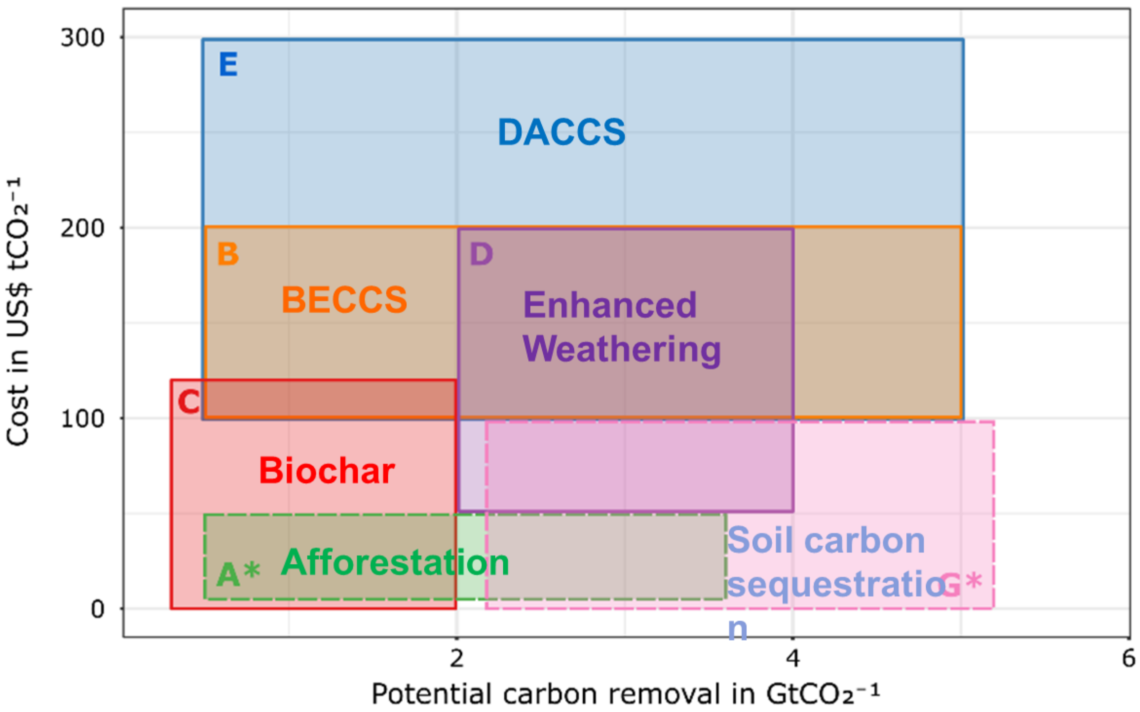
The fair comparison of technologies relies on transparency and availability of performance data.

Regulators are not ready for "load balancing of technologies" (*e.g.*, power from only intermittent renewables, or variable biomass supply). Need to address this for both BECCS & DAC.



Fuss, S., et al. (2018). Environmental Research Letters, 13 (6), 063002.
Nemet, G. F., et al. (2018). Environmental Research Letters, 13 (6), 063003.

Figure: Minx, J. C., et al. (2018). Environmental Research Letters, 13 (6), 063001.

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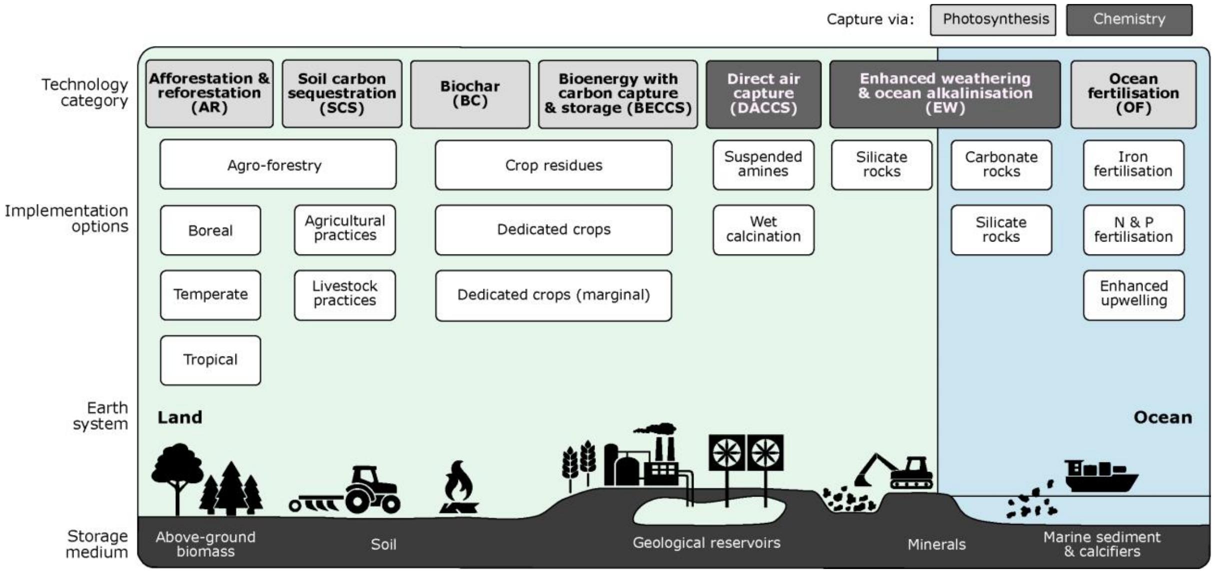
The portfolio of *readily available* technologies that enable negative emissions is very limited, and all solutions should not be regarded as competing but as complementary.



BECCS and DAC rely on accessibility/availability of reliable CO_2 storage. Deploying both in parallel could enable risk sharing, thereby promoting progress of these technologies.

Fuss, S., et al. (2018). Environmental Research Letters, 13 (6), 063002.
Nemet, G. F., et al. (2018). Environmental Research Letters, 13 (6), 063003.

Figure: Minx, J. C., et al. (2018). Environmental Research Letters, 13 (6), 063001.

Direct air capture (DAC)

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Easier to regulate but some misconceptions need to be clarified.

Growing evidence that DAC can work at a relatively low cost (at least in the lower range of cost estimates), but the only viable business model remains DAC to fuels (*e.g.*, Air to Fuels™).

DAC plants cannot simply be put anywhere – need to be near a source of energy.

The type of energy source and the carbon accounting of the whole cycle impacts the cost of net CO_2 removal.

Clarification of terminology is important – carbon removal vs. carbon avoided.

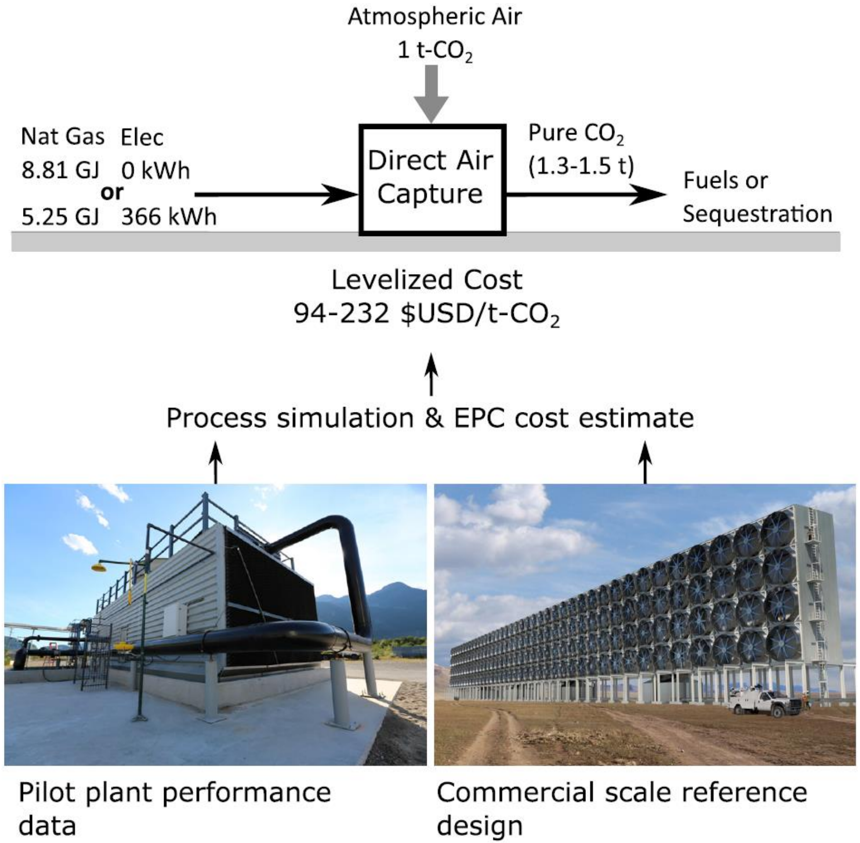

Fig: Keith, D. W., Holmes, G., St. Angelo, D. & Heidel, K. (2018). *Joule,* 2 (8), 1573-1594.

Bioenergy with CCS (BECCS)

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No agreement on whether biomass can actually be grown on marginal land.

Concerns about access to marginal land (e.g., small pockets dispersed across a large area), productivity and supply reliability (e.g., bad season).

Regulation, monitoring and certification systems is needed to help ensure that BECCS is sustainable (*i.e.*, net negative CO_2 removal) and that there is a net energy production.

Delays in regulation development and certification is a bottleneck for technology deployment.

BECCS can provide energy as a co-product, but very inefficiently. Another solution could be to combine DAC + PV, which may replace the need for BECCS altogether.

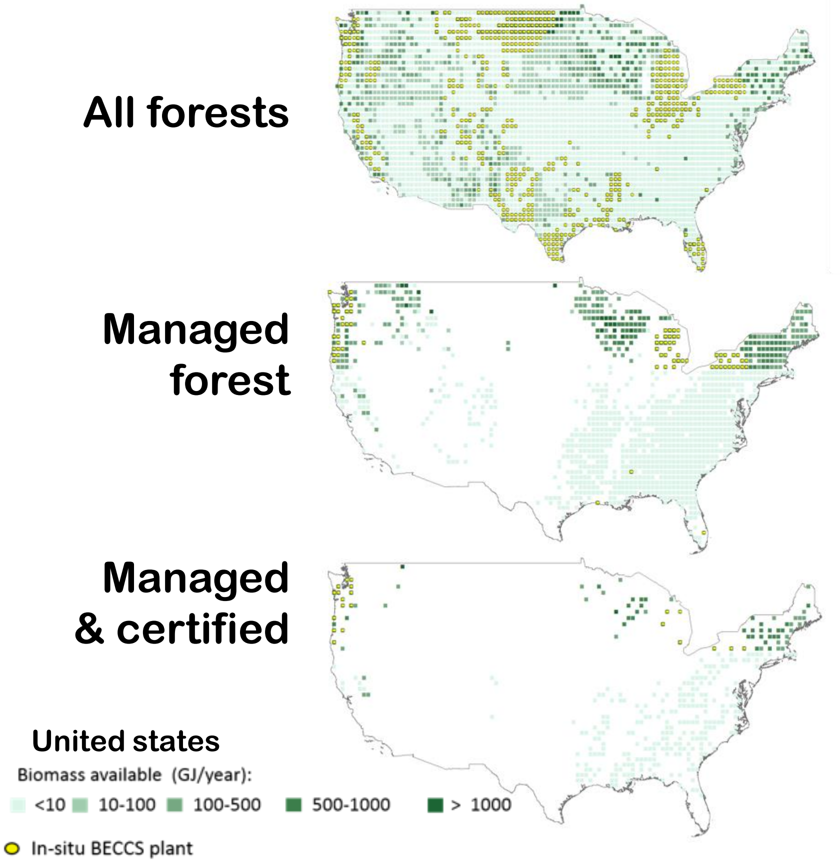

Figure: © Kraxner et al., 2018, IIASA.

CO_2 Conversion & Utilisation (CCU)

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There are a variety of CCU pathways with different

- Impacts, Time scales, Costs.
- Purposes: climate change mitigation, carbon removal, get cheaper chemicals.

Need to capture in the message communicated to policy makers, e.g., ensure comparable carbon removal vs. carbon avoided for different pathways.

Are uncertainty ranges helpful?

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

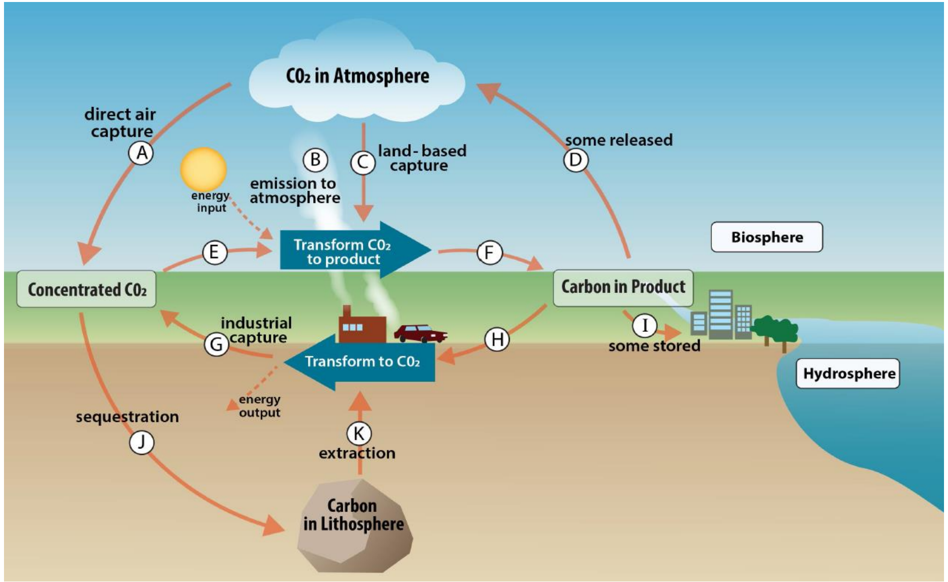

Fig: Cameron Hepburn, Ella Adlen, John Beddington, Emily A Carter, Sabine Fuss, Niall Mac Dowell, Jan Minx, Pete Smith and Charlotte Williams, CO_2 utilisation and removal: promises and challenges - A Review, 2018

CO_2 Conversion & Utilisation (CCU)

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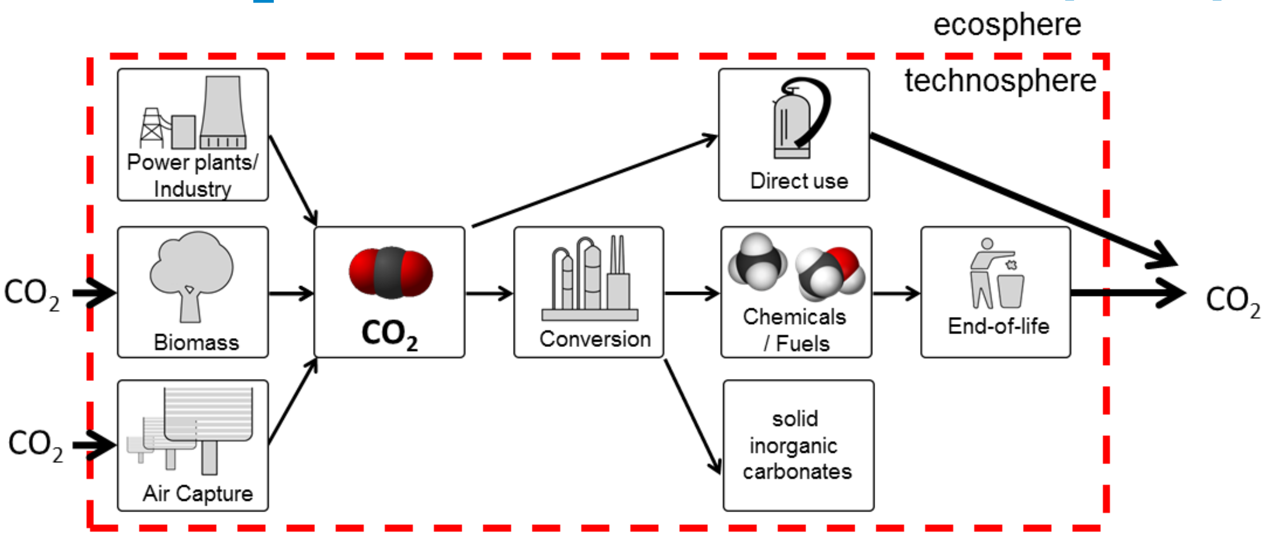
Like any product, CCU needs to be marketed. “Carbon recycling” may appeal to consumers and general public.



There is a tendency to design CCU products in a way that outperforms products from conventional pathways, *e.g.*, with higher material strength.

But over performance should not be taken as benchmark.

Opportunities: niche markets, industrial symbiosis, help develop CCS infrastructure.

We should focus on synergies between CCU & CCS rather than difference. Possible sharing of infrastructure and risk.

CCU may also suffer from regulation issues: how do you make sure you are displacing the right product?

We should not forget about the importance of permanence → CCU, enabler or distraction for CCS?

Fig: Bui, M., et al. (2018). Energy & Environmental Science, 11 (5), 1062-1176.

Advanced sorbents & CCS cost reduction

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For improvements in economic and technical performance → need the development of second and third generation CCS processes.

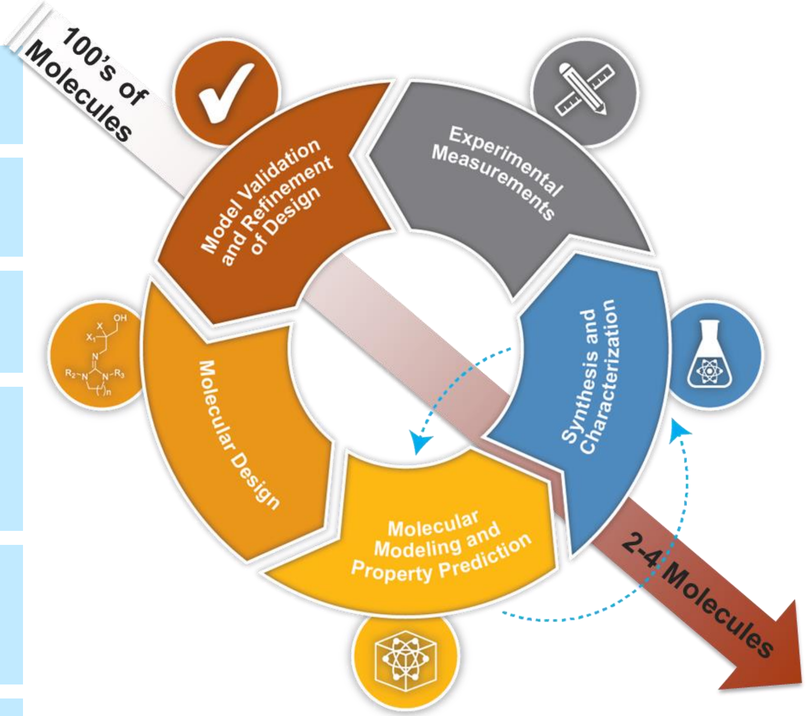
The demonstration of technology, *i.e.*, "learning by doing", is essential communicate technical feasibility, thereby convincing policy makers.

Development should employ multi-scale approach, also considering the coupling effects of multiple process parameters.

Modelling advances can help accelerate the development of new technologies, *e.g.*, high-throughput modelling for material screening and reduced order modelling to decrease CPU time.

Development of new technologies can have co-benefits (spill-over benefit) to multiple sectors, *e.g.*, membrane designed for desalination and now finding new applications in gas separation.

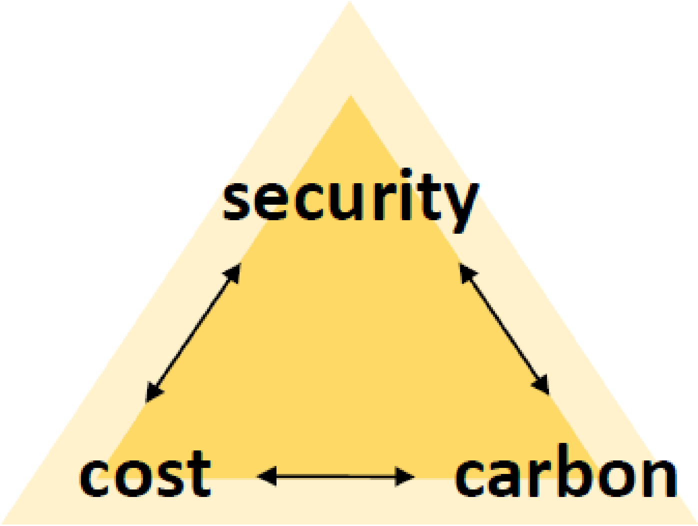
Design based on fundamental understanding rather than using a "shot-gun"/Edisonian approach is shown to be highly valuable, saving a significant amount of time, money and resources.



Employing integrated multi-disciplinary teams can further accelerate technology development.

Fig: David Heldebrant, Pacific Northwest National Laboratory, 2018

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 event, e.g., 1970s Khmer Rouge in Cambodia, Oil crises, 1990s Burst of Dot Com Bubble, 2008/09 GFC.

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".

Growing importance of cost within the energy trilemma. Why CCS?

1) Governments waiting for technical innovation to decrease costs.
2) 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 → uncertainty deters project investment.

If there is no confidence in the market, will investments really happen? How do we break the circle?

Fig: Clara Heuberger, Imperial College London, 2018

Enabling policy frameworks

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The development of supportive policies can drive business.

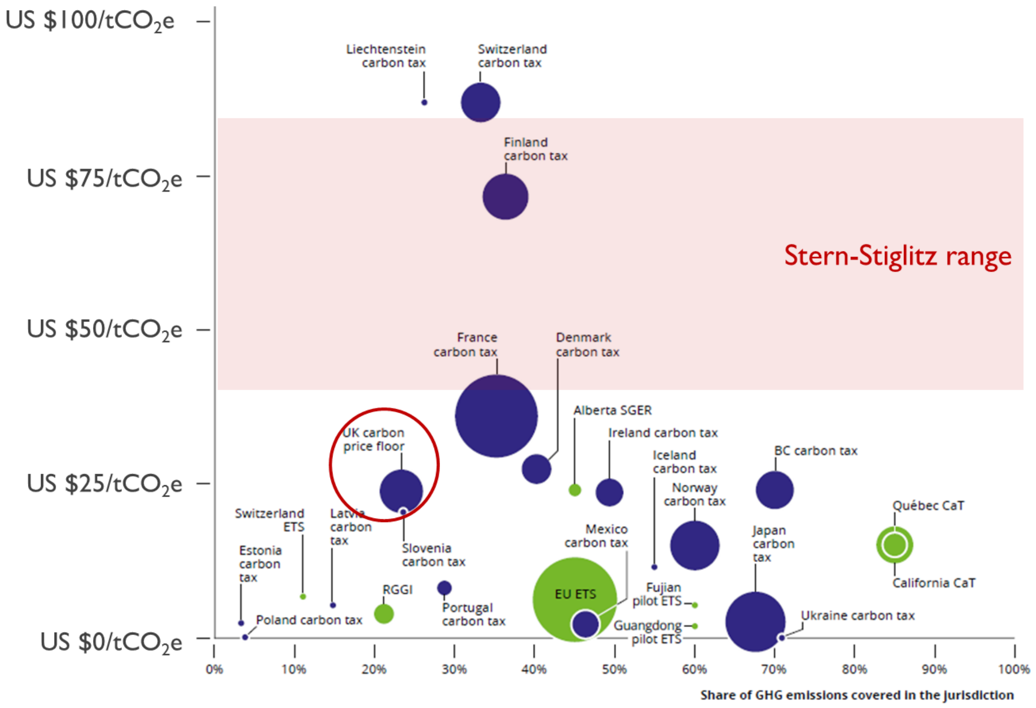
There is a need for pragmatic long-term policy based on detailed LCA and economic analysis which allow the free-market to work.

Busting misconceptions: renewables are often used as a proxy for decarbonisation so CCS can never compete.

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.



“Too expensive” is subject to political priority.

Source: World Bank (2017) State and Trends of Carbon Pricing

Value of CCS in today's and tomorrow's energy system

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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),
- Transparent about whether non-standardised approach was employed for analysis (e.g., heat requirements).

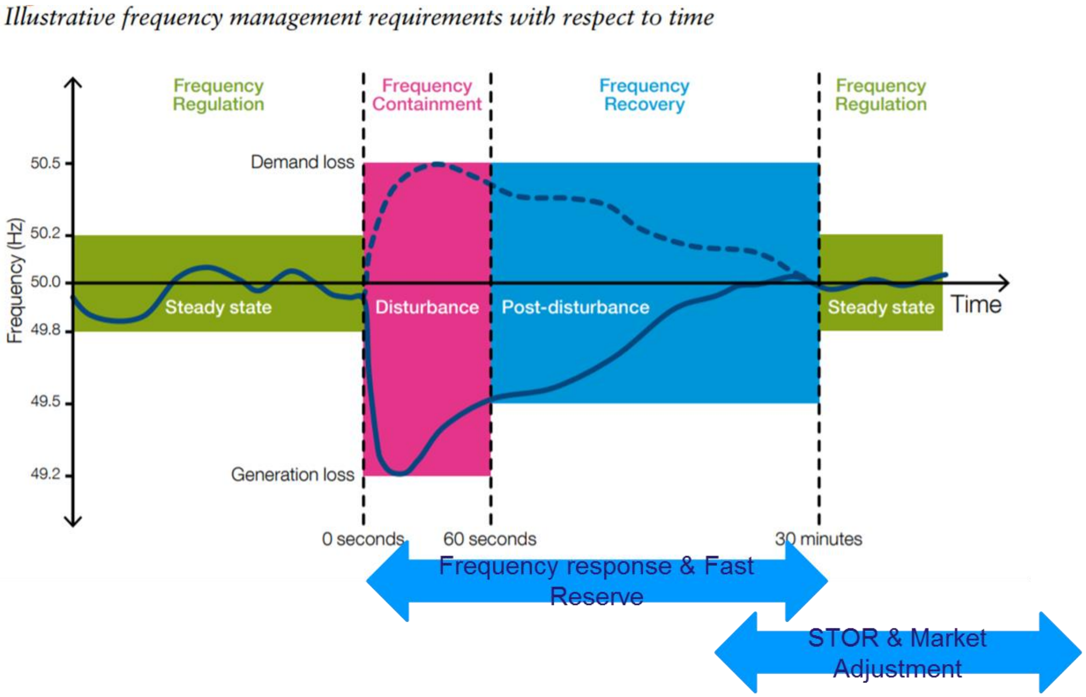

Fig: NGC System Operability Framework, 2016

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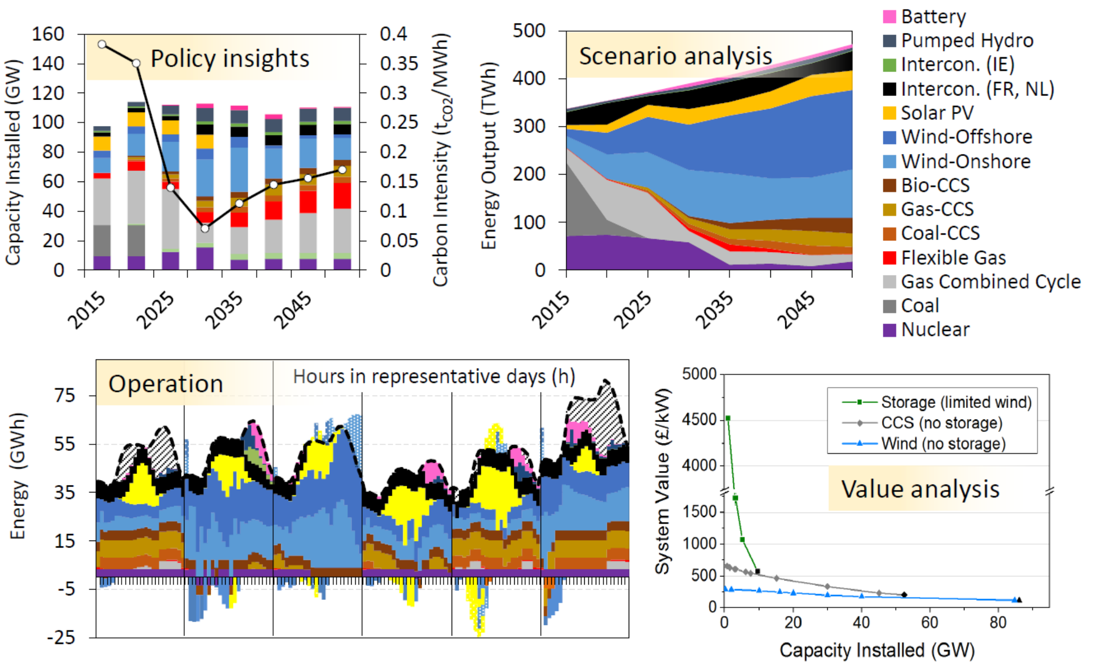
Value of CCS in today's and tomorrow's energy system

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."

Fig: Clara Heuberger, Imperial College London, 2018

Value of CCS in today's and tomorrow's energy system

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Policy and decision makers are looking for tangible benefits rather than technical detail, e.g., GDP and employment benefits.

The offer of energy services (e.g., firm capacity, system resilience, managing contingency events) do not convince/compel policy makers.

However, monetising these services could help support CCS.

Need to demonstrate the societal value of CCS/CCUS.

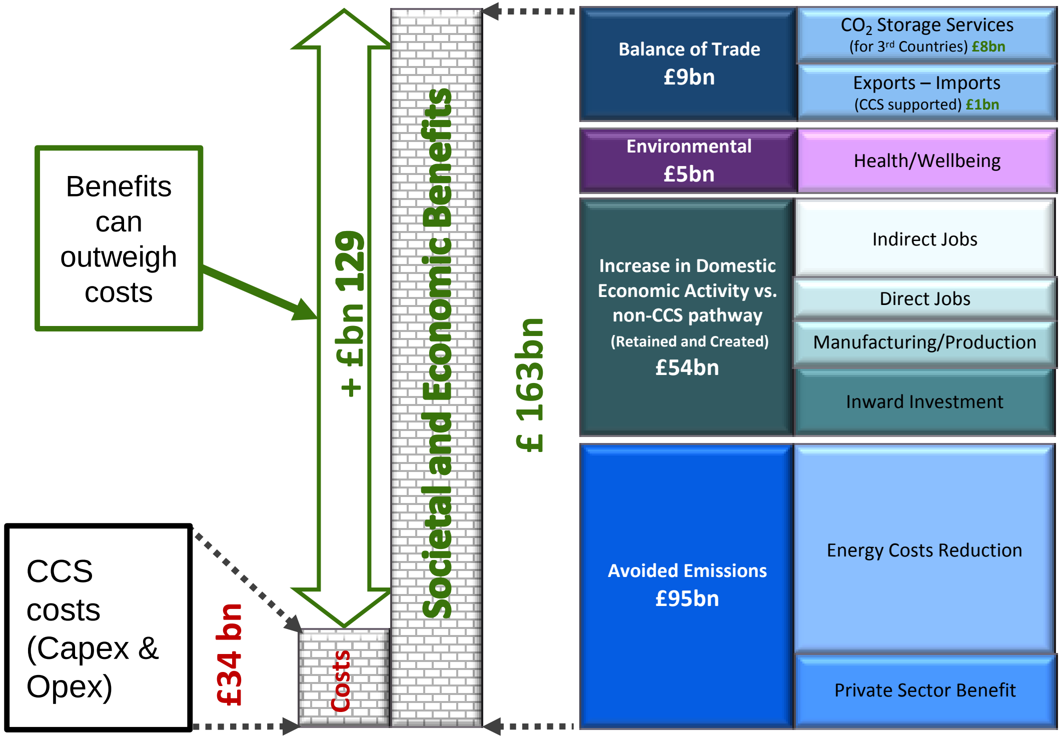

Fig: Leigh Hackett, Industria Mundum, 2018

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CleanFaB

Clean Fossil and Bioenergy Research Group (CleanFaB)

Report available online (soon):

https://www.imperial.ac.uk/a-z-research/clean-fossil-and-bioenergy/ccs-forum/

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