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‘Capture readiness’ – lock-in problems for CCS governance

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Abstract

The term ‘capture ready’ has been used by the UK Government when granting licences for power plants. However, the term has not as yet been given an agreed definition.

This paper draws on literature on lock-in of large socio-technical systems and on regulation of technology undergoing development. Further, the paper compares some of the versions of the capture readiness concept proposed to date. It also explores capture readiness beyond the minimum requirement of space on the site for capture operations, including integration of capture and power plant, downstream operations, overall system integration and regulation of future retrofitting.

Keywords: Carbon capture and storage; sequestration; capture ready; regulation; lock-in

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1. Introduction and background

Steep reduction of CO_2 emissions is a repeatedly stated core goal of the inter-linked UK energy and climate change policies. Current targets include 20% reduction by 2010 and 80% reduction by 2050. However, only limited progress has been made to meet those targets, and forecasts indicate that strong additional policies are still needed [1,2]. At the same time, there is a renewed interest from commercial companies in investing in new coal-fuelled plants. This raises the policy issue of whether to license new unabated fossil – especially coal – fuelled plants before CCS has been demonstrated (as an integrated system at large scale). There is a risk that new fossil plants without abatement systems implemented from the outset will never be abated, and that the UK is then stranded with these new emission sources for a long time.

‘Capture ready’ (CR) power plants have been proposed as a technical solution for this conundrum. The basic notion is that new plants are built in such a way that capture equipment can be added at a later date. This idea has now been incorporated in new plans for fossil build in the UK. The idea of CR power plants has also been taken up

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in policy making. A check of recent license consents for CCGT plants (see table 1), shows that capture readiness is now used – but not consistently – as a regulatory requirement.

Table 1 Recent CCGT licenses [3]

Date	Name/Place	Investment type	Company	CR requirement?
19/12/07	Chequers Lane/ Dagenham	Extension	Barking Power	Yes
16/10/07	Drakelow	Construction	E.ON	Yes
03/10/07	West Burton	Construction and operation	EDF	Yes
13/07/07	Carrington, Trafford	Construction	Bridestones Development	No
21/08/06	Uskmouth/ Newport	Construction	Severn Power	Yes

Moreover, the criterion is formulated in general terms: "The layout of the Development shall be such as to permit the installation of such plant as may reasonably be required to achieve the prevention of the discharge of carbon and its compounds into the atmosphere" [4]. Government has recognized the need to specify further what a CR criterion should mean. A public consultation recently closed and Government aims to formulate its response within three months [5]. We can conclude that there is no well-developed and accepted standard for capture ready regulation.

The jury is thus still out on what an adequate CR regulation should look like, and indeed whether it is a feasible and desirable approach to regulate power plants in a way that would allow for immediate new build. Alternatives that have been proposed include emission limits and moratoria on new build of fossil plants. This paper aims to analyse what a stringent capture readiness requirement might look like, and identify some of the important considerations to take into account when designing such a requirement. The paper will draw on research about lock-in phenomena and the regulation of large technical systems from Science and Technology Studies research. Within this framework, the paper will review proposed definitions of CR, as well as synthesise CCS-related literature to explore whether and how it might be possible to design a more stringent definition. A fuller version of this research can be found in Markusson and Haszeldine [6].

2. Literature on lock-in and regulation of large technical systems

Capture readiness has been proposed as a solution to a lock-in problem, as a way of avoiding a situation where we are stranded with even more unabated fossil plants, and even more locked into a future development path with large CO_2 emissions from fossil fuelled energy production. The basic notion of 'lock-in' is about self-reinforcing decisions and actions. If we invest in a technology today, we gain more experience from using this technology and invest in it, and are therefore even more likely to do so again tomorrow. Lock-in becomes a problem if we decide to switch to a new development path based on a different technology, and discover that it is difficult to do so.

Lock-in has been observed in the study of many technologies, with an often cited example of the QWERTY keyboard [7], and especially in studies of large technological systems, like electricity production systems [8]. In line with this phenomenon of technology lock-in, Unruh [9], has coined the term carbon lock-in, referring to societies that are technologically locked into dependence on fossil fuels.

Lock-in is caused by positive feedbacks among different elements of a socio-technical system, as well as resistance to the introduction of new technology from institutional interests. As technical systems develop, they come to consist of a set of inter-related elements that are aligned with each other and mutually supportive. This is of course true for, say, the combination of rail, train engines and railway stations. But socio-technical systems also incorporate other elements, like the experience of design engineers, safety regulations, business models, and so on. The more developed and mature a socio-technical system is, the better aligned are the different elements, and the more stable is the system. This also means that to introduce a new, competing technology, a whole system has to be re-aligned. Old elements have to be replaced, new ways of doing things introduced and old ones phased out. Moreover, adding a new element may add new tensions that propagate through the system. Technological systems are never completely resistant to change [9], but they can be entrenched and difficult to shift. New technologies, promising potentially better performance, may as a consequence remain locked-out and not get the chance of proving their worth.

Socio-technical systems thus develop along increasingly stable development paths, as more and more elements become well-aligned. It is worth pointing out, however, that this does not mean that the end-point is known beforehand. Technologies evolve over time through the emergent interactions between different elements. Early promises about performance and functionality are rarely good predictors of the properties of mature technologies. Future developments are always, and especially at early stages, uncertain.

The combination of such uncertainty with lock-in has proven to create difficult dilemmas for policy-makers and regulators [11]. One the one hand, when a technology is young and comparatively malleable its final properties and impacts cannot be known with any precision, and it is hard to know exactly what to regulate against or to promote. On the other hand, when the socio-technical system has stabilised and the properties are known, the technology may be so entrenched that it is difficult to modify or abandon it.

3. Regulating fossil plants towards CCS abatement

The concept of lock-in helps us understand the current energy system with its strong dependence on fossil fuels: carbon lock-in. But the concept may also help us understand energy systems with CCS and energy systems with CR power plants. CCS has been proposed as a technical fix for carbon lock-in. The idea is to add a new component to existing technology. CCS is in this perspective characterised as an abatement technology similar to for example Flue Gas Desulphurisation technology. This evokes images of an add-on solution, which promises to leave existing elements of the system unchanged. This solution accepts the carbon lock-in situation, but the promise is to remediate it using an end-of-pipe technology that is said not to disrupt the status quo. Waiting for CCS to materialise, capture readiness has been proposed as a way to deal with lock-in risks. By designing power plants so as to be ready for envisioned future capture operations, we are said to avoid a future with even more un-abatable power plants.

But, whereas there are mature coal and gas power plant technologies and the component technologies of CCS have been used for other applications, the new technological system – CCS-abated fossil plants – is still in its early stages. This technological system will develop and change over time. Necessary changes include, for example, scale-up of capture technology and integration of the full chain of power plant, capture, transport and storage. The technology will need to be demonstrated at full scale before wide deployment. This introduces technological uncertainty in any predictions of the future of CCS-abated fossil plants. Experience also shows that adding new elements to an existing system may introduce tensions that cause further change. The issue of integrating CCS with power plants – including whether CCS is easily added-on or not – will be discussed in more detail below.

The technological uncertainty further complicates any effort of trying to design power plants today, so that they will be suitable for the adding-on of capture technology tomorrow. This uncertainty is difficult to judge. Policy makers depend on technology specialists to assess these issues, and arguably technology specialists are best placed to predict the technology's development. Predicting technology futures is, however, notoriously difficult and even the best of experts get this wrong (the more so, the further into the future, and the more radical the technological departures). There will, therefore, always be a residual uncertainty.

We will below give our view of the challenges involved in the CR approach to the regulation of power plants, including our assessment of how well these challenges are understood. To avoid lock-in, CR designs should make it possible that the power plants can be abated tomorrow. The question is whether this can be guaranteed. And finally, to avoid exacerbating carbon lock-in, it is not enough to know that it will be possible tomorrow to abate CO_2 emissions from power plants built today. The real goal is that CCS abatement systems will be implemented (and continually used) shortly after the technology is proven. What matters in the end is the outcome in terms of CO_2 abatement, not the good intentions. Can the promise of abatable and abated plants tomorrow be guaranteed?

Having briefly reviewed the literature on lock-in and the regulation of technology, and applied this to CCS and CR, we can re-state the research questions for this paper. Firstly, given the uncertainties of any technology development pathway, will CR now guarantee that abatement will be possible later? Secondly, given a scenario where plants are built CR now, will that guarantee later CCS abatement?

This paper will discuss what CR regulation might look like, in two ways. Firstly, the paper will review and compare some of the definitions proposed in the literature to date. Secondly, the paper will explore what a robust CR regulation could look like, by synthesizing CCS-related literature. Throughout, the paper will draw on the perspective on lock-in and regulation of technology under development, from Science and Technology Studies, as set out above. The paper will focus on the UK situation.

4. Proposed CR definitions

We will here give a few examples of proposed definitions of CR. The first example focuses on what is a common, minimum standard of CR: enough space on the site to accommodate capture operations. The second example extends this to include also transport and storage considerations. It is also more explicit with regard to the feasibility assessments that it proposes should be made with regard to capture technology. It thus attempts to specify a procedural requirement, aiming towards a standard of knowledge and information provision, rather than a physical requirement. The third example provides an example of a definition that explicitly mentions economic criteria, in addition to physical/artefactual ones, and procedural/knowledge criteria. The fourth example adds a regulatory dimension (and would make CR regulation explicitly dependent on other regulation). This also includes the provision of information to regulators. Furthermore, this definition sets out limits to the responsibility of operators, specifying that they are only responsible for known factors, and things that are under their own control.

1. “The layout of the Development shall be such as to permit the installation of such plant as may reasonably be required to achieve the prevention of the discharge of carbon and its compounds into the atmosphere.” [4]

2. “...have suitable space on the installation site for the equipment necessary to capture and compress CO_2 and the availability of suitable storage sites and suitable transport facilities, and the technical feasibility of retrofitting for CO_2 capture have been assessed”. [12]

3. “A plant can be considered ‘capture ready’ if, at some point in the future it can be retrofitted for carbon capture and sequestration and still be economical to operate”. [13]

4. “A CO_2 capture ready plant is a plant which can include CO_2 capture when the necessary regulatory or economic drivers are in place. The aim of building plants that are capture ready is to reduce the risk of stranded assets and 'carbon lock-in'.

Developers of capture ready plants should take responsibility for ensuring that all known factors in their control that would prevent installation and operation of CO_2 capture have been identified and eliminated.

This might include:
- A study of options for CO_2 capture retrofit and potential pre-investments
- Inclusion of sufficient space and access for additional facilities that would be required
- Identification of reasonable route(s) to storage of CO_2

Competent authorities involved in permitting power plants should be provided with sufficient information to be able to judge whether the developer has met these criteria.” [14]

These few examples clearly show a variation in definitions, and specifically, in what types of criteria are included: physical, procedural and contextual (economic and regulatory drivers). The examples given here are all summary or headline definitions trying to capture the essence of CR in a few sentences. The IEA GHG report, for example, also provides extensive further specification of what such a definition would mean.

It can be helpful to turn the question around and ask what a not-capture-ready plant would be. IChemE [15] argue that since we know that there are solvents that can capture the CO_2 from flue gases, it is in principle possible to fit capture onto any power plant already, the only snag being the cost. That is, with a narrowly technical definition, all fossil plants are CR. But this fails to reflect that power plants can be more or less easy and costly to add capture technology to. Including economic criteria can thus make CR regulation more robust, if they are stringent.

This section has briefly discussed the variation in proposed CR definitions and discussed some of the underlying principles that have been identified in the literature. The next section will discuss in more detail how the concept needs to be specified and extended from a minimum definition of site layout, to include capture-power plant integration, transport and storage, system integration, and future retrofitting.

5. Exploring the dimensions of CR further

5.1. Integrating power generation and capture

The IEA GHG report on CR [14] represents the most comprehensive attempt at specifying CR plant designs to date from an engineering perspective. Apart from recommending setting space on the site aside for capture, it sets out design changes (investments) to be made to make power plants CR. These changes include (depending on different configurations of power generation technology and capture technology), for example, adding or upgrading FGD equipment, modified steam turbine designs and addition of CO_2 separation plant.

There are different levels of plant modifications that could be done to make a plant CR [13, 14]. The modifications can be more or less radical, and more or less expensive. The range of options stretches from relatively easily accommodated changes like providing space for the pipes that would be necessary to re-route flue gases, to core technology modifications like converting gas turbines to combustion of hydrogen combustion (for IGCC plants). This seems to challenge the idea of easily adding-on capture to power plants. Depending on the power generation technology, and the specific designs, integrating a capture function can have extensive impacts on plant design. The add-on ideal is most closely approximated for post-combustion capture, but even here, given the size of the capture investment, optimization of power plant and capture plant together is will involve modifications to both.

The IEA GHG report makes a distinction between essential and optimal investments, but without being very clear as to what criteria are used to classify investments as essential or optimal. This is a problem, since that seems to be what a regulatory CR requirement would have to do. From a regulatory point of view, this is also problematic, since a more arduous specification of CR is not necessarily more effective. Capture (and power plant) technology will develop, and CR modifications thus run the risk of becoming obsolete and even counter-productive. This risk also becomes more costly, the more expensive the CR modifications are. There is thus a risk to exacerbate lock-in risks by over-modifications, by imposing too arduous CR requirements. There is thus a need to specify an optimum level of modification, that strikes a balance between technological, climate and financial risks. But it is not clear that this balance has been sufficiently explored yet and, in particular, that the technological uncertainty involved has been treated in a rigorous enough manner. Indeed, there may be genuine uncertainty involved, in which case CR is by necessity a gamble and leaves us with a residual lock-in risk.

It is also necessary for utilities to have the expertise, skills and routines for investing in and operating capture technology. One could argue that companies to be ready for capture should develop such organisational capabilities. A possible way to regulate this would be to mandate slipstream-scale capture operations.

Further considerations with regard to power plants include impacts on availability and flexibility of the plant [16], on environmental impact [15], and on health and safety [14].

5.2. Downstream operations: transport and storage

Preparing for future CCS implies that it should be possible to not just capture but also transport and store the CO_2. A common way to phrase this is: "identifying a route to storage", but this phrase covers a range of more or less thorny issues.

The technology envisaged for CO_2 transport: pipelines on and off shore, alternatively by ships, is well known for other liquids or hydrocarbons, but not yet applied to CO_2. There are also unresolved issues regarding its use. Firstly, securing control of the land needed for on-shore pipelines may not be easy or even possible for all desirable locations [5]. Critical areas may be close to the plant where there are likely to be few routing options, and the beachhead where planning issues are difficult in the UK. Secondly, there are as yet no environmental or health and safety regulations in place, that could guide authorities to permit the construction of pipelines, on or off shore. This also means that choosing a feasible route is uncertain. A further complicating issue is that the construction of new infrastructure, like pipelines, may open up debates on public acceptance. As part of necessary studies planning for transport routes, public consultation should be done to reveal the existence of any such barriers.

Choosing a suitable storage site also requires a regulatory framework, and exploration of public attitudes. The regulatory framework also has to include financial arrangements for governing long-term risks of leakage, in the form of for example an insurance. A workable balance of responsibility between operator and state needs to be found, which would also vary over time reflecting the limited ability of companies to manage longer-term risks. The properties of depleted gas and oil fields are especially well known, and may therefore be targeted first for storage. However these are generally deeper and thus more difficult to reach, and have more legacy boreholes forming potential leakage points. Large uncertainties remain with regard to storage in aquifers, both with regard to capacities and seals. Even so, generic predictive appraisal simulations can already be done routinely as part of planning for storage when preparing for CR investments.

5.3. Integration of the whole system

The integration of the whole new socio-technical system is a challenge in itself, and is necessary for the implementation of CCS. All the elements along the chain from power plant to rock reservoir have to be made to work together. This also includes both technical elements, and the actors, institutions, etc. needed for the system to function. System integration also needs to be prepared as part of planning for CR investments.

System integration involves relatively technical issues like managing impurities and water in the gas that could cause problems for pipeline corrosion, and the sealing of injection wells. There are also matching problems between sources and sinks of CO_2 in terms of the rate of supply of the gas, and the timing of supply and storage site operations (including timing with previous oil and gas extraction operations if off-shore equipment is to be reused). Moreover, there are also coordination problems of a less technical nature. A core question is whether transport infrastructures will be proprietary, or whether there will be shared structures, which would likely require Government intervention and support. A strategy is needed setting out expected future CO_2 volumes, to enable planning of transport investment. The lack of a policy for this increases the uncertainty in preparing for CCS.

Furthermore, there is the fundamental issue of who will pay for the CO_2 not emitted, and how any profits will be shared among the actors involved. The uncertainty of economic drivers, and the lack of clear business models for the coordination of the actors along the supply chain, further increases the uncertainties involved. There is a need for political leadership on this issue. This also relates to the difficulty of assessing the cost of CCS. Demonstration of the technology is needed also for price discovery.

Finally, integrating CCS with fossil power plants will not leave the existing system unchanged. It will have an impact on power plant technology and operations. It will have an impact on business models in the sector, and change the relationship between the power and the oil and gas industries. Integrating power plants into another infrastructure of CO_2 transport and storage will pose new coordination challenges. It is not clear from the outset that this will be an easy add-on operation, but may require more fundamental change to the socio-technical system.

5.4. Regulating the future addition of CCS abatement

Capture readiness needs to be seen as an investment in two stages. A CR power plant today, and a full CCS investment in the future, including a retrofit of capture technology onto the power plant. Both stages of the overall investment would be driven by policy (regulation or policy-generated emissions markets). And the stages should not be seen as separate things. Again, ultimately, the intention behind a CR investment does not matter; what matters is the outcome in terms of CCS-abated power plants as rapidly as securely possible.

Future policy-driven retrofitting matters technically today for CR investments. For example, the capture rate that will be required after retrofitting, matters for what pre-investments are made as part of a CR power plant investment. This means that current CR regulation needs to indicate future performance standards. Similarly, the expected time lag between CR investment and CCS investment matters for CR designs [14]. A timeline for future emissions requirements is also needed.

It is difficult for anyone to guarantee what policy makers will do tomorrow, which introduces political uncertainty into the calculation. Efforts should be made when designing a CR policy to make as binding as possible commitments for future policy. Taken together, technical, financial and policy uncertainties mean that there is no certainty that CR investments today, will lead to CCS investments tomorrow. CR regulation and CR investments do, however, seem to make CCS investments more feasible as well as making it easier for policy makers to introduce CCS requirements later.

6. Discussion and conclusions

Summing up, the CR concept needs to be extended from “some space around the site”, to include core power generation technology, downstream transport and storage, system integration, and future retrofitting requirements. Doing so, however, makes CR regulation a lot more complex, and reveals several uncertainties, some of which may be very difficult to manage.

Firstly, we have seen that adding capture to a power plant may not be a simple add-on operation. This depends on the choice of power generation technology and capture technology, and may contribute to which technology is chosen. But we could also see the adding on of capture (and certainly full CCS) as potentially introducing a tension in the fossil-fuelled power generation system, leading to more radical change. Secondly, the new socio-technical system of CCS-abated power generation is in its early days, and there are still uncertainties as to how it will emerge. This introduces technological uncertainty in any effort of trying to design power plants now, so that they will be suitable tomorrow for the adding on of capture technology. It also introduces uncertainty with respect to how the vision, design and preparation for the overall system. This includes downstream operations, encompassing both narrowly speaking technological elements and organisational, financial and political elements. Our assessment is that the most difficult and least well understood actions are for utilities to prepare for storage and system integration, and for policy-makers to implement a stringent and timely retrofit regulation, to transfer to full CCS operation.

We have seen that drawing on Science and Technology Studies, and especially studies of lock-in and regulation of large technical systems undergoing development, has helped us understand the issues surrounding CR. There are clearly uncertainties inherent in a CR approach to the regulation of power plant CO_2 emissions. CR regulation may well help towards ensuring that power plants are fit for CCS retrofitting in the future, but uncertainties remain and this can not be guaranteed. Moreover, the promise of CR is not just that this will be possible, but that abatement will happen. Even if the technology works out, there are huge financial and policy uncertainties. Having technology in place, as well as licenses that stipulate capture readiness, may help when making future policies, but CR is clearly a gamble today.

As mentioned above, there are alternative policies for the regulation of CO_2 emissions from power plants, including emission performance standards, moratoria the building of new unabated plants, mandating CCS, etc. CR regulation is not necessarily the optimal approach to the regulation of CO_2 emissions from fossil plants. It may also be possible to combine CR regulation with some of the other approaches. This is an area for further study [6].

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