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Jonas Pigeon

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Underground as a Controversial Mitigation Of Climate Change Option: Example Of Carbon Capture And Storage (CCS) implementation

Presenter: Jonas PIGEON, jonas.pigeon@yahoo.com, IDEES, Université du Havre, France, Congress of the Society for Social Studies of Science; 4th -7th September 2019.

The idea of capturing CO₂ from industry to solve global warming issue was first detail in a Marchetti paper in 1977 (Marchetti 1977). In his paper Marchetti highlight the critical impact of CO₂ emissions on global warming. According to him, managing these emissions is a needed action to maintain economical model. According to Marchetti store CO₂ on ocean ground to dissolve it and consequently reduce it impact on global warming is the most relevant option. He also envisioned geological storage but stressed the limited capacity of this option. However, after some controversial experimentation of oceanic storage of CO₂ (De Figueirdo 2003) the application of the technology evolved and only geological storage was considered as a relevant option.

In this paper we will describe various CCS actor-networks in focusing on the role assigned to the underground. Our research material is composed of scientific paper, newspaper articles, but also case studies in various European countries that implement CCS. In order to understand the role assigned to underground reservoirs, these materials were analysed according to narratives analysis principles applied by actor network scientist (Deuten and Rip 2000). This analysis will allows us to show issues related to CO₂ underground storage and consequently draw the actor network of Carbon Capture an storage technology (CCS). Finally, we will be able to clarify the role of underground and then of CCS in climate change mitigation

1. Carbon Capture and Storage: a sociotechnical description

The concept of Carbon Capture and Storage first appears in a Marchetti paper in 1977 (Marchetti 1977) he shares the view that increase of CO₂ emissions will lead to global warming and the need to act against this phenomenon and its economic consequences (p.60). In this paper he displays a vision of the global warming issue with a geophysicist view: as problem of global carbon cycle. According to him the main issue related to the carbon cycle is the loss of concentration during the combustion process. As he notes:

“We start from a very concentrated form of carbon; We go to a dilution of two or three order in magnitude in the combustion gases; We dilute it again perhaps by three or four orders of magnitude by dispersing these gases into the atmosphere; We have to wait this very dilute stuff to diffuse through the surface of the sea into the thin mixed upper layer of the ocean”. (p. 61).

After the problem description Marchetti describes the solution to solve the CO₂ emissions responsible of global warming. He formulated it as follow:

“The obvious line of attack would be to avoid the whole chain of dillutions interfaces and to put CO₂ directly into the deep ocean. This may seem more easily said than done but I will show later the basis for a technologically and economically feasible operation does exist”. (p.61)

According to Marchetti the oceanic mass is large enough to keep its equilibrium after dissolving atmospheric CO₂. Therefore to manage this plan CO₂ have to be collected, transported and disposed into deep ocean or exhausted gas field. The following pages of its paper are dedicated to describe the system. Marchetti thinks that apply CO₂ capture on power plant or in energy production plants are the most relevant solution to collect easily a large amount of CO₂ (p.62 - 63). According to him compressed CO₂ until it become liquid is and transport it by pipeline is in 1977 the best way to carry it to disposal reservoirs or deep oceans. (p.64).

Finally regarding the CO₂ disposal Marchetti imagined to options: exhausted gases & oil fields and oceanic disposal. Regarding the storage in exhausted oil & gas field he considered that

“This possible storage of liquid CO₂ at pressure lower to than 100 atm guarantees a large storage capacity than for the original methane, although the solubility of CO₂ in water and the solubilization of carbonate rocks do not guarantee a similar stability over the time. The same could be said for exhausted oil fields and other types of natural or artificial cavities. I did not go into the details of this system on the grounds that the capacity of natural structure which is available at reasonable cost may be insufficient” (p.64-65)

The previous extract shows that if Marchetti recognized the CO₂ storage potential of underground he does not considered it as relevant in a first time and focuses on deep ocean storage. Initially the Carbon Capture and Storage consider mainly the deep Ocean CO₂ disposal. The following graph represent the ANT network of the first CCS system as think by Marchetti.

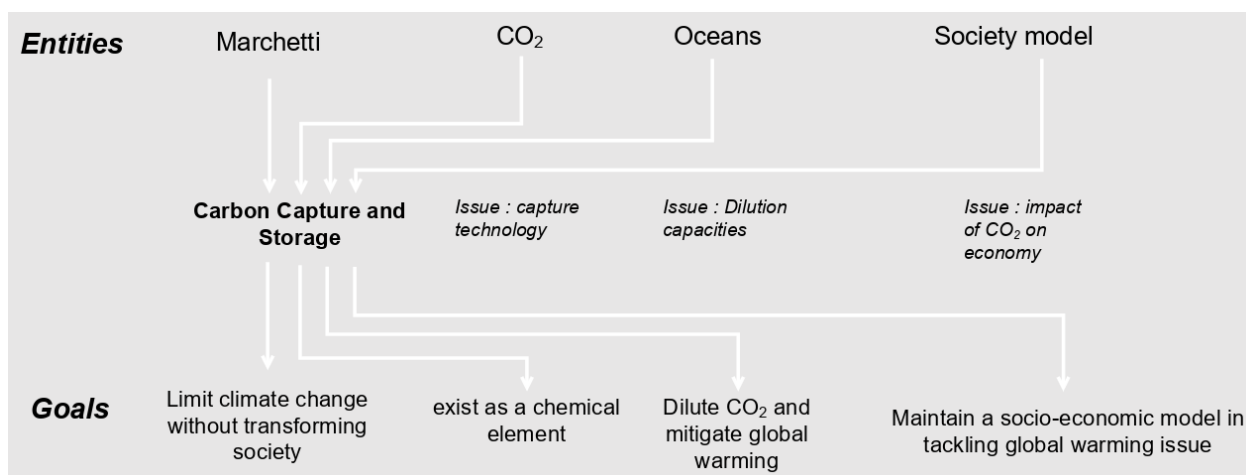


Figure 1: CCS as an obligatory passage point

2. How efficiently manage CO₂ storage? From oceanic storage to deep underground storage.

In 1997 after Kyoto agreement signature, Japan, Canada and Australia are willing to test CO₂ oceanic disposal. The depiction of this first attempt is based on report of three scientists involved in this project (Herzog, De Figueirido and Reiner 2003). The main goal of this first experience is to monitor the evolution and impacts of CO₂ disposed on oceanic floor. In order to manage this experience scientists need to find a testing site nearby the coast to have a CO₂ source but with relatively deep ocean (800 to 1000 meters deep) (De Figueirido 2003). The Keahole point site in Kona island in Hawaii archipelago suits these expectations. In addition, a scientific institution - Natural Energy Laboratory of Hawaii Authority - could host the project.

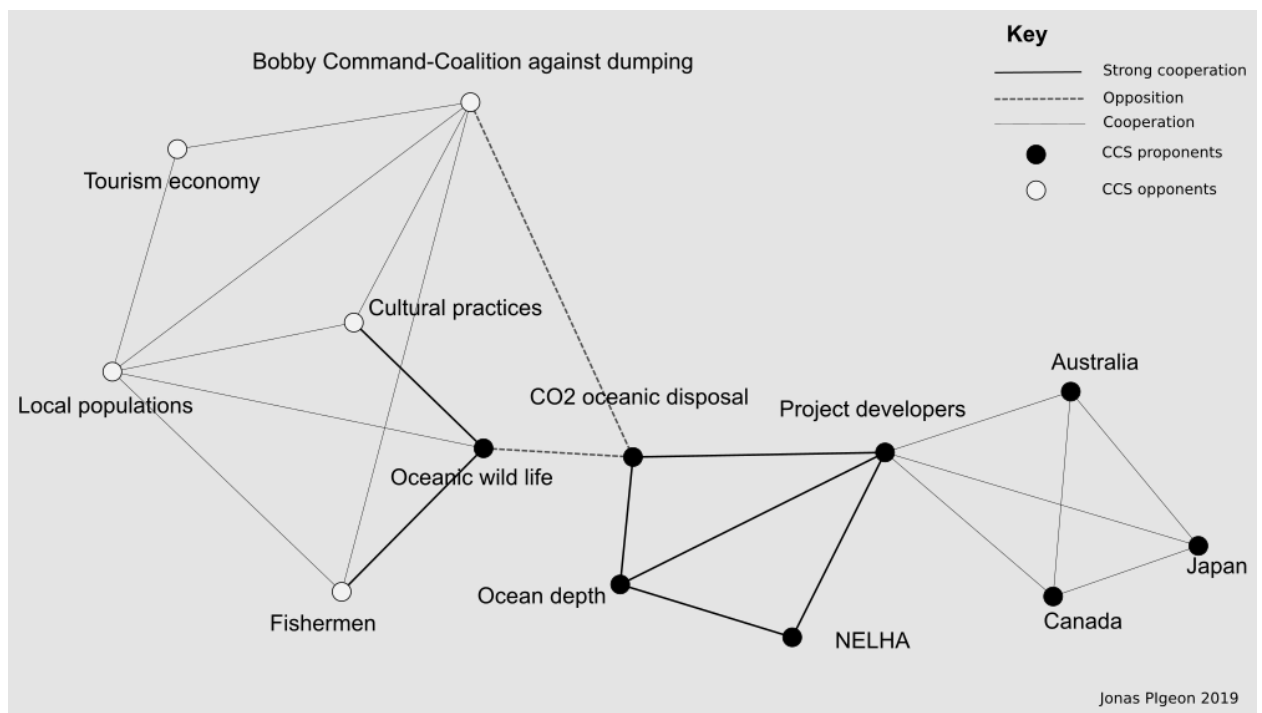


Figure 2: Sketch of the network of entities involved in Hawaii Kona Island CO₂ oceanic disposal

Initially the developers of the project planned to communicate with local populations. However fund dedicated to the communication campaign were allocated one year after the start of the project. During this period a first newspaper article entitled "Feds to test impact of Dumping CO₂ in Kona water " was published in the west Hawaii today in the 18th of March 1999 (De Figueirido 2003). This article based on data of the United State Department of Energy stresses the impact of CO₂ on ocean chemical composition and raises concerns among local population regarding on oceanic life. A second newspaper article in the Hawaii Star Bulletin published the 10th of August 2000 shows that the testing site was currently a refuge for whales. After these two articles the CO₂ disposal project developers made a website to communicate on CO₂ disposal but the opposition against the project was more and more organized and the coalition against CO₂

dumping was funded. It gathers fishermen and natives to denounce the impacts of the project on environment but also on cultural and tourism aspects.

The developers of the projects answered to these opponents with scientific arguments but didn't convince them. Finally the project aborted. After this first attempt the CO₂ oceanic disposal was progressively abandoned because of controversies related to its impacts (Gough and Schackley 2005). In addition the OSPAR convention¹ regulating international cooperation and environmental protection in North East Atlantic forbade the CO₂ disposal.

This first experience reveals new actants in the actor network that Marchetti had not identified. It illustrates that oceanic wildlife but also socio-cultural dimensions have to be taken into account in order to dispose CO₂ on oceanic floor. This experience shows that the enrolment process (Callon 1986) of all the actors of the network had not been undertaken by project developers but had a strong impact on this technological option.

3. Build the Actor-Network of CO₂ Deep underground storage: bring together CO₂ & underground reservoirs

After the abandon of the deep ocean disposal of CO₂ underground storage remains the main CO₂ storage option. But despite the long history of the CCS concept the Actor Network related to this technology remains to consolidate. The following paragraphs describe the "interestment process" (Callon 1986) of underground rocks to build the CCS Actor Network. Indeed the main issue pursued by scientists is to fix CO₂ permanently in geological rock reservoirs. Cap rocks of geological reservoirs or fault and seismicity as well as injection processes are all agents to gather in order to build an efficient CCS.

3.1 What kind of rocks are reliable allies?

In order to manage an efficient CO₂ storage, scientists involved in carbon capture storage implementation have to prove the reliability and permanency of the geological storage. The main sources of uncertainties related to CO₂ geological storage are leakages of CO₂ on drinkable water as well as on the surface through faults for instance. To prevent CO₂ leakage scientists design pilot projects, CO₂ tracking methodologies or big data analysis on analogous natural CO₂ storage reservoirs. According to the literature two kinds of rocks are mainly dedicated to permanent storage (without other activities combination) : Saline aquifers and basaltic rocks.

3.1.1 Saline aquifers: an agent to enroll

Saline aquifers are deep underground very high salted water reservoir rocks. This type of geological reservoirs don't enter in competition with other economic activities. Experts estimate these reservoirs are able to store safely and permanently CO₂ (IPCC 2005). However various

¹ <https://www.ospar.org/convention> visit 14-08-2019.

uncertainties remains around CO₂ behaviour inside saline aquifers. International Panel on Climate Change special report on CO₂ storage shows that after its injection CO₂ stay liquid and move inside the reservoir. After hundred of years it mineralized and become stable. Therefore the main issues for scientists is to ensure that CO₂ is contained in the reservoir as well as to forecast evolution of the gas for hundreds of years.

In order to efficiently track CO₂, scientist had identified other gases that could be efficient trackers of the presence of CO₂ in the rock. The CCS journal refers to the work led by the school of geoscience at Edinburgh University (CCSJ-58, 2017 p. 26). These Researchers uses nobles gases to track CO₂ unplanned migration in the subsurface. These Gases are selected because they move inside the rock quicker than CO₂. Therefore they could allow CO₂ Storage developers to managed leakage. According to these researchers accurately identifying leaks is a key issue regarding the successful implementation of CCS. The following extract illustrates this idea

“Securely storing captured CO₂ is critical to its success and our method of identifying any leaks should give assurance to local communities. Our work provides a simple way to easily and unambiguously spot leaks from future storage sites, using the fingerprint of noble gases that the CO₂ picks up during storage.” Dr Stuart Gilfillan

In addition of tracking methodology to ensure CO₂ containment, scientists also managed data analysis related to natural CO₂ storage and design statistical models. The article *“CO₂ stored ten times longer than needed”* (CCSJ-53, 2016, p.33) refers for instance to a survey managed by a Cambridge university laboratory. Based on data related to natural CO₂ reservoir the statistical model designed by researcher shows that stored CO₂ in deep underground is more safe than expected. The CO₂ storage in deep underground is more predictable over long periods. According to the Professor Mike Bickle, that takes part to the survey the result of this survey are critical for the success of CCS. The following reference illustrates this idea :

“A major obstacle to the implementation of CCS is the uncertainty over the long-term fate of the CO₂ which impacts regulation, insurance, and who assumes the responsibility for maintaining CO₂ storage sites. Our study demonstrates that geological carbon storage can be safe and predictable over many hundreds of thousands of years.”

Finally to complement their data scientists also design instrumented pilot projects The goal of the Aquistore project in Canada² is to validate the efficiency and the safety of the CO₂ storage in saline aquifers as well as to collect data that could be reused in other project (CCSJ-49, 2016, p.32).

The previous paragraphs shows that in a long terms saline aquifers are relevant allies of CCS. However, in a short and middle terms the addition of another agents (noble gases) is needed to ensure the reliability or this type of rocks.

² <https://ptrc.ca/projects/aquistore/>
<http://aquistore.ca/index>

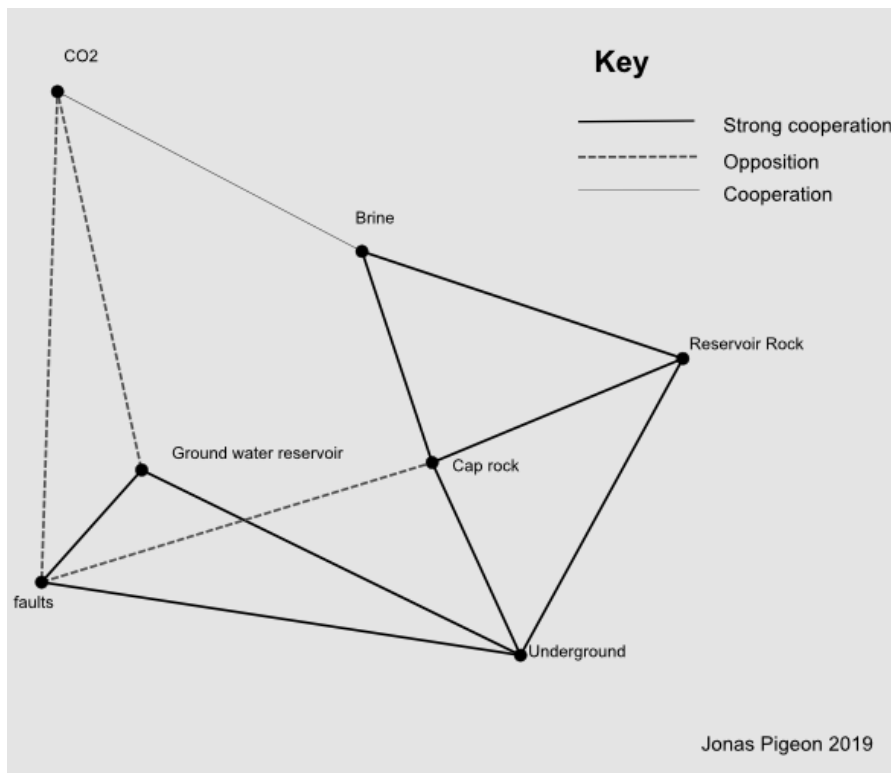


Figure 3: Sketch of entities involved in CO₂ storage in saline aquifer case.

3.1.2 Basaltic rocks: an efficient ally of CCS?

Despite saline aquifers other kind of rocks are also tested to store CO₂ as only purpose. This is for instance the case of basaltic rocks (CCSJ-52, 2016, p.31). A news published in the CCS Journal described the project CarbFix that in Iceland. The following extract summarize the main results of the project:

“We find that over 95% of the CO₂ injected into the CarbFix site in Iceland was mineralized to carbonate minerals in less than two years. This result contrasts with the common view that the immobilization of CO₂ as carbonate minerals within geologic reservoirs takes several hundreds to thousands of years”.

According to the previous extract, basaltic rocks are more reliable allies compared to saline aquifers. Indeed most part of the CO₂ injected in this kind of rocks is mineralized quickly and then play the role they are expected by scientists and CCS developers. Saline aquifers as well as basaltic rocks are according literature two complementary reliable geological reservoirs to store CO₂. However, in order to be develop at a large scale CCS and attains its goal of climate mitigation also have to allies with other social and economic entities.

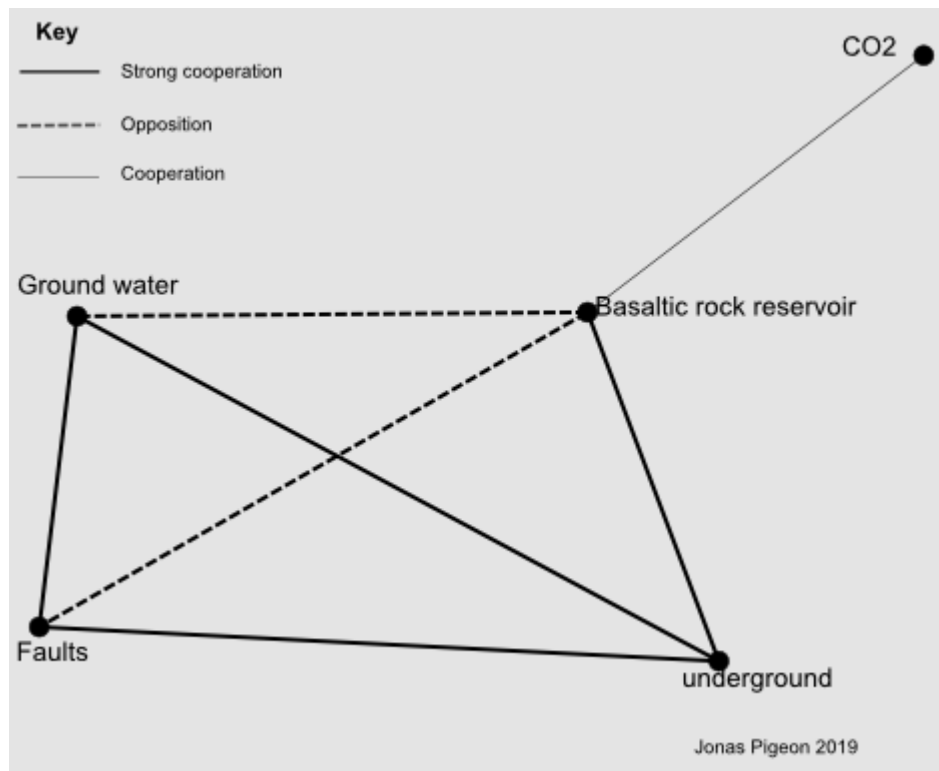


Figure 4: Sketch of entities involved in basaltic rock storage

3.2 Injection process: a key component of the alliance between Rock and CO₂?

The injection process is a key step in order to build an reliable alliance between CO₂ and the rock of geological reservoirs. The scientific literature surveyed shows CO₂ injections in reservoir rock is surrounded by uncertainties related to its effects on the reservoir especially for CO₂ storage in saline aquifers. According to CO₂ storage developers each storage reservoir will face during its history various injection rates caused by various delivery of CO₂, or well maintenance operation. However, they don't know the effect of various injections rate on the storage safety. A survey managed by the university of Edinburgh showed that:

[The] storage security would be enhanced because interruptions have the effect of increasing the amount of CO₂ trapped within the pore spaces of the rock; the efficiency of storage is increased because trapped CO₂ is less mobile than free flowing CO₂ and so its migration within the reservoir is more contained; injection pressure would rise due to the increasingly trapped CO₂ acting as a barrier to flow and this effect would need to be managed by storage site operators (CCSJ-68, 2019, p. 24).

The previous extract shows that conversely to the expectations of CO₂ storage developers Various injection rates has positive effect on safety. However pressure in reservoir is still to manage. Therefore, injection agent is not as strong as expected by CCS developer to destabilise the overall Actor Network of CCS.

4. How interest Economy & societies to CO₂ storage

Previous paragraphs shows that scientists have quite reliable methods to “interest” and “enrol” (Callon 1986) various technical and natural agents. However to implement successfully Carbon Capture and Storage, an alignment of social, economic and political agents are also needed. Followings paragraphs shows various narratives as well as arguments used by CCS proponents to interest and enrol these social, economic and political forces.

4.1 Reaffirm CCS benefits in Paris agreement context

In order to interest social, political and economic agents proponents of CCS first mention the critical role of this technology in order to reach quickly greenhouse gas mitigation targets as defined in the Paris agreement in 2015 as illustrate the following extracts.

“The UN Paris agreement has committed the world to limiting climate warming to well below 2°C from pre-industrial levels. This requires huge reductions in the amount of the greenhouse gas, carbon dioxide, which is released to the atmosphere from industry, electricity generation, heating and transport. Capturing these emissions and ensuring that carbon dioxide can be safely trapped underground is crucial for the successful protection of the atmosphere”. (CCSJ-64, 2018, p. 25).

“Fossil fuels are likely to be a significant energy source for the foreseeable future. CCUS is the only currently available technology that can solve the carbon problem while still allowing fossil fuels to be used. All current projections of a low-carbon energy future include significant amounts of CCUS.” Princeton University researcher (CCSJ-66, 2018 p.25).

Paris agreement allows CCS proponents to actualise the original narrative related to CCS. Societies still facing greenhouse gas emissions growth as well as the dependency to fossil fuels. However limit these emissions is critical and CCS could provide a real support to manage this task quickly compared to other renewable energy and social transformation they implies. The previous paragraphs only depict the role of CCS in climate change mitigation. Describing that way the situation is unfair regarding other renewable energy. The last part of this paper wil give a more accurate overview of the competition between CCS narrative and other renewable narratives.

4.2 Show the immediate profitability of CCS

The main argument of Paris agreements has not enough strength to support the implementation of all the CCS system. Indeed international agreements are not strongly prescriptive and some states could easily withdraw from these agreements. Therefore, to implement successfully the technology the proponent of CCS insist on its profitability.

CCS proponents shows that CO₂ storage is not only a source of economic costs but can also contributes to improve oil and gas production in current fields or extract shale gas. This framing of the technology is designed to involve economic stakeholder in CCS development. Researchers of Princeton university researchers insist for instance on the improvement of oil & gas production through Enhanced Oil Recovery (EOR) as illustrates the following extract.

Conventional recovery from an oil well yields about 40 percent of the total oil within the rock, . Injecting carbon dioxide into the reservoir enables recovery of more oil, typically around an additional 15 percent, he said. The carbon dioxide is separated from the oil at the surface, then the gas is returned into the ground and ultimately trapped there. Princeton University researcher (CCSJ-66, 2018, p. 25)

In addition according to some experts re-use infrastructures of exhausted oil & gas field could be a right start to develop CCS. The director of the Scottish Carbon Capture and Storage affirm the economic benefit to start this way to develop CCS as illustrates the following extract.

"The recent announcement from OGA heralds a new future for the North Sea. The Acorn site could launch a new multi-billion offshore industry, which progressively and systematically takes the place of oil and gas extraction as fields end production from now to the 2030s. By unlocking access for re-use of existing oil and gas infrastructure, this allows the first CO₂ storage projects to reduce capital costs by 20-50%." Stuart Haszeldine Director of SCCS (CCSJ-67, 2019, p. 25)

The CCS plays in this configuration a double role of climate mitigation system but also an enhancing oil & gas production technology. As detailed in the last part of the paper this double role of CCS as consequence in its perception as an energy transition technology.

4.3 Demonstrate the value of geological storage to convince local population

Store CO₂ in geological reservoirs located onshore is not an easy business. Case studies shows that local populations contest CO₂ storage projects. The most contested case of onshore CO₂ storage is the project of *Barendrecht* led by Shell in Netherlands (Brunsting et al. 2011). This city is located in the vicinity of Rotterdam and the main goal of this project was to store CO₂ from an hydrogen plant in geological reservoir located under a Barendrecht residential district. The choice of the storage location was motivated because its suits risks evaluation but also by its proximity from the emitting source (16.5 km) (Eijs, Kuijper and Bisschop 2011). However, after the first public meetings the project was contested locally. The project was both contested regarding its impacts on environment, health as well as real estate market. In addition this project was also regarding its general ambition giving subsidies to CO₂ and impacting local population. After this local opposition the project was finally abandoned.

Scientific literature often shows a great concern on safety of the CO₂ storage that is a key issue. However as illustrated by the Barendrecht case, local conflict goes most of the time beyond safety concerns. Therefore, convincing people need to undertake an overall approach of a project.

4.4 Ask for the design of relevant regulations and subsidies to develop CCS

According to the CCS experts the implementation of CCS infrastructures at a large scale needs a political support. Two regulations tools could contribute to the the implementation: the establishment of tax and tax credits as well as the public funding of CCS infrastructures. Indeed regarding the history of CCS technology Tax systems are key drivers. In Norway the introduction of a tax in 1991 on the CO₂ emissions of offshore oil & gas infrastructures (Kongsjorden, Kårstad and Torp, 1998) contribute to stimulate the implementation of CCS.

Princeton university researchers showed that in the U.S tax credits are a relevant tool to enhance large scale CCS development as illustrates the following extract.

“The new tax credits are the most significant policy incentivizing carbon capture, utilization and storage (CCUS) in the world today, (...) This is the first time we’ve had a policy in front of us that lets us seriously consider deployment on a large scale,” Ryan Edwards - Princeton University (CCSJ-66, 2018, p.25)

In addition, according to Ryan Edwards tax credit only are not efficient to ensure CCS large scale implementation. Infrastructure funding by national states is also a key issue. The following extract illustrates this idea.

“In order for CCUS to have any chance for large-scale development, the necessary infrastructure needs to be built (...) Similar large-scale infrastructures such as the Interstate Highway System and electric-power grids have been built with government financing and coordination (...) Our analysis shows that additional public support beyond the tax credits will be necessary to enable large-scale deployment in the near-term, (...) That’s how these things are done - governments play a key role. An excellent recent example is the leadership on clean-energy infrastructure by the Texas state government that enabled the big wind energy boom there.”

In previous extract researchers compared CCS infrastructure to Interstate Highways System to insist on general need related to such type of infrastructures. This argument attribute to state government a key role in CCS implementation and some states like Texas seems willing to play this role.

The previous paragraphs shows that the large scale CCS implementation largely depend from regulation as well as state policies. In some states like Norway regulation and/or subsidies make easy the development of CCS, in making it profitable. In other countries regulations didn’t fit with CCS expectations. Political stakeholders are still to interest and enroll.

4.5 An international standard to legitimate the CO₂ storage implementation as a climate change mitigation option.

Another way to strengthen the Actor Network of Carbon Capture and storage use by industry in favour of CCS development was to design a body of standards related to these technologies. Since 2016, five ISO standards related to CCS were passed and three ISO technical reports on technological specifications related to various parts of this carbon capture and storage were edited (ISO/TR 27912:2016, ISO 27913:2016, ISO 27914, ISO/TR 27915, ISO 27916:2019, ISO 27917, ISO/TR 27918, ISO 27919-1). According to Mallard (2000) standards plays a key role in a technology development process. He shows that standards bring together various socio-technical networks and establish a consensus between various measurement methodologies or indicators used to assess the performances of a technology. In addition Mallard also show that standard assigned role to all the actants of a technological system.

Regarding the CCS technology the edition of a body of standards legitimate the CCS and especially the CO₂ storage as an option recognized internationally to tackles the global warming issue. Indeed through standardization process this technology is no more just a pilot technology but become an industrial reality and therefore, contributes to derisk investment in these technologies. Through standards it is easier to distinguish what are the projects that follow standardized methodologies and instrument that could benefit from insurance and those that won't.

Conclusion: Is underground belongs to the climate mitigation narrative?

This paper summarize the building of Carbon Capture and Storage (CCS) actor network in order to identify various role assigned to underground storage reservoir. According to the various sources surveyed the “non-human” part of this actor network have been successfully enrolled in the system. In the contrary we also noticed that the CCS proponents have to undertake a strong conviction works with political and various societal stakeholders to fully establish the Actor Network of CCS as a climate change mitigation technology. According to us this difficulty faced by CCS proponents is related to the narrative that frame CCS technology. This last part of this paper will illustrates why CCS is in some way in contradiction with climate mitigation. First, main ideas of climate mitigation narratives will be summarized and then mismatch with CCS narrative will be identified

Narratives related to climate mitigation and more broadly ecological transition often mention the idea of a decentralize renewable energy technology but also larger behavioural changes. Most discourses of Environmental NGO (e.g. Greenpeace), but also in some expert reports³, the need to focus on renewable decentralized energy and to change our behaviours to successfully mitigate climate change. Therefore all these narratives support an ecological imaginary based on the ideas of transformation as well as “small scales” energy and consumption systems (Manceron, Roué 2013) where life is based on local activities.

³ IPCC last report from August 2019 6th illustrates the need to change our food production and consumption systems.

Narratives detailed in this paper shows that contrary to this ecological imaginary CCS narratives promote a quick cut of CO₂ emission without behavioural changes. In addition this technology is also strongly related to Oil & Gas industry and draws part of its profitability from enhanced oil recovery. CCS narrative is thus strongly attached to “old” energy model that doesn’t match with the ecological imaginary and may be not convincing enough for some political stakeholders incentivized by experts, NGO, but also citizen to engage in an ecological transition.

However CCS proponents had also adapted their narratives and including the idea of CO₂ re-use. Circa 2013, Carbon Capture and Storage became Carbon Capture Utilization and Storage. According to experts (Valentin 2013; Pierre, 2013) about 1% of total CO₂ emissions could be re-use easily. Nevertheless, various CO₂ programs are already engaged. For instance CCS journal mentioned various CO₂ re-use project. In addition, with the development of hydrogen energy as well as synthetic fuel Carbon Capture could also plays a critical role.

As a conclusion CCS has not yet a strong enough Actor Network. Its proponents still have to convince political stakeholders as well as society of the relevance of CCS but also to connect CCS with new energy narrative to make inscribe CCS in energy transition.

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CCSJ-64 Scottish researchers show safety of CO₂ storage July/Aug, 2018, p.25

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CCSJ-67 UK Oil and Gas Authority awards first CCS license to Acorn project, Jan/Feb 2019, p.25

CCSJ-68, Varied CO₂ injection rates can boost CO₂ storage effectiveness, Mar/Apr, 2019, p.24